Water Quality Monitoring of Candlewood Lake & Squantz Pond 2023

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For the Communities of Brookfield, Danbury, New Fairfield, New Milford, and Sherman

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All Raw Data is available from the Candlewood Lake Authority upon request to science@candlewoodlakeauthority.org

Introduction

The Candlewood Lake Authority

Candlewood Lake is a pumped storage reservoir built in the late 1920's for the purposes of power generation. It has since become a premier destination for lake recreation in both Connecticut and the New York City tristate area and is a critical economic and environmental asset for local communities. The Candlewood Lake Authority (CLA) is an organization formed from ordinances by the municipal governments of Brookfield, Danbury, New Fairfield, New Milford, and Sherman pursuant Connecticut General Statute §7-151a, to enforce boating law on the water and to provide lake management to protect and conserve the environmental value of Candlewood Lake and Squantz Pond. Those five municipalities equally share a substantial amount of the responsibility for much of the CLA's operational budget. FirstLight Power, the owners and operators of Candlewood Lake and its hydropower generation have also historically made a voluntary contribution to the Candlewood Lake Authority's budget. Annual donations, grants, and fundraising projects constitute the final portion of the Lake Authority's budget.

Candlewood Lake Authority Mission Statement

The Candlewood Lake Authority provides lake, shoreline and watershed management to foster the preservation and enhancement of recreational, economic, scenic, public safety and environmental values of the Lake for the City of Danbury and the Towns of Brookfield, New Fairfield, New Milford and Sherman in cooperation with the State of Connecticut and the hydro power owner of the lake.

Lake and Watershed Characteristics

Candlewood Lake is Connecticut's largest, with a surface area of 5,064 acres. The Candlewood Lake & Squantz Pond shared watershed is approximately 25,907 acres and contained almost entirely in the Connecticut municipalities of Brookfield, Danbury, New Fairfield, New Milford, and Sherman. (Jacobs and O'Donnell 2002). New Fairfield and Sherman contain 73% of the watershed, while a small portion crosses the border into New York State (Table 1).

Town	Acres of Watershed	% Of watershed within municipal boundary	% Of municipality within watershed boundary
Brookfield	1,177	4	9
Danbury	2,726	10	10
New Fairfield	12,197	46	72
New Milford	2,629	10	6
Sherman	7,132	27	51
New York State	600	3	
Total	26,461		

***Table 1**: Percentages of the Candlewood Lake & Squantz Pond watershed contained within each bordering municipality, and the percentage of each municipality contained within the watershed.*

Squantz Pond has a surface area of 270 acres, with a watershed of 3,662 acres contained entirely within the borders of Sherman and New Fairfield, making it a sub-basin of the Candlewood Lake watershed. A culvert below the Route 39 causeway in New Fairfield connects the two hydrologically, allowing free water flow between Candlewood Lake and Squantz Pond.

The Candlewood Lake watershed has changed dramatically over the course of the lake's life, becoming more urbanized and losing forested and agricultural lands. Since 1970, the percentage of the watershed classified as urban has increased from 11.7% to 28.3% in 2007 (Table 2) (Kohli et al. 2017).

Year	Urban (%)	Agriculture (%)	Wooded (%)	Water (%)
1970	11.7	8.5	57.0	22.0
1977	19.5	2.1	57.0	22.2
1990	28.7	5.6	43.6	21.7
2007	28.3	1.9	47.1	22.7

***Table 2**: Candlewood Lake Watershed percent coverage of different land classifications (Table from Kohli et al. 2017).*

The Candlewood Lake Monitoring Program

Long-term management of water resources requires consistent and standardized monitoring to make informed management decisions. By tracking critical water chemistry and biological metrics that are indicators of lake health, we can analyze how management activities are affecting the in-lake ecosystem, and what additional management activities may be necessary. To that end, the CLA began a monitoring program in 1983 to provide a scientifically standardized method of assessing Candlewood Lake & Squantz Ponds health and water quality over time to the surrounding communities.

Initially undertaken by researchers from Western Connecticut State University (WCSU) and later by Connecticut College (CC), the CLA has conducted this monitoring itself since 1998, with the exception of the years 2017-2019, when the monitoring was contracted to Aquatic Ecosystems Research (AER), a freshwater consulting organization specializing in in-lake chemical monitoring. Since 1999, all whole-water sample laboratory analyses have been performed at Hydro Technologies, Inc. at their CT Department of Health certified laboratory in New Milford, CT. In 2022, that laboratory analysis was changed and conducted at York Analytical Laboratories Inc. in Newtown, CT due to an ownership change at Hydro Technologies, Inc. In 2023 the decision was made to transfer analysis to the UCONN Center for Environmental Sciences and Engineering's nutrient and metals divisions.

2023 is the third year where there were two distinct sampling events (one early month, and one late month sampling) from May-October. This was done to give the CLA a more fine-grained view of the chemical monitoring results, allowing us to better understand trends over the course of a season, as well as being able to calculate representative averages of our key metrics more accurately. Due to equipment issues and the lab transition, monitoring in 2023 began as normal in Early July. Now that the relationship with UCONN is established and the monitoring equipment has been upgraded, we will once again begin monitoring in May in 2024. We hope to continue with the twice-monthly schedule moving forward. For the sake of keeping this report a reasonable size, raw data has not been included as an appendix, but all raw data and lab results are available from the Candlewood Lake Authority upon request: science@candlewoodlakeauthority.org

Materials & Methods

The CLA began its water quality monitoring program in 1983 to provide the community with a scientifically rigorous and standardized method of assessing changes in Candlewood Lake and Squantz Pond over time. The program has continued largely uninterrupted since then, providing us with historical data for 38 years and counting.

More Specifically, The Candlewood Lake Authority has been conducting monthly monitoring from May – October of 4 sites on Candlewood Lake, and one site on Squantz Pond. From 1985-1987 sites in Lattins Cove, Pocono Point, and the southern end of the New Milford arm of the lake were sampled as well. From 1985-1990 an additional site in New Fairfield Bay was sampled. From 1988-1990 the New Fairfield Bay site was sampled instead of the standard New Fairfield site. In 1990 the New Fairfield site was re-established, and the New Fairfield Bay site was eliminated.

The monitoring has taken some different forms over the years, and different metrics have been added, eliminated, and transferred to new methods of measurement at various times over the course of the monitoring's history. However, the metrics being measured regularly at each monitoring location are:

At each location:

1. Secchi Depth (m)

At 1-meter intervals:

2. Depth (m)
3. Temperature (C°)
4. Dissolved Oxygen (mg/l)
5. pH
6. Standard Conductivity (µmhos/cm)
7. Relative Cyanobacteria (cells/mL)
8. Relative Chlorophyll-a (µg/L) - Started in 2019

At the Epi, Meta, and/or Hypolimnion:

9. Total Phosphorous (ppb)
10. Total Nitrogen (ppm)
11. Chlorophyll-a ($\mu g/m^3$)
12. Ca^{++} (mg/l) – Bi-monthly
13. Mg^{++} (mg/l) – Bi-monthly
14. Na^{+} (mg/l) – Bi-monthly
15. K^{+} (mg/l) – Bi-monthly
16. Cl- (mg/L) –Bi-monthly

Phaeophytin, phytoplankton diversity and cell counts (including Cyanobacteria cell counts), and Chlorophyll b and c have also been included in past years' monitoring, but have been monitored inconsistently, or monitoring has ceased. Phytoplankton diversity and cell counts were monitored from 1985-1998, at which point that monitoring was discontinued until 2017, and has been re-incorporated into the monitoring from 2017 to 2020. We plan to re-incorporate some form of phytoplankton monitoring in 2024. In 2011, a Zebra Mussel Veliger Monitoring program was added in conjunction to the normal monthly monitoring and has continued since.

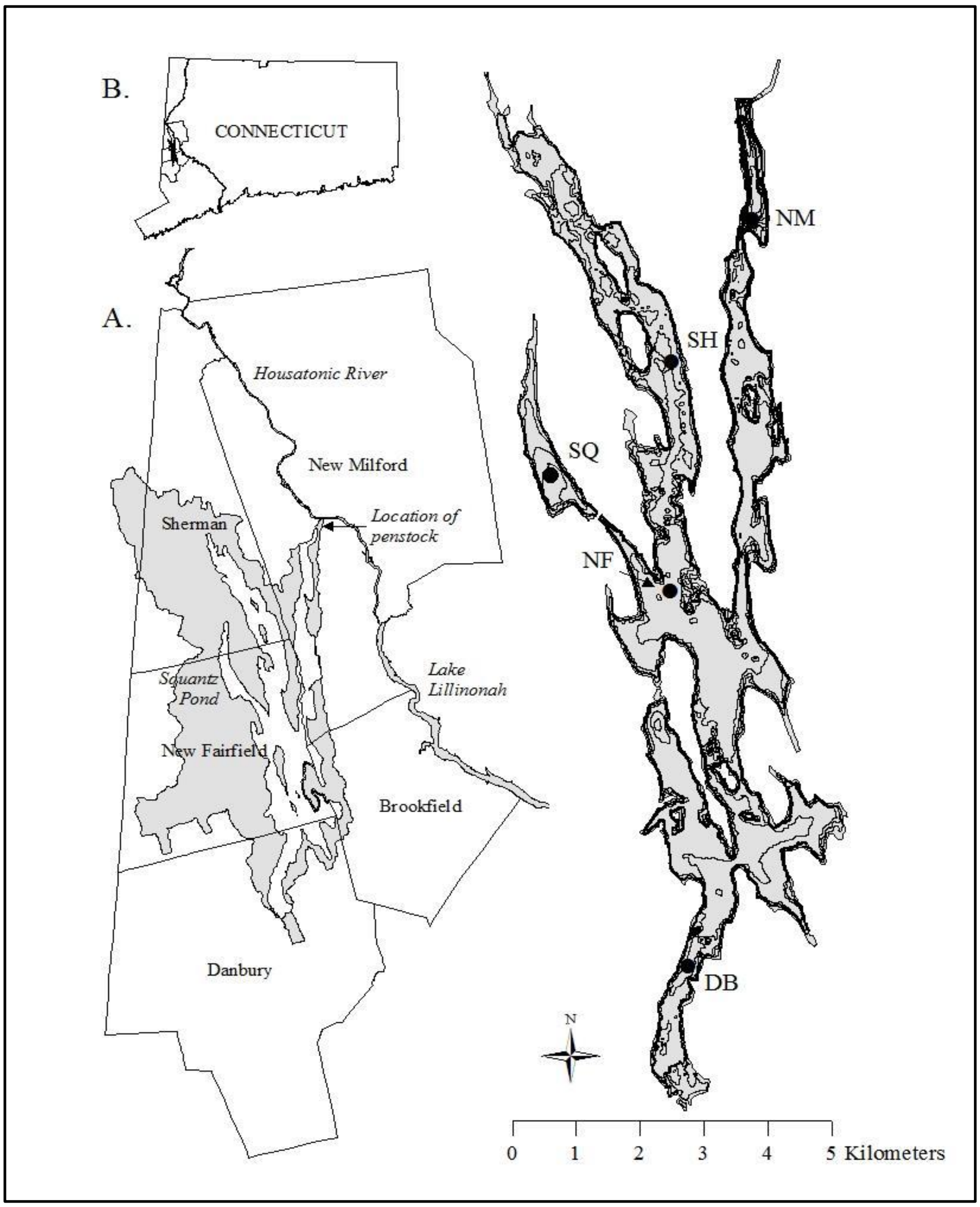


Figure 1: *A) Relation of the Candlewood Lake Watershed to the five bordering municipalities. B) Location of watershed and municipalities in the state of Connecticut. C) Location of the five sampling sites on Candlewood Lake and Squantz Pond.*

Results

Temperature and Dissolved Oxygen Profiles

Candlewood Lake is a dimictic lake, meaning that twice per year, the temperature difference between the surface water and the lake bottom is negligible. That remains true this year, although due to the delayed start we can't see the mixing at the beginning of the season. We can however see it at 4 of the 5 locations by the end of September, and the thermocline is weakening at New Milford, the deepest sampling location.

