Appendix D: Extended Lake Data Evaluations

Section 1: Introduction

The UNRBA is developing two mechanistic (process-based) lake water quality models for Falls Lake using the Environmental Fluid Dynamics Code (EFDC) and the Watershed Analysis Risk Management Framework (WARMF). Both models simulate the growth of algae using three groups: blue green algae (i.e., cyanobacteria), diatoms (Bacillariophyceae), and green/other algae. To simulate chlorophyll-a, each algal group has an assumed chlorophyll-a to carbon ratio. These ratios are initially set using published modeling studies and adjusted during model calibration. While the ratios can be set differently for each algal group, they cannot be adjusted within the algal group to reflect changing ratios due to varying environmental conditions or dominance of different algal species within the group through time. While this is a limitation, it is standard practice for these types of models.

Water temperature and availability of light and nutrients (including silica for diatoms) impact/limit growth of each algal group. Key model parameters specified for each group (depending on the model) include optimal water temperature, half saturation constant for nitrogen and phosphorus, maximum growth rate, basal metabolism rate, settling rate, and predation rate (EFDC).

During model calibration, the simulated chlorophyll-a concentrations are compared to the observations collected in Falls Lake. However, there is uncertainty associated with laboratory data, and the observations should not be considered exact. Model parameters are adjusted to improve the simulation with the goal of meeting the model performance criteria specified in the North Carolina Division of Water Resources (DWR)-approved UNRBA Modeling Quality Assurance Project Plan (QAPP). Ranges of these parameters are well established in the literature for diatoms, blue green, and green algae (USEPA 1985 and 2019). Other algal groups are less studied and typical ranges are not available for the set of parameters required by the models.

The EFDC modelers tested the addition of two other groups of algae that are frequently dominated in Falls Lake, but this change did not improve model performance. One reason is a lack of reasonable ranges for the full suite of algae growth parameters and another is that high chlorophyll-a concentrations often do not correspond to increased algal biovolume in Falls Lake (based on historical sampling data).

During development of the WARMF Lake and EFDC models for Falls Lake, the modeling team, modeling staff from the DWR, and the “third-party reviewers” funded by the NC Collaboratory met to review the lake model calibrations with a focus on chlorophyll-a. During these meetings, staff from DWR and the “third-party reviewers” requested the following comparisons to inform model development and provide context for the lake model performance statistics:

- Comparison of algal biovolume to chlorophyll-a concentrations (Section 2:)
    - Time series
    - Scatter plots
- Comparison of Secchi depth to chlorophyll-a concentrations (Section 3:)
    - Time series
    - Scatter plots
- Evaluation of Jordan Lake fluorescence data (Section 4:)

The comparisons presented in Section 2: and Section 3: rely primarily on Falls Lake water quality stations monitored by DWR (Figure D-1). Jordan Lake fluorescence data were collected by Dr. Rick Luettich.