	Danbury		New Fairfield		New Milford		Sherman		Squantz	
	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)	Metalim. Boundary (m)	Anoxic Layer (m)
11-Jul	6-7	8	5-7	N/A	5	20	5	7	7-8	9
25-Jul	6-7	8	6-8	8	5-8	20	7-8	8	7-9	10
14-Aug	8	9	8	N/A	7-9	10	8	9	9	10
28-Aug	9-10	9	8-9	9	8-10	10	8	10	9	N/A
12-Sep	9	9	9	10	10	9	9	9	9-10	9
27-Sep	N/A	N/A	11	11	10	10	10	11	10	11
12-Oct	N/A	N/A	11	12	12-13	19	11	N/A	10	N/A
18-Oct	N/A	N/A	N/A	N/A	14	15	N/A	N/A	N/A	N/A

Table 3: *Stratification, mixing, and oxygen depletion characteristics at 4 locations on Candlewood Lake, and one location on Squantz Pond in 2023. The metalimnetic boundaries are presented as meters below the surface, and the anoxic layer is presented as the upper boundary of the anoxic zone, extending from that level to the bottom.*

The tendencies of Candlewood Lake of top-to-bottom mixing, and strong mid-season stratification followed by a period of mixing are characteristic of deep lakes in the American northeast. The colder, denser, water "sinks" to the bottom of the water column, effectively preventing mixing with the shallower surface water – creating the anoxic layer in the lake bottom. These layers are shown in Figure 1. As surface waters begin to cool at the end of the season, the metalimnion (middle layer) recedes deeper into the water column until such time that the temperature of the column reaches a homogenous state, and the anoxic zone disappears, allowing for a consistent level of dissolved oxygen throughout the water column.

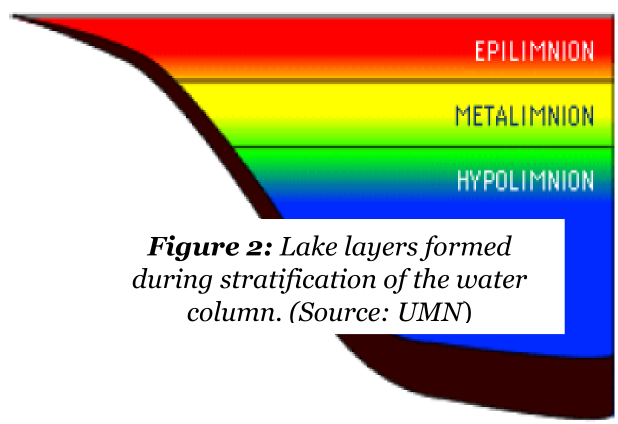


Figure 2: *Lake layers formed during stratification of the water column. (Source: UMN)*

When we began our monitoring in early July May all five sites had a pretty well-established thermocline (the "barrier" of the largest temperature difference between the epilimnion and the hypolimnion, preventing mixing). However, deep oxygen concentrations hadn't dropped to the lowest levels still by that point, and in fact, there wasn't even a true anoxic zone (below 0.1 mg/L of oxygen) at the new Fairfield site yet. As the season continues the drop in DO in the deeper water is due to respirating single-celled organisms utilizing that oxygen to digest sinking phytoplankton and other materials for energy. Stratification tended to be strongest at all 5 sites during the early August sampling, by which point respirating bacteria had been able to establish significant anoxic zones at all 5 sites. Stratification is calculated by comparing temperature differences between meter intervals and calculating RTRM (relative thermal resistance to mixing). Temperature and oxygen profiles generally mirror one another due to their strong relationship with thermal resistance to mixing and lake stratification.

To help illustrate this, the graphs of the temperature and dissolved oxygen concentrations in August and October at the Danbury site have been included below:

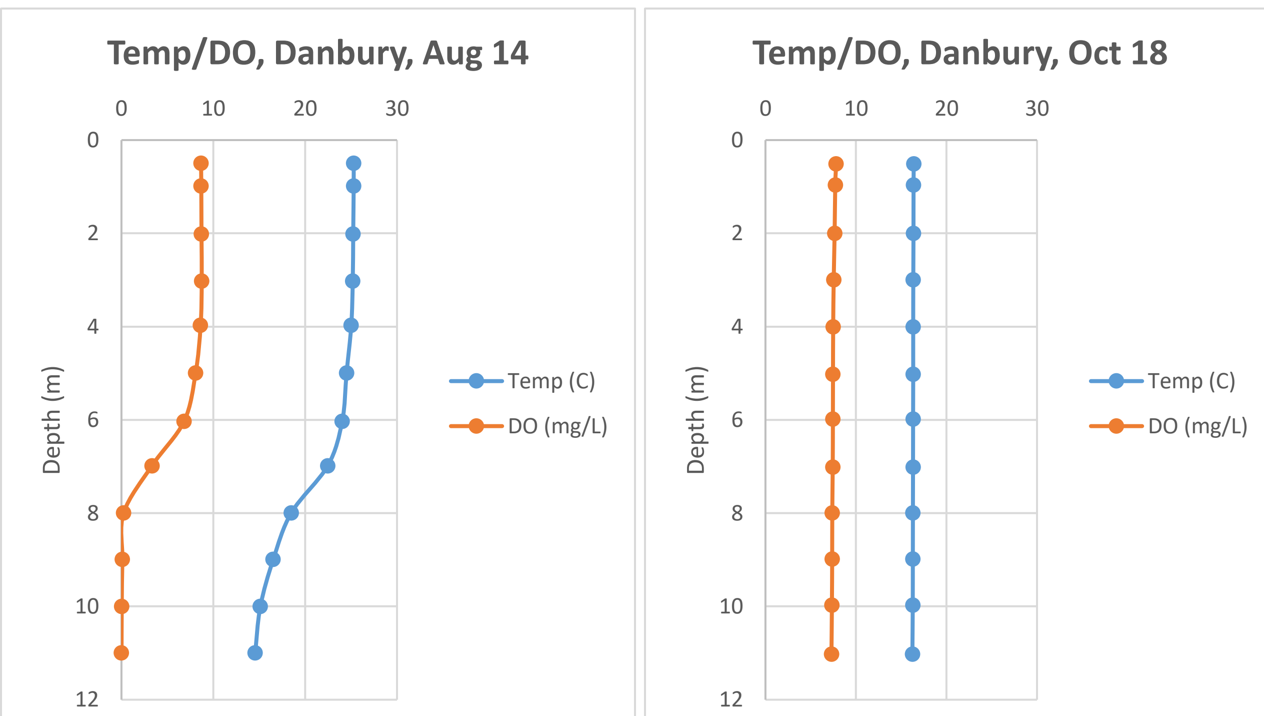


Figure 3: *Temperature and dissolved oxygen concentrations, taken at 1m intervals at the Danbury location in 2023. Graphs meant to illustrate the difference between the lake at its most strongly stratified state and a well mixed state.*

The New Milford site shows a unique property of sometimes having two separate anoxic zones. With low levels of dissolved oxygen between the two zones. This is our deepest site, but the cause of this is somewhat unclear. It could indicate outgassing at a certain point in the deep lake's geology or indicate layers of oxygen utilization by deep water respirating bacteria. 2023 also represents the first year that FirstLight Power, the current owners of the lake, pumped water up into the lake from the Housatonic River at semi-regular intervals during the summer. While the impacts of this aren't clear in the data, and pumping wasn't occurring consistently, the pumping will likely increase the lake's ability to mix as relatively shallow water from the Housatonic River is pumped into the deeper layer of the lake. This tendency might also be strongest at the New Milford site, which is the closest to the input from the penstock. We hope to better understand the impact of this moving forward.

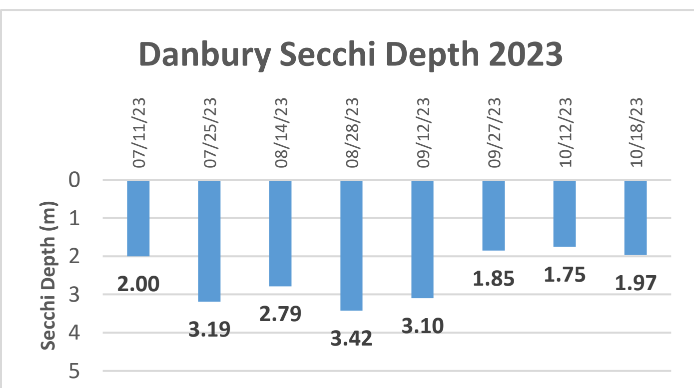
Anoxic zones in the hypolimnion require respirating bacteria to use anaerobic respiration, increasing nutrient release in the hypolimnion as compounds containing both nitrogen and phosphorus are broken down into forms usable by bacteria. This is known as "internal loading" and is a critical component of lake monitoring and management. Mixing allows for the hypolimnion to be refreshed with oxygen, allowing for aerobic respiration and a relative pause in nutrient release while the water column is homogenous. As temperatures continue to increase due to climate change, strong stratification can last for a longer period, increasing the potential for nutrient release in anoxic zones. This can and will accelerate eutrophication (lake "aging") in the long term.

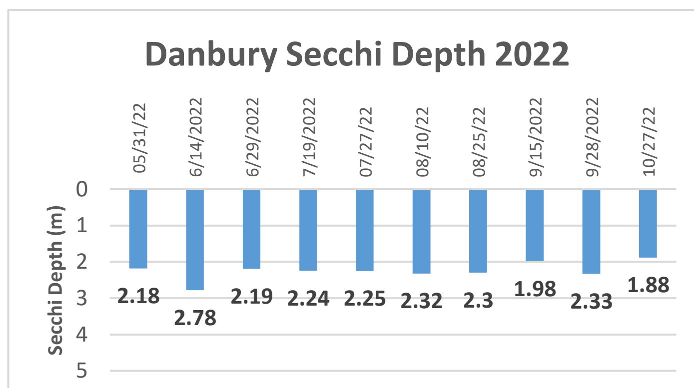
Secchi Transparency

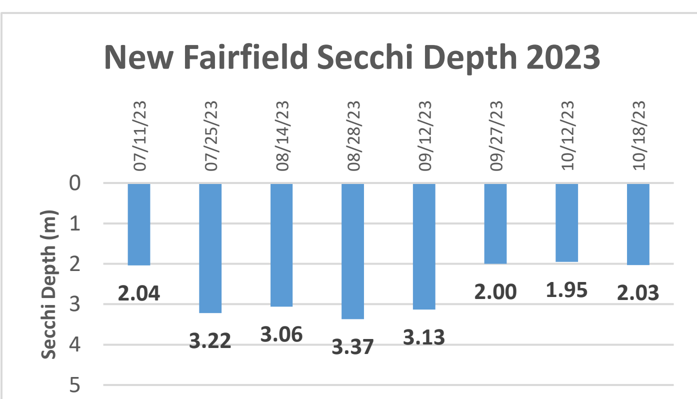
In 2023 secchi transparency (water clarity) in Candlewood Lake ranged from a low of 1.75m in Danbury in early October to a high of 4.44m in New Milford in late August. The average reading across the whole of both Candlewood and Squantz was 2.68m, with the highest average being New Milford at 2.93m, and the lowest being Danbury at 2.51m.

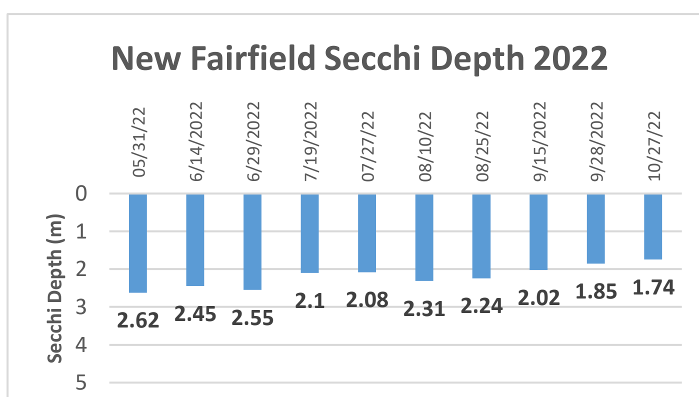
	DB Secchi (m)	NF Secchi (m)	NM Secchi (m)	SH Secchi (m)	SQ Secchi (m)	Average
11-Jul-23	2.00	2.04	2.07	2.04	3.79	2.39
25-Jul-23	3.19	3.22	3.02	3.44	3.10	3.19
14-Aug-23	2.79	3.06	2.54	2.69	2.86	2.79
28-Aug-23	3.42	3.37	4.44	3.10	2.79	3.42
12-Sep-23	3.10	3.13	3.47	3.48	2.70	3.18
27-Sep-23	1.85	2.00	3.16	1.83	2.90	2.35
12-Oct-23	1.75	1.95	2.65	2.05	2.35	2.15
18-Oct-23	1.97	2.03	2.07	1.97	1.93	1.99
Average	2.51	2.60	2.93	2.58	2.80	2.68

Table 4: *Secchi depths measured at each sampling location during the 2023 season.*









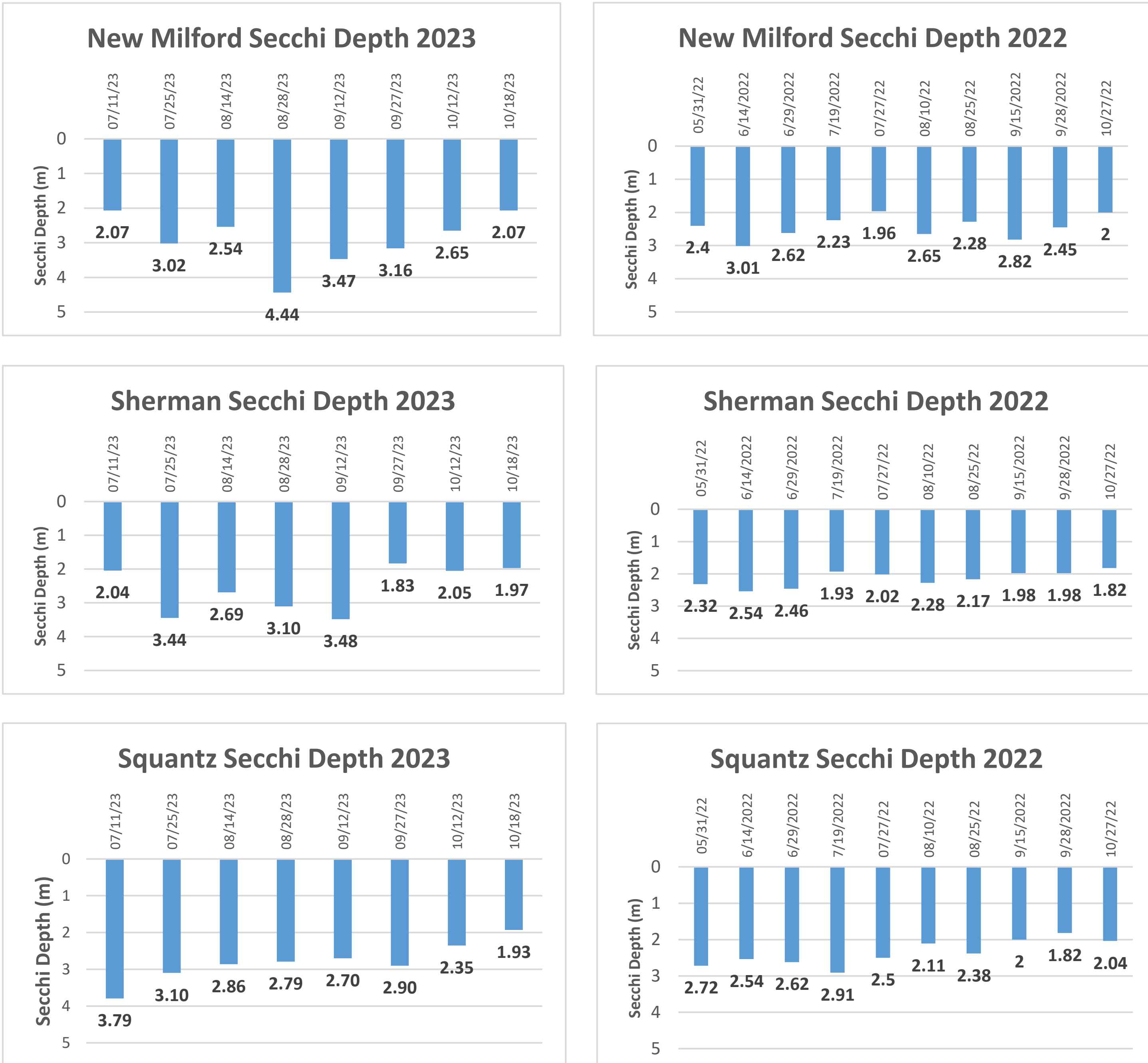


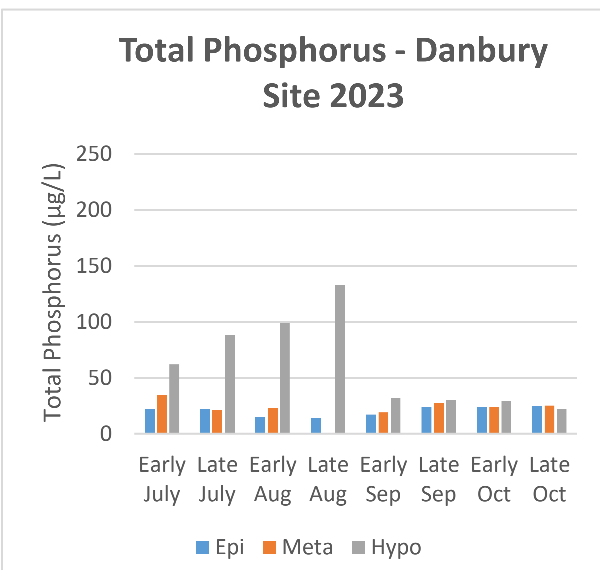
Figure 4: *Measured Secchi Transparency in Candlewood and Squantz in 2022 & 2021.*

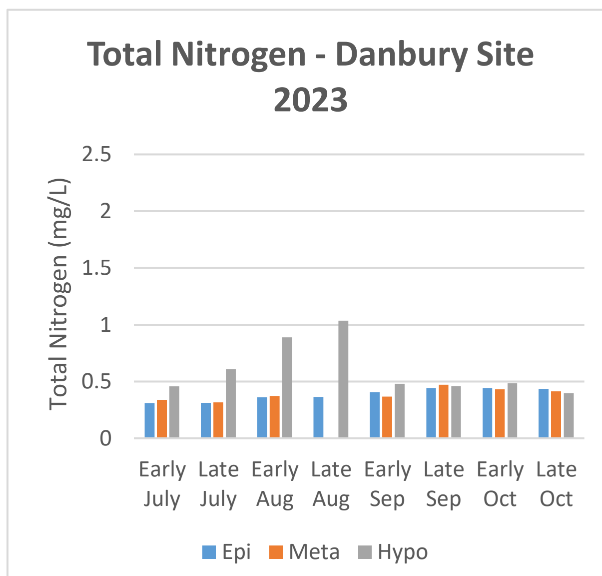
2023 has the highest average secchi transparency since 2020, when the average was 3.23 -- the second highest average in the history of monitoring (only 1989 was higher at 3.38). In 2021, that average dropped to 2.38 and in 2022 the average dropped again to 2.28. Thankfully we are not seeing higher chl-a values (discussed later in the report) or higher nutrient availability for algae as side-effects from the lack of plants in the lake over the past 3 years. It's encouraging to see average secchi increase, ranking 2023 number 14 out of 39 years of monitoring.

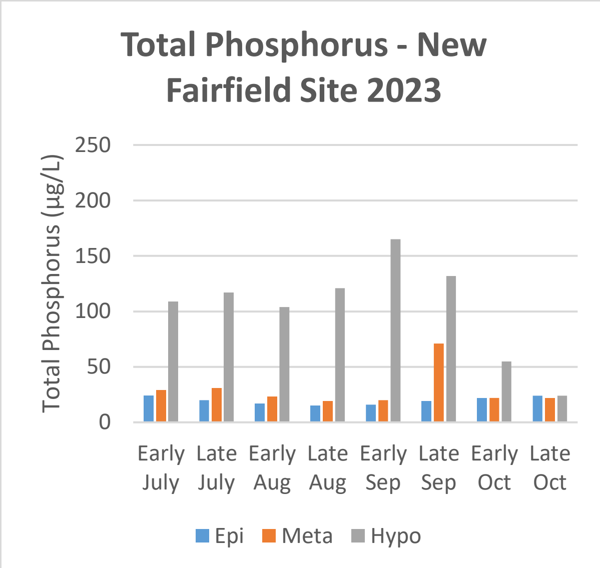
Nutrient Levels

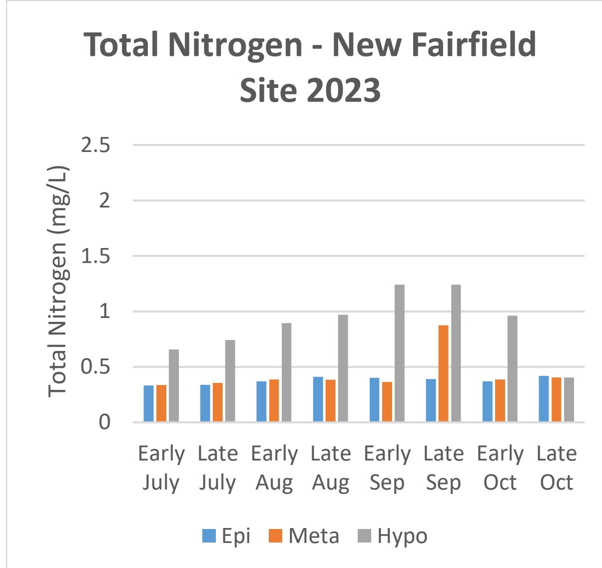
In 2023, nutrient measurements were taken 24 times at each site. This includes 3 samples at each location (Epilimnion, Metalimnion, and Hypolimnion samples) twice per month except for May and June, when equipment repairs and lab transfer delayed monitoring. The hope with the twice-monthly sampling throughout the season is that it will give us a better impression of nutrient dynamics in the water, and how that might impact blue-green and green algae growth in the water. This will also allow for a closer look at how nutrients are “locked” into the hypolimnion due to stratification and subsequent internal loading, and when those nutrients begin to mix with the rest of the water column. We sample total phosphorus, as well as four different forms of Nitrogen, but to visualize the nitrogen levels, we will use total available nitrogen levels.