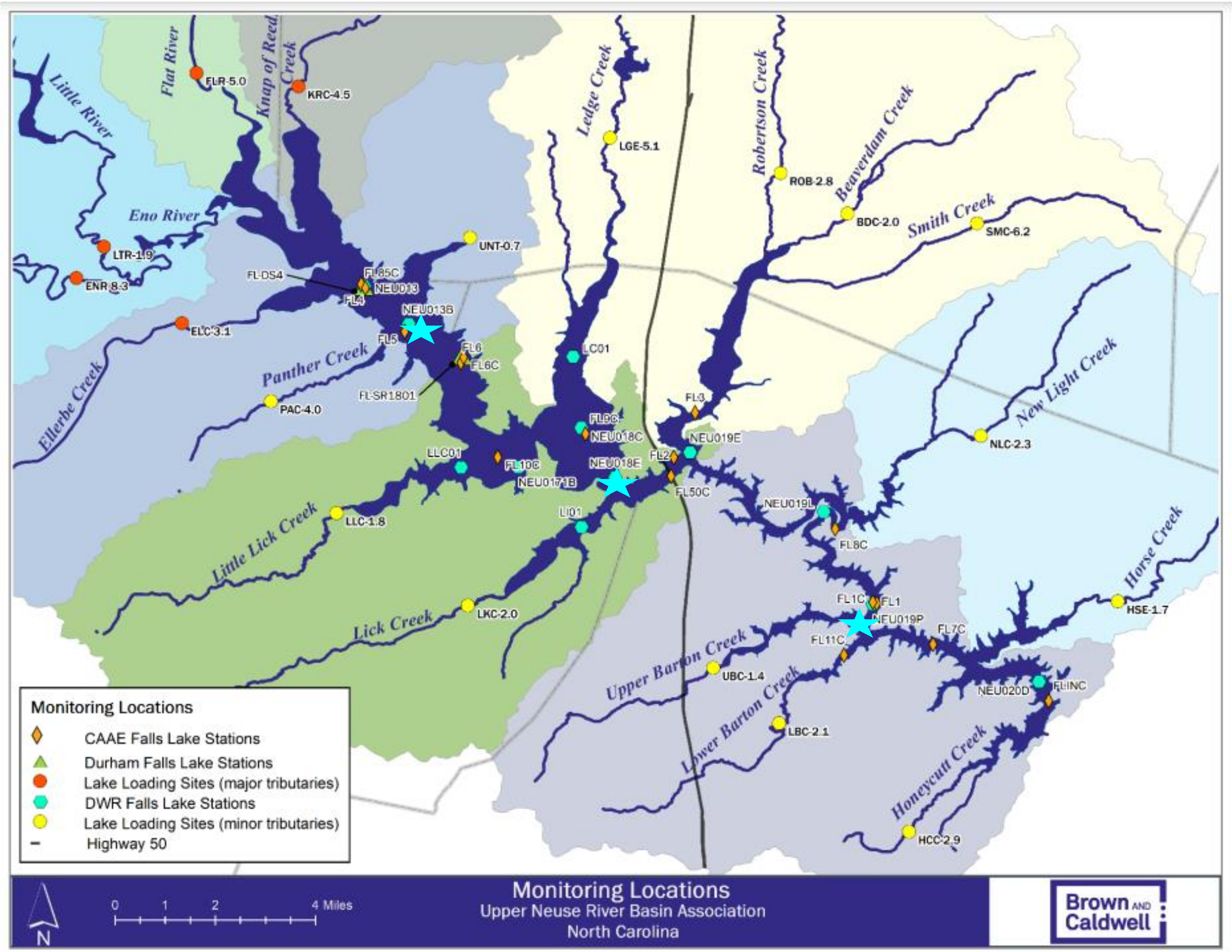


Figure D-1. Falls Lake Monitoring Stations (blue stars indicate the approximate location of the three DWR algal biovolume locations)

Section 2: Comparison of Biovolume Estimates to Chlorophyll-a Concentrations

DWR collects samples at three locations in Falls Lake that are evaluated for water quality (e.g., nutrient and chlorophyll-a concentrations) and algae composition. Chlorophyll-a measures the amount of green pigment in a sample and is used as an indicator of algal abundance (i.e., higher chlorophyll-a concentrations imply more algae). However, other sources of green pigment may exist in a sample, like sloughed periphyton entering from tributaries following large storms. Algae may produce more or less chlorophyll-a depending on environmental conditions. The NC water quality criterion for chlorophyll-a is 40 µg/L, applied as an instantaneous standard that applies everywhere in a waterbody.

Algal biovolume is an estimate of the volume of algae within a volume of water and has units of millimeters cubed per meter cubed (mm^3/m^3). The method involves microscopic counts of algae and estimates of biovolume for individual groups of algae (greens, diatoms, blue greens, etc.) using empirical equations. Biovolume estimates are uncertain relative to other types of data collected in Falls Lake. Therefore, relative magnitudes and trends across algal groups are the focus of this discussion rather than absolute magnitudes.

DWR uses a biovolume threshold of 5,000 mm^3/m^3 to indicate an algal “bloom.” This threshold is not indicative of a specific use impairment. The time series show that sometimes high chlorophyll-a concentrations correspond to high biovolumes and sometimes they do not. When biovolume is higher, the dominant algal groups change temporally and spatially. The most frequent groups that exceed the biovolume threshold for bloom are Pymnesiophytes and Euglenoids.