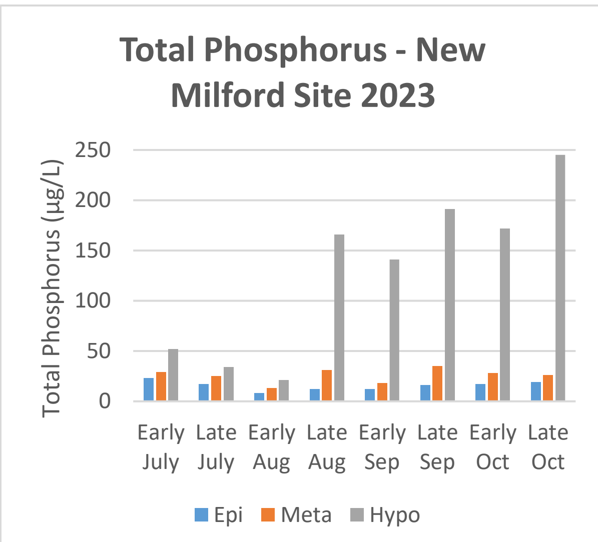
One important caveat for the 2022 monitoring year is that when we switched labs due to the changes at our old lab, our 2022 lab was not able to get us the results at a level of detection we needed for much of the season. Unfortunately, for both Nitrogen and Phosphorus, a detection limit was established that, while it improved over the course of the season, prevents us from the finer-grained nutrient level results we’ve had in the past. This change necessitated another change of labs in 2023 to the UCONN CESE lab, which thankfully does not have detection limits that impact our nutrient analysis of Candlewood. For this reason, in the below graphs there are no measurements that were impacted by being below a detection limit threshold.

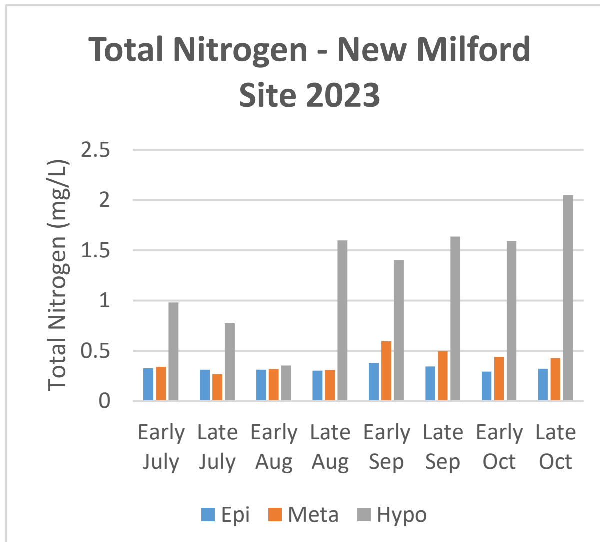


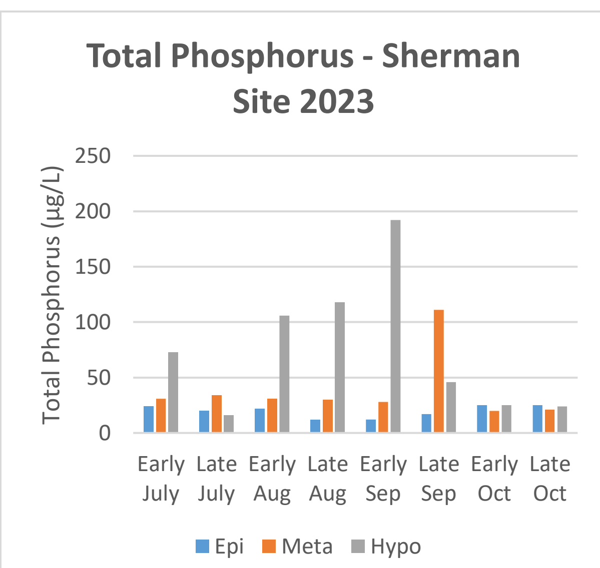


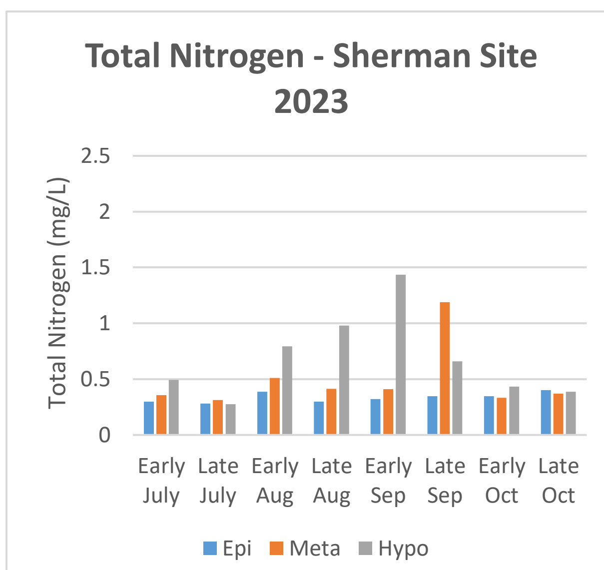

Total Phosphorus - New Fairfield Site 2023
Total Phosphorus (µg/L)
250
200
150
100
50
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo


Total Nitrogen - New Fairfield Site 2023
Total Nitrogen (mg/L)
2.5
2
1.5
1
0.5
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo


Total Phosphorus - New Milford Site 2023
Total Phosphorus (µg/L)
250
200
150
100
50
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo


Total Nitrogen - New Milford Site 2023
Total Nitrogen (mg/L)
2.5
2
1.5
1
0.5
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo


Total Phosphorus - Sherman Site 2023
Total Phosphorus (µg/L)
250
200
150
100
50
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo


Total Nitrogen - Sherman Site 2023
Total Nitrogen (mg/L)
2.5
2
1.5
1
0.5
0
Early July
Late July
Early Aug
Late Aug
Early Sep
Late Sep
Early Oct
Late Oct
Epi
Meta
Hypo

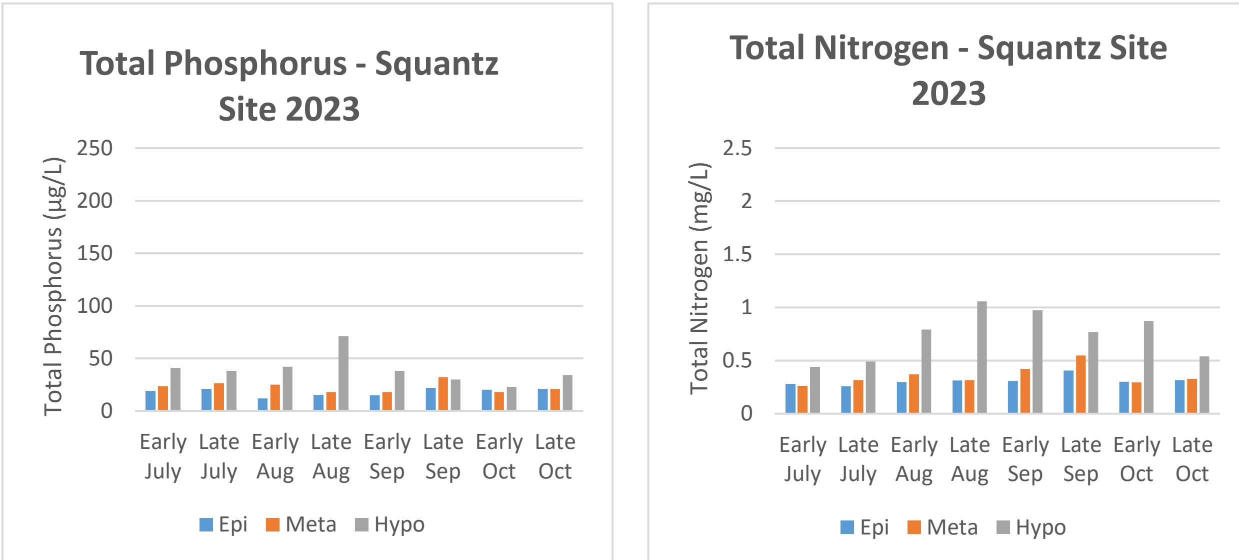


Figure 5: *Measured Total Phosphorus and Nitrogen at 3 depths in 2023.*

While there are different schools of thought about which of these two nutrients are more important in algae dynamics and eutrophication in freshwater systems, both are critical raw materials for algae blooms. Historically, Candlewood Lake has been considered phosphorus limited, and the blue-green algae community has been largely dominated by Microcystis cyanobacteria. To examine how the nutrient profile in Candlewood has changed over the course of the CLA's monitoring, it is useful to visualize epilimnion phosphorus levels, as those are the most relevant to algae growth, and thus the most likely to impact recreation during the boating season.

In 2023, the largest measurements for both nitrogen and phosphorus were generally found in the hypolimnion from late July through September, and even through October at the deeper New Milford site. This is because the New Milford site had not yet been mixed completely. By October, every other monitoring site had oxygen mixed through the water column, which slows internal loading dramatically. These measurements indicate strong internal loading in hypoxic conditions, a well-documented phenomenon in Candlewood Lake. Sediments at the lake bottom contribute nutrients to the system during the midsummer months, and those nutrients are incorporated into the rest of the water column after mixing.

Of particular interest this year is a general improvement in phosphorus measurements at the epilimnion. There were no readings above 30 µg/L giving an average reading of 18.8 µg/L. For reference, 2021's average was 24 µg/L. This continues the encouraging trend of modest decrease of nutrients in the epilimnion.

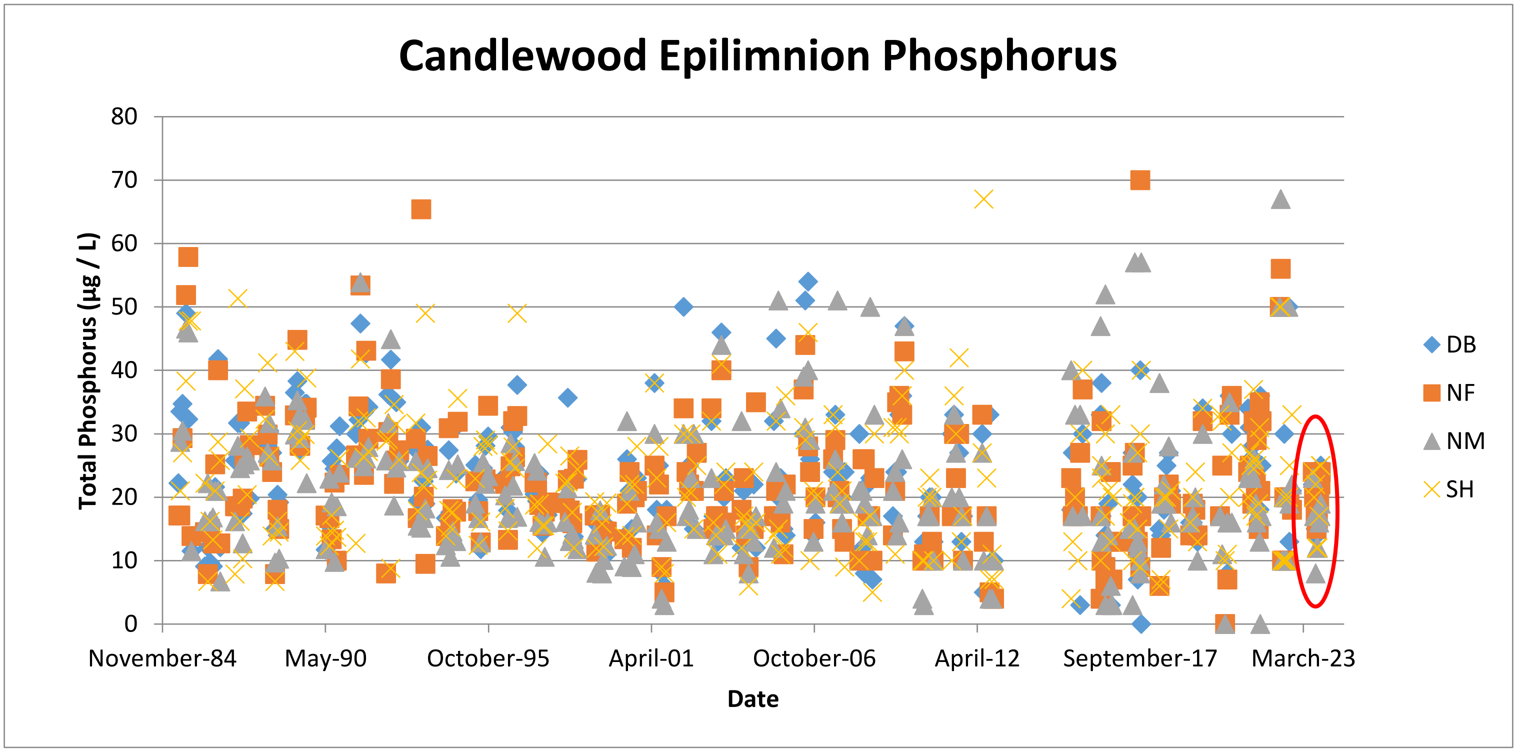


Figure 5: *Epilimnion phosphorus measurements at all 4 Candlewood monitoring sites taken from 1985 to 2022. The 2022 measurements have been highlighted.*

To help illustrate the trend over time of these measurements, we can look specifically at one sampling location, in this case we will look at Danbury:

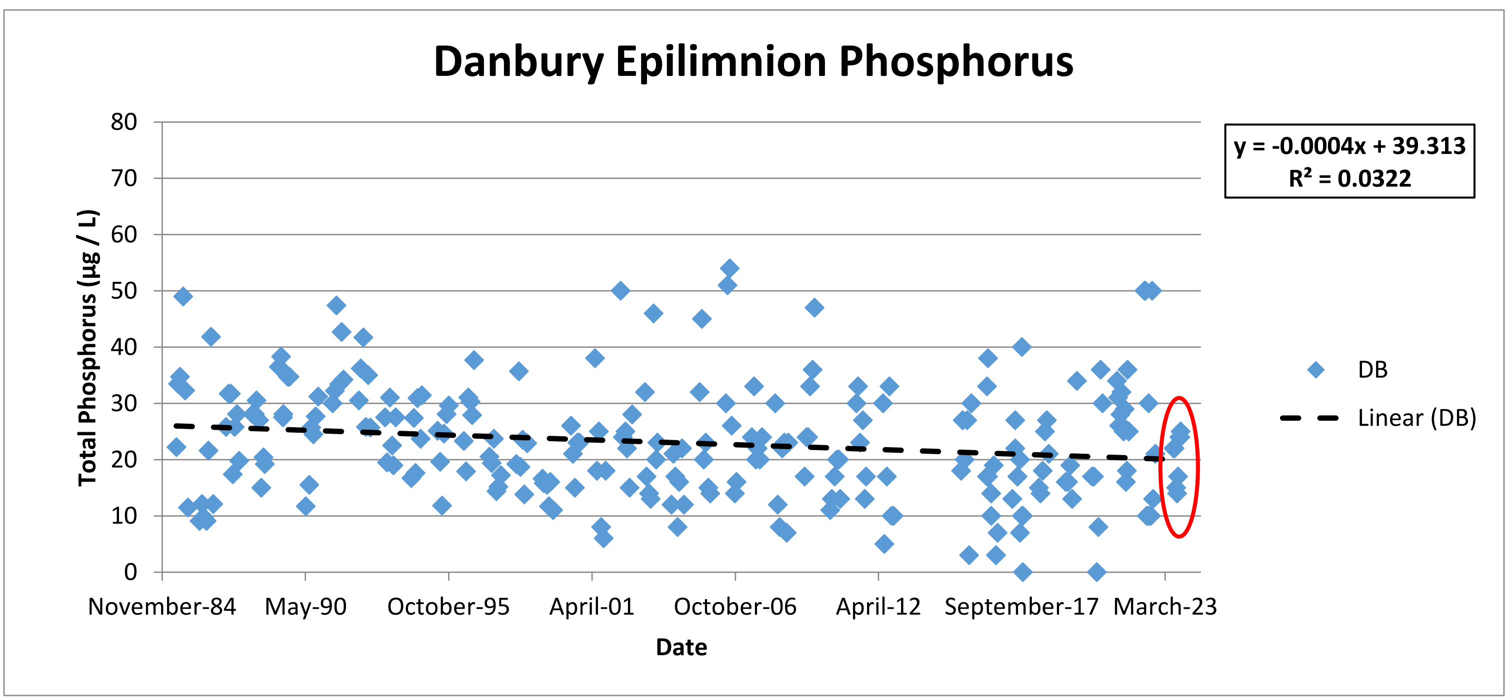


Figure 6: *Danbury Epilimnion Phosphorus from 1985-2022. Data clusters due to detection thresholds highlighted.*

While there is substantial variation in the data, (R^2 value of 0.0322) the negative slope of the line is encouraging, and this year the R^2 value increased from .0305. Based on all the above data from the Danbury site, a 95% confidence interval of the population mean of epilimnion of phosphorus was found to be 21.62 – 24.18 µg/L. Hopefully continued expanded sampling can can help us determine a more accurate mean measurement in the coming years. Last year the R^2 value decreased quite a bit due to the detection limits, but hopefully continued normal analysis will begin to get us back to a representative regression.

At this point, the slope representing the average epilimnion phosphorus levels is negative at all 4 sites on Candlewood. This means, over the past 38 years of monitoring, the average phophorus concentrations at the surface of the lake have been going down. This is very encouraging news, since most lakes around the country are battling rapidly increasing nutrient levels due to increased human activity. This is a sign of increasing awareness of the problem, education of the public on nutrient pollution, and implementation of best practices at properties around the lake. All that said however, the slope of these lines is a maximum of -0.0004 at the Danbury and New Fairfield sites, with New Milford being the closest to 0. This represents a very small, modest decrease over a long period of time; a decrease that can be reversed very easily should nutrient pollution in the watershed increase.

Chlorophyll Concentrations

Chl-a	Early July	Late July	Early August	Late August	Early September	Late September	Early October	Late October	Average
DB	6.32	5.64	4.3	3.6	6.3	7.7	5	9.5	**6.05**
NF	7.15	3.02	1.9	4	5.3	8.1	4	7.5	**5.12**
NM	5.01	5.12	1.4	2.9	5.2	5.5	6.8	7.5	**4.93**
SH	5.77	4.89	4.1	3.4	6	7.2	4.8	9.3	**5.68**
SQ	5.31	5.6	10.6	4.5	5.6	7.5	8.4	7.7	**6.90**
Average	**5.91**	**4.85**	**4.46**	**3.68**	**5.68**	**7.2**	**5.8**	**8.3**	**5.74**

Table 5: *Chorophyll-a as measured in the lab during the 2023 season (µg/L). Note that there was no chl-a sample for late october in Sherman.*

One of the best ways to measure both eutrophication and potential recreational impact on a freshwater lake system is by measuring Chlorophyll-a. This measurement is effectively a measurement of the algal material in the lake by measuring the green pigment present in green algae and cyanobacteria. The largest measurement taken in 2023 was in Squantz in late July at 10.6 µg/L, and is actually the only measurement above 10 µg/L taken in 2023.

The highest measurement in Candlewood was in late October at the Danbury location, coming in at 9.5 µg/L, with the second highest that same month in Sherman. This year was marked by generally lower productivity, giving lower average chlorophyll-a readings than in the past. This is supported by a lack of large scale algae bloom events during the year, with the exception of some in the Danbury/Lattins Cove area in June. Unfortunately, due to our equipment and lab delays we were not able to capture that month, contributing to a lower average measurement. However, the highest average measurements tend to be in October following lake de-stratification, so we can still meaningfully compare these results to past years.

By plotting chlorophyll-against secchi depth, we can get a good idea of how the lake generally compares to other years. This is a useful way to track two critical measures of eutrophication, while also displaying important aspects of the recreational value of the lake compared to past years.

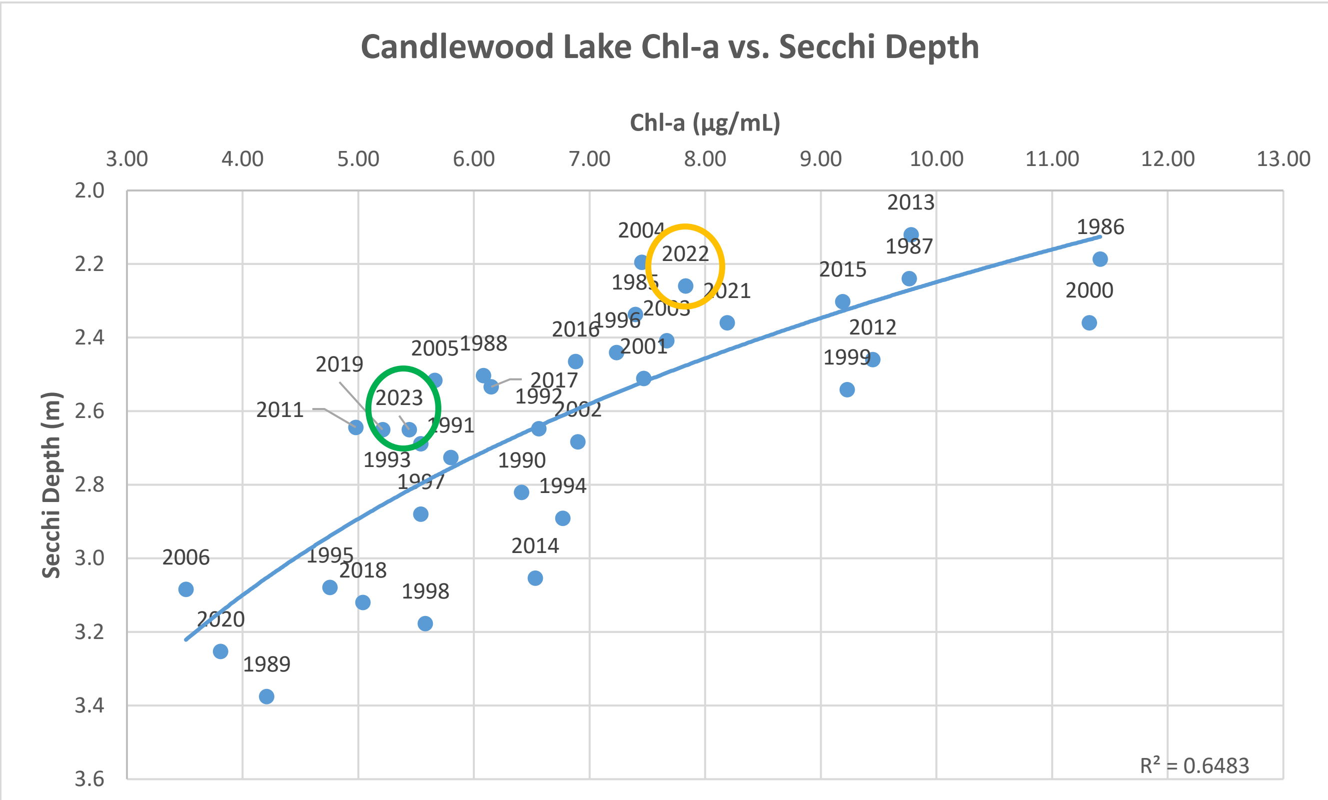


Figure 7: *Chlorophyll-a plotted against Secchi Depth in Candlewood from 1985-2023. The years 2023 and 2022 have been highlighted (Note that this graph does not include Squantz Measurements).*