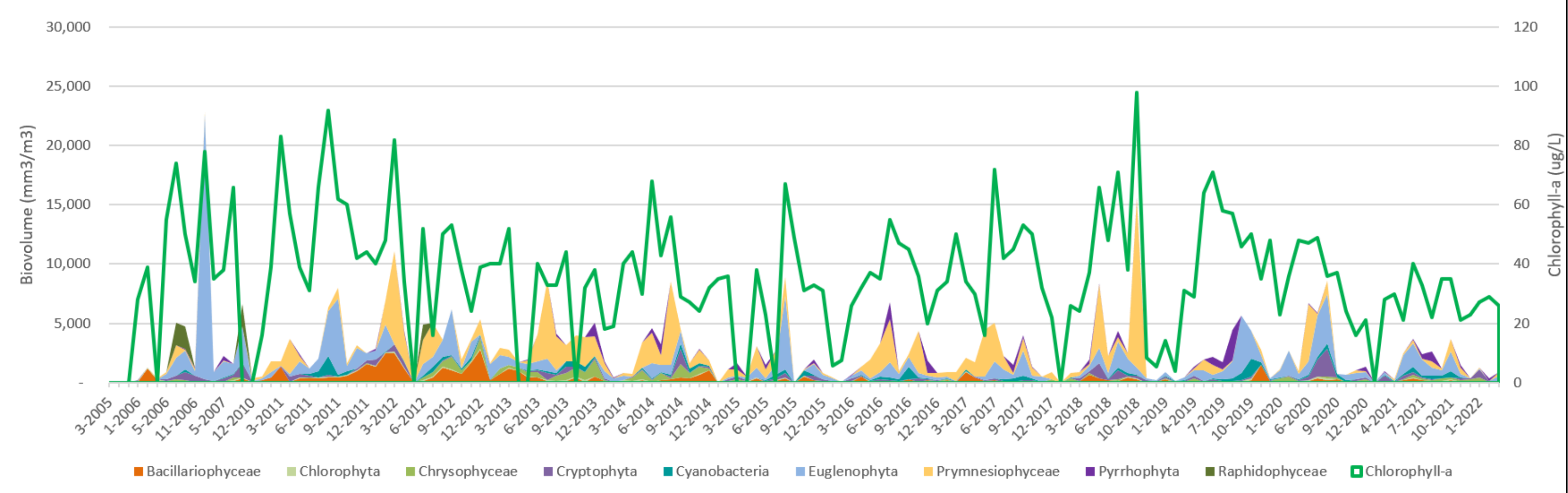
During EFDC model development, there were elevated concentrations of chlorophyll-a that were not being simulated by the model. In order to understand which algal groups were dominant during these “spikes,” the modeling team created time series of algal biovolume and chlorophyll-a to target further calibration efforts (top panel in

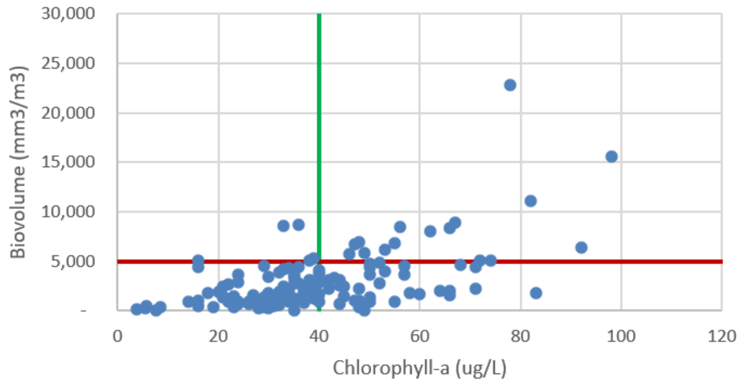
Figure D-2 through Figure D-4). To show the more general relationship between biovolume and chlorophyll-a, scatter plots of the total biovolume (all groups) were created at each station (bottom left panel in

Figure D-2 through Figure D-4). There are some samples where the biovolume is higher when chlorophyll-a is higher, but often total biovolume is low, even when chlorophyll-a is greater than 40 micrograms per liter (µg/L). To illustrate the general trends in total biovolume and chlorophyll-a for different periods, the bottom right panels in

Figure D-2 through Figure D-4 show the average total biovolume and average chlorophyll-a for four periods: 2005 to 2007 (baseline period for the Falls Lake Rules), 2011 to 2014, 2015 to 2018 (the UNRBA study period), and 2019 to 2021. Data are not available from 2008 to 2010 to support this comparison. The percent of the total biovolume exceeding 5,000 mm^3/m^3 and the percent of chlorophyll-a concentrations greater than 40 µg/L are also shown in the bottom right panel.

While there are some observations where high chlorophyll-a corresponds to high biovolume, this is not always the case. For example, at station NEU018E, 80 percent of the time when chlorophyll-a exceeded 40 µg/L, the total biovolume was less than 5,000 mm^3/m^3 and sometimes less than half that. This phenomenon can be seen in early 2017 at both NEU018E and NEU019P where the relative magnitude of a spike in chlorophyll-a does not necessarily correspond to a comparably sized spike in biovolume. Sometimes a spike in a specific algal group causes elevated chlorophyll-a concentrations and sometimes a bloom of the same size, or larger, does not [e.g., at station NEU019P where in February 2017 the chlorophyll-a concentration was 81 µg/L and the biovolume of the dominant algal group (Prymnesiophytes) was approximately 3,200 mm^3/m^3; a few months later in May 2017, the biovolume of Prymnesiophytes was approximately 14,000 mm^3/m^3 and the chlorophyll-a concentration was lower at 65 µg/L].