The above figure is really useful in displaying the general productivity (that is, algae growth) of the lake, and comparing different years. The line shows the general (logarithmic) relationship between the two metrics. 2023 is a year where we saw lower than average chl-a measurements, and relatively expected clarity measurements. Based on the relationship, you could generally expect slightly clearer water based on the aveerage chl-a measurements taken. 2023 ranks relatively well compared to past years in both secchi depth and chl-a. It is very similar to 2019, while the recent year of 2020 was a near record setting year with the second highest average clarity and the second lowest average chl-a. This banner year was likely due to a host of factors, including very low precipitation and low mixing, denuding the epilimnion of most of its usable nutrients for algae early in the season. 2023 is a year that was marked by high precipitation and wind action, which might have prevented the effective proliferation of large algae colonies while in drought conditions, was marked by high temperatures, and possible high nutrient availability. While there is no clear trend to the relationship between chl-a and secchi clarity over time, the graph presents a useful method to comparing the “recreational usability” of the lake between years.

In 2019 we added a new sensor to our probe to measure chlorophyll-a using spectrophotometry. This uses a specific wavelength of light that bounces off of chlorophyll-a pigment to measure the concentration in the water and returning a relative value based on that measurement and the water volume in the sensor, rather than taking an entire water sample, filtering it, and measuring the pigment in the lab. We purchased this sensor in the hopes that a relationship could be established between the two methods that would allow us to rely on the new sensor rather than having to take whole water samples to the lab for analysis. To help establish that relationship, we have to compare the results from the two methods and see what their linear relationship looks like. We can then run an F-test to see if that relationship is indeed significant, and we can look at the R^2 value to see how strong that relationshisp is (how much the difference in the two measurements can be explained by only those two measurements).

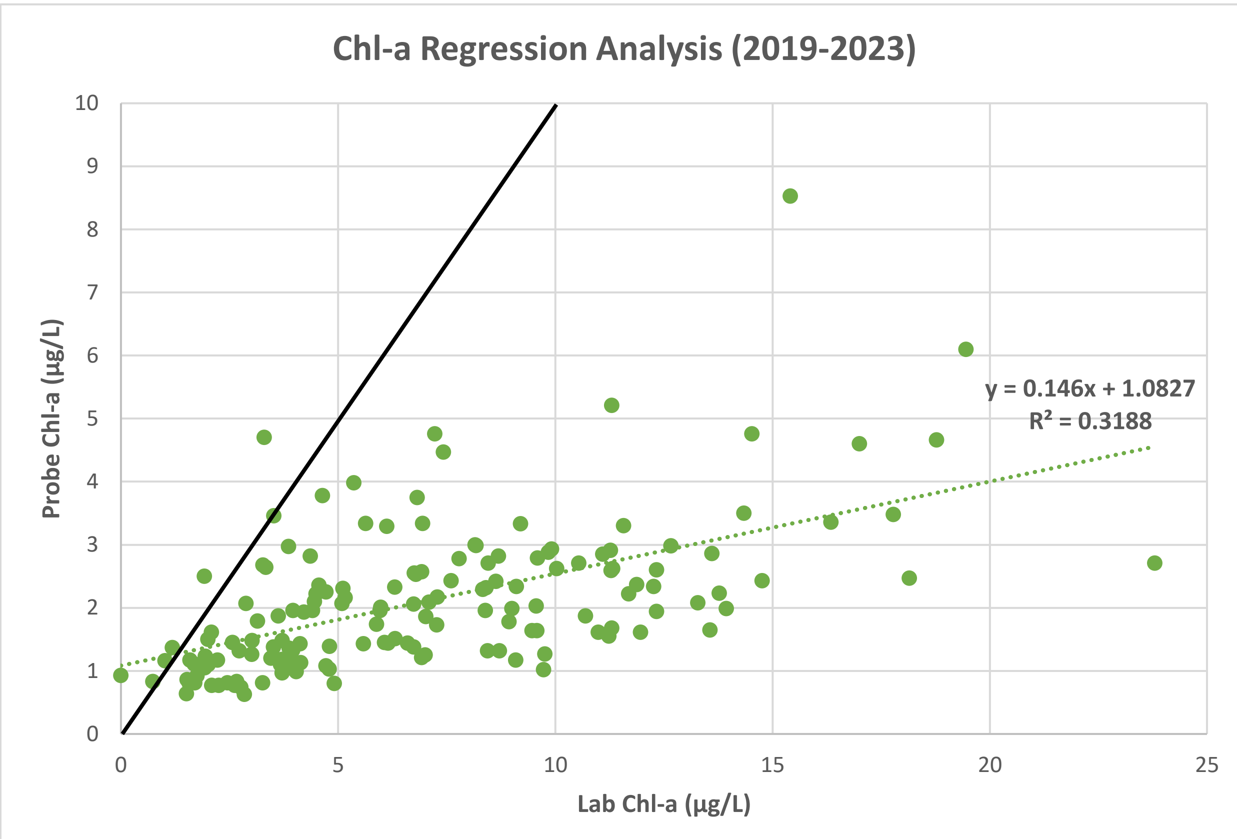


Figure 8: *Regression model for Probe and Lab measurements of Chl-a at 1m depth, including the equation for the relationship and the adjusted R^2 value. The black line illustrates what a 1:1 relationship would look like for the measurements.*

This green line shows the relationship between the probe measurements (the dependent variable, in this case) and the lab measurements (the independent variable). The black line shows the ideal 1:1 relationship that would occur if the probe was measuring exactly the same amount of chl-a as the lab was. Instead, we see that generally the probe measures the amount of chl-a as less than what we find in the lab (the only exceptions are those measurements above the black line). This makes sense logically, as the sensor on our probe is more limited to chance, if a high level of algae or cyanobacteria happens to be passing through the sensor at the time of meaurement or not, while the lab measurements take a much larger volume of water and measure the entire concentration in that sample. This makes the lab samples more representative of the "population" of 1m depth where the samples are taken than the sensor samples. This is why we also see that the goodness of fit of the trendline gets worse as the concentration increases, as the likelihood that the sensor might be missing areas of high algae concentration increases as the total amount of algal material in the 1m band increases.

With all that said, the F-test of significance returns a p-value (that is, the test of whether the relationship between the variables is significant at all) of 1.28×10^{-14}. The closer this number is to 0, the more certain we can be that we can reject the null hypothesis that there is effectively no relationship between the two measurements. What this means is that while the entire relationship between these measurements is confounded by other things (like the concentration issue mentioned above), that there is very strong evidence to say that these two variables are related in at least some capacity. The R^2 value can tell us, in general, how much of that relationship can be attributed to these two variables, and in this case, 31.8% of the relationship can be explained through comparison of these two variables alone. Ultimately, the trend does not fit the data well enough to confidently say we can switch to using the new sensor entirely (by correcting the values with the equation $y=0.146x+1.0827$).

In 2023, the sensor that was added to the probe malfunctioned and can no longer be used. Based on the above analysis from the four years the sensor was entirely functional, we have come to the conclusion that we will go back to relying exclusively on the lab analysis as opposed to the fluoremtry in the sensor. While the sensor provided some interesting context about the relative levels at deeper parts of the water column, ultimately the results were not accurate enough to justify replacing the sensor, and the utility of chlorophyll data from deeper portions of the water column is pretty low. As chlorophyll-a is a measurement that directly impacts recreation at the surface, we will move forward once again focusing exlusively on that. Our probe also has a fluroemter measuring phycocanin, which can deliver a relative cell count of blue-green algae at every depth. While this fluorimeter likely faces many of the difficulties of the chlorophyll-a sensor, it can provide much of that interesting context for algae content and how it changes throughout the water column.

Conductivity

Conductivity is a measurement of how well the water can conduct an electric charge. This is a good analog for measuring the level of dissolved salts in the water, as these salts dissolve into charged ions, which increase the water's ability to conduct an electric charge. This means that the higher the conductivity is, the higher the "saltiness" of the water. Over time, Candlewood has been accumulating more and more of these ions mostly through stormwater runoff and stormwater discharges that empty into the lake, precipitating a pretty clear increase in the water's conductivity.

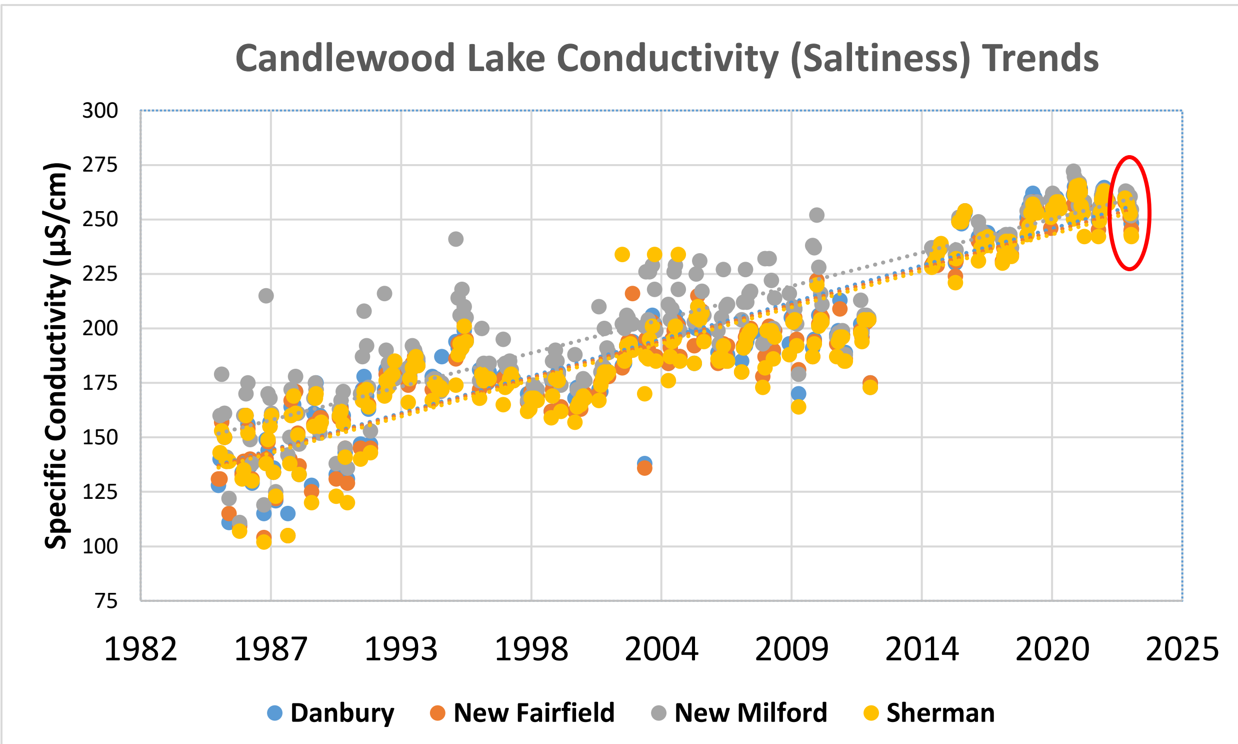


Figure 9: *Candlewood Lake Conductivity from 1985-2023 measured at 1m depth. 2023 has been highlighted, and trend lines have been included to illustrate the clear increase over time.*

2023 is now the second consecutive year where this concerning trend has changed course slightly, decreasing from an average of 261 in 2021 to an average of 258 in 2022 and now an average of 256 in 2023. To put these numbers in context, seawater has a conductivity of 50,000 µS/cm, and the limit of drinkable freshwater is around 3000 µS/cm, so while the lake is not in immenent danger of becoming a salt lake, there are species of fish and plankton that are more sensitive to these measurements, and eventually, should the trend of salt accumulation in the lake continue, we might begin to have impacts on the lake's fishery and ecosystem.

Cations and Anions

As part of the measurement of salts in Candlewood Lake we test the water bimonthly for key positive and negatively charged ions that are parts of certiain biological or ecological pathways. Those ions are calcium, magnesium, sodium, potassium, and chlorine. The measurement of these ions began in 1992 and has continued since

	Sodium (Na+)		Calcium (Ca++)		Chloride (Cl-)		Magnesium (Mg++)		Potassium (K+)	
Danbury	16.55	(17.59)	20.30	(19.80)	32.50	(33.19)	7.48	(7.07)	1.53	(1.34)
New Fairfield	15.90	(17.16)	20.78	(20.18)	32.35	(32.15)	7.19	(7.14)	1.53	(1.39)
New Milford	16.54	(16.77)	21.10	(20.02)	32.20	(32.06)	7.30	(7.15)	1.53	(1.32)
Sherman	16.07	(17.93)	21.05	(21.01)	32.10	(32.33)	7.18	(7.48)	1.54	(1.46)
Squantz	11.88	(13.98)	12.50	(12.81)	24.05	(25.20)	4.61	(4.75)	1.27	(1.24)

Table 6: *2022 (in parantheses) and 2023 average cation and anion concentrations measured at 1m depth (in mg/L).*

Of particular interest are the calcium ion levels, as these are a critical raw material for zebra mussel shell formation, and there are well documented thresholds for effective zebra mussel infestation of waterbodies based on calcium levels.

Risk	pH	Calcium (mg/L)
Low	<7.4	<12.0
Medium	7.4 – 8.0	12.0 – 20.0
High	>8.0	>20.0

Table 7: *Risk thresholds for Zebra Mussel Colonization (via: Murray et al. 1993, Biodrawversity 2013). Note: O'Neill 1996 classifies the range from 20-25mg/L as moderate risk.*

In Candlewood, most readings are at or above the high threshold of 20 mg/L. Since last year, most locations increased slightly, with the exception of Squantz Pond. Ideally, Squantz will remain at a relatively low concentration which will hinder the effective establishment of a zebra mussel population in Squantz. However, the slight decrease could indicate that the available calcium is being used by a growing population of mussels there, and particular care will be made to look for mussels in Squantz this upcoming winter and summer.

Other cations and anions in general remained relatively stable or decreased slightly. Perhaps the lower need for winter-time salt applications due to higher than average temperatures could be slowing this trend, as seen also in the conductivity graph (Figure 9).

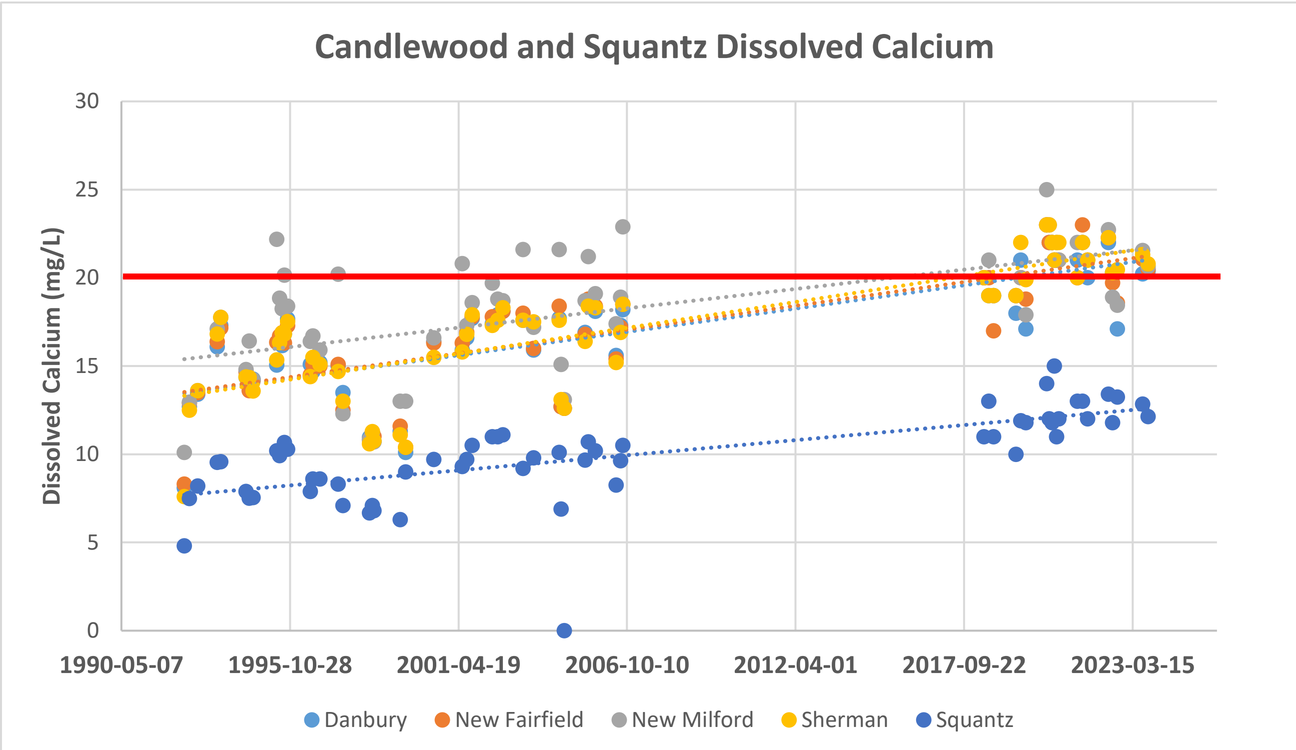


Figure 10: *Calcium concentrations in Candlewood and Squantz since 1992. Note that missing data between 2006 and 2018 is still being re-organized and undergoing quality assurance, and will be included in future reports. The red line shows the "high" risk threshold for zebra mussel colonization.*

This trend is concerning, but unsurprising, as calcium shows a strong correlation to conductivity in freshwater systems, meaning that as conductivity increases much of that increase is likely due to increases in dissolved calcium concentrations. We'd also like to work to keep Squantz Pond below high risk thresholds for zebra mussel colonization. As zebra mussels continue to colonize Candlewood, it will be interesting to see how efficiently they are able to spread into Squantz Pond where risk is low to moderate.

Zebra Mussel Monitoring

In May 2020, the first zebra mussel was found in Candlewood Lake by a diver off the tip of Vaughn's Neck in New Fairfield. This is in the main basin of Candlewood Lake, which is relatively surprising, as it is not near a usual vector for invasion (boat launch, natural stream, or housatonic river penstock). This spurred a more in depth search over the course of the next three summer and winter seasons. This search included:

1. Additional samplings for zebra mussel veligers using vertical net tows and cross-polar microscopy.
2. Shoreline searches during the drawdown by CLA employees, volunteers, and other organizations.
3. Zebra mussel "hotels" deployed by CLA employees and volunteers off of residential docks.
4. eDNA analysis of water samples by Dr. Wong's lab at Western Connecticut State University.
5. Dive searches from CLA volunteers and Biodrawversity.

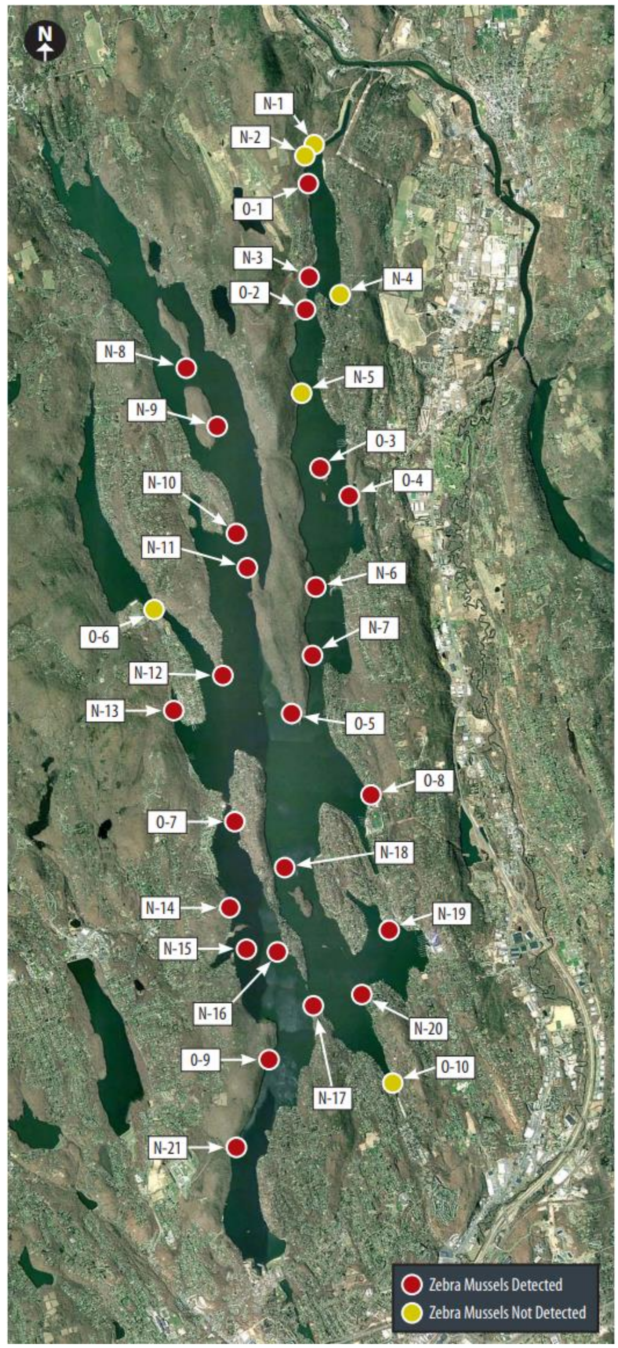


Figure 11: *Map of Zebra Mussel dive locations from Biodrawversity in May of 2022 with locations of found zebra mussels highlighted in red.*

Since that first discovery in May of 2020, 153 were found in 2020 and 2021, and an additional 77 found on the shoreline in 2022, and 370 found via Biodrawversity's 2022 dive. The mussels discovered cover a wide range of age classes, and include both juvenile and adult mussels, and their distribution in the lake is low density but widespread. This map illustrates the locations of this 2022 dive from Biodrawversity, and the locations where mussels were discovered. It’s important to note also that this dive focused on depths below the deep drawdown level, meaning that these depths could not be managed by the annual dewatering of the lakeshore.

In 2023, zebra mussels began to establish in all sections of the lake significantly, and at depths both at the level of the deep drawdown and deeper. Unfortunately, all indications point to zebra mussels establishing an efficient and self-sustaining population in Candlewood. Over the next 5 years, we expect normal exponential growth until the ecosystem reaches its carrying capacity, at which point the population size will cycle through crashes and recoveries, as seen in most newly invaded water bodies.

Figure 12: *Photo of Zebra Mussels found by a CLA volunteer in Brookfield in the winter in January of 2024.*

It is difficult to say exactly how zebra mussels arrived in the lake based on the pattern of expansion in the lake. A general “hotspot” was found in 2021 near the N-14 location on Figure 11, which is far from the first discovery at location O-5. It is possible that a very small population of zebra mussels have been in the lake for many years, coming through one of the common vectors like a transient recreational boat from another lake or through the Housatonic River water pumped into the lake. This small population might have been effectively managed for a long time be the winter drawdown, preventing its discovery until it grew enough for discovery in 2020. As it stands now however, zebra mussels have now become a part of Candlewood Lake’s ecosystem. While the wintertime drawdown might help mitigate some of their impact in shallow areas, ultimately their effective and rapid reproduction will continue in spite of that management.

Plant Monitoring

In early 2022 a substantial change in the plant community was noticed in Candlewood. In the spring the beginning of plant growth was observed, but quickly stopped and disappeared. For the remainder of the season, little new plant growth was observed, although some areas did still display modest growth, and all the plants historically found in Candlewood were found in small quantities in various places in the lake. Some regrowth was observed using sonar in late September and October. The plants did not have time to re-establish the population while lake temperatures and sunlight were conducive to growth. In 2023, very similar conditions to 2022 were observed -- very little plant growth, with a few small quantities of plants being found in different places around the lake.

This change was likely due to the combined impact of the sterile grass carp that were stocked in the lake in 2015 and 2017 to manage the overabundant Eurasian Milfoil, as well as the wintertime drawdown. In 2023, to evaluate this theory, as well as understand the potential for regrowth, five exclosures were placed in the lake at locations of historic plant growth. These exclosures, placed at roughly 6ft depth and covering an area of roughly 6.5m² were meant to protect an area of plant growth from the sterile grass carp that are thought to be keeping the plant population down by constant grazing pressure.

Exclosures 2-5 all showed growth of various plants within the protected area, including *Vallisneria spiralis, Elatine triandra,* and *Myriophyllum spicatum*. No plants grew to the surface though, and Exclosure 5 showed the most growth out of all of them – with that being the only location with active growth of Eurasian Milfoil. We hope to expand this program, with the help of DEEP, in 2024.

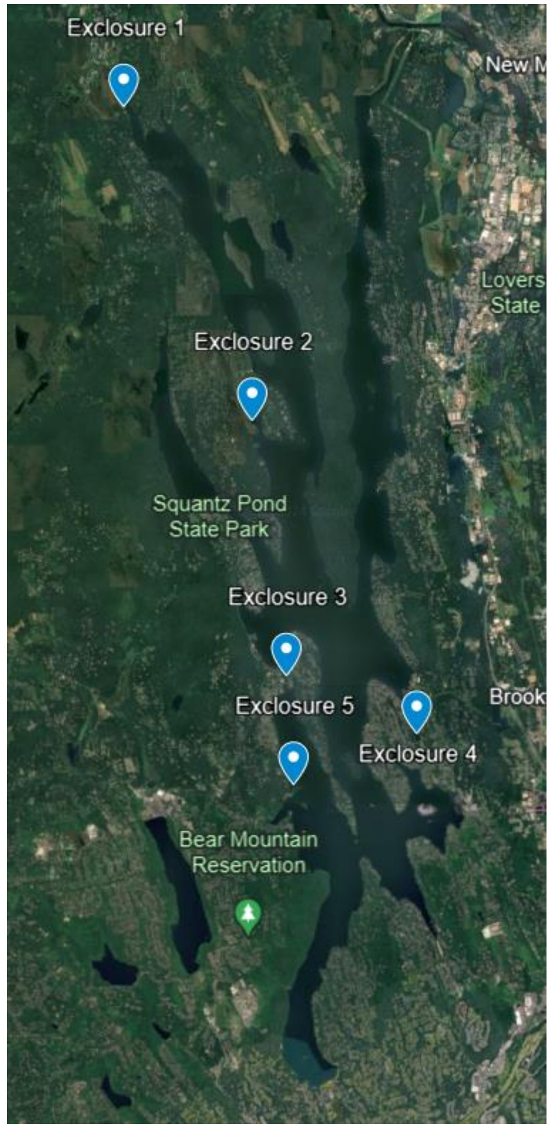


Figure 13: *Map of exclosure locations on Candlewood Lake in 2023.*

Discussion

2023 was a unique year in that it marked an improvement in many water chemistry metrics, but continued changes in Candlewood's Ecosystem. This marks the third year where the CLA was able to do two separate monitoring events per month for all of our key metrics. By increasing our samples per month and year, we can get a more accurate idea of the actual state of Candlewood Lake. We plan to continue this moving forward so that all of our measurements more closely approximate the true values in the whole lake, while also allowing us to see changes in the chemistry over time more accurately. Our equipment and lab are prepared to begin monitoring in May in 2024 as normal.

While the lake saw some improvements in nearly every metric, with the exception of certain ions including calcium, the ecosystem is changing in other concerning ways. In particular, the rapidly increasing population of zebra mussels, and the continued lack of macrophyte plants. While the loss of plants is now pretty well understood in the context of the sterile grass carp and drawdown, work will continue to attempt to balance the plant community in the lake. We are encouraged that nutrient concentrations in the epilimnion continue their meager decrease over time – a trend likely attributable to public education efforts and better community engagement. However, this trend might be slowing in recent years, so careful watch of nutrient level average change will be critical. The lake still shows strong internal loading tendencies during stratification, which can lead to strong algae blooms at the end of the season when the water column mixes, and those nutrients become available for use by the algal community. For the first time we are beginning to see a potential decrease in salt levels over time in the lake. Hopefully we see that trend continue over the next few years.

Trophic Category	Total Phosphorus (μg / L)	Total Nitrogen (μg / L)	Summer Chlorophyll-*a* (μg / L)	Summer Secchi Disk Transparency (m)
Oligotrophic	0 - 10	0 - 200	0 - 2	>6
Early Mesotrophic	10 - 15	200 - 300	2 - 5	4 - 6
Mesotrophic	15 - 25	300 - 500	5 - 10	3 - 4
Late Mesotrophic	25 - 30	500 - 600	10 - 15	2 - 3
Eutrophic	30 - 50	600 - 1000	15 - 30	1 - 2
Highly Eutrophic	> 50	> 1000	> 30	0 - 1

Table 8: *Eutrophication "report card" with 2022 average levels highlighted to illustrate the general eutrophic identity of the lake.*

In most categories in 2023, Candlewood improved from a late mesotrophic condition to a mesotrophic or early mesotrophic condition. While Candlewood Lake is not an old lake, it is substantially impacted by the surrounding human development, precipitating higher nutrient measurements, lower clarity, and greener water. By working to lower nutrient levels in the lake, ideally we might begin to see improvements in chlorophyll-a and secchi disk measurements as well.

In 2024, the CLA will be conducting a Nutrient Budget analysis, pinpointing the primary sources of Phosphorus and Nitrogen in the lake. Although we understand these sources now, this project will illustrate just how much impact each source is having, and the best course of action for potentially managing those sources. Work on hopefully achieving a balanced and healthy plant community will also continue as additional exclosures, native species planting, and additional carp removals if necessary are being evaluated.

The general recommendations for the coming years based on the 2023 results are as follows:

1. Develop a long-term nutrient mitigation strategy based on nutrient budget analysis to inform a Lake Management Plan.

2. Continue community education efforts surrounding phosphorus and nitrogen pollution to continue and strengthen downward trend.

3. Engage town public works and departments of transportation with a focus on efficient road salting to minimize lake impacts of road salt runoff with a hope of potentially creating a sustainable negative trend.

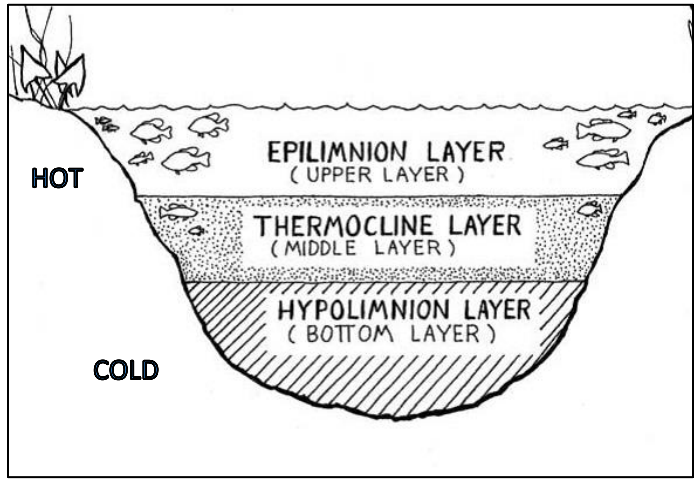
4. Continue twice monthly sampling and consider adding April to monitoring to catch early season information before stratification begins.

5. Re-integrate a phytoplankton analysis to view the impact of zebra mussels on phytoplankton community.

6. Expand active recreation management and education at the boat ramps to help stop invasive species threat both into and out of Candlewood Lake.

Glossary

Temperature: Often measured in Celsius, different layers (surface vs. very deep water) of the lake often have very different temperatures! A larger difference between the temperature of shallow and deep water can mean that those two layers are less likely to mix, since colder water is denser and sits at the bottom. A diagram of the various lake layers is illustrated below!



Dissolved Oxygen: This is measured in milligrams per liter (mg/L) and is a measure of how much oxygen the water has, which many fish species and other organisms rely on.

Total Phosphorus: This is measured in micrograms per liter (µg/L) which is the same as "parts per billion" (ppb). This measures the concentration of phosphorus in the water which can feed algae and aquatic plants.

Total Nitrogen: This is measured in the same way as total phosphorus, but instead measures nitrogen concentration, which can also feed algae and aquatic plants.

pH: This is a measure of how acidic or alkaline (basic) the water in the lake is by measuring hydrogen ions (H^+). This is measured on a scale from 0-14, where zero is the most acidic and 14 is the most basic. Neutral pH is 7, and this measure is of singular importance to organisms living in the water, many of which require a pH that is slightly basic (7-9). However, higher pH can also allow more phosphorus (and other compounds) to dissolve in the water; potentially increasing total phosphorus measurements.

Secchi Depth: This is a method used to measure how clear and transparent the lake water is. It is measured by dropping a circular black and white disk on a rope into the water, and the depth at which the disk can no longer be seen is recorded in meters (m). Higher measures mean the disk could be seen longer, and that the water is clearer. This is illustrated in the diagram below!

Chlorophyll-a: This is measured in micrograms per liter (µg/L) which is the same as "parts per billion" (ppb). Chlorophyll-a is the compound that makes plants green, and what they use for photosynthesis. This measure gives insight into how much green algae is in the water and can decrease transparency (and secchi depth).

Conductivity: A measure of the ability of water to pass an electrical current, increased by the presence of charged particles in the water.

Ions: Charged particles that increase conductivity. Often From salts that have dissolved in the water – which certain aquatic species are very sensitive to.