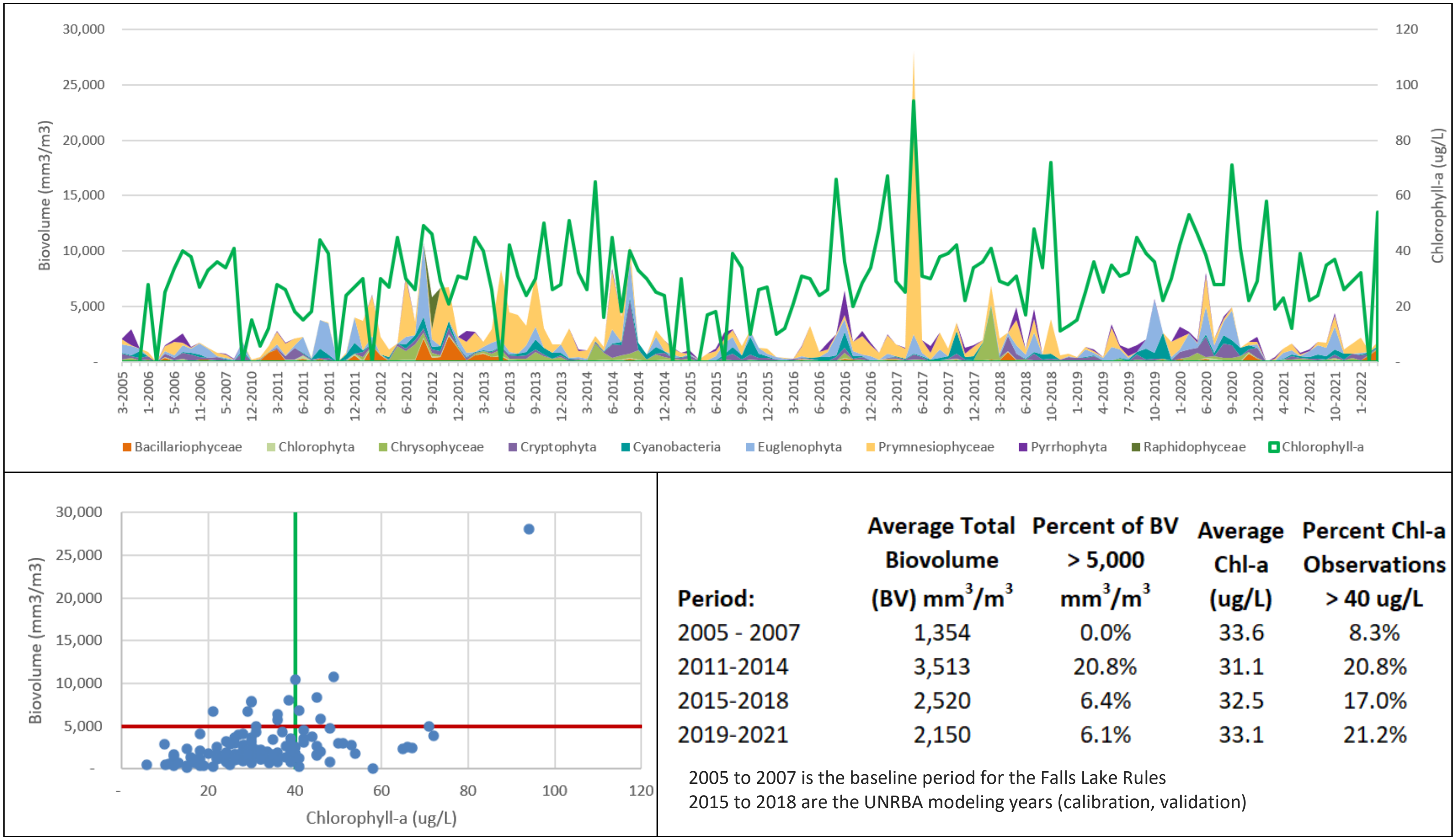




Period:	**Average Total Biovolume (BV) mm^3/m^3**	**Percent of BV > 5,000 mm^3/m^3**	**Average Chl-a (ug/L)**	**Percent Chl-a Observations > 40 ug/L**
2005 - 2007	3,994	25.0%	49.7	41.7%
2011-2014	3,590	20.8%	42.9	39.6%
2015-2018	2,411	10.6%	37.7	31.9%
2019-2021	2,353	12.1%	35.4	30.3%

2005 to 2007 is the baseline period for the Falls Lake Rules
2015 to 2018 are the UNRBA modeling years (calibration, validation)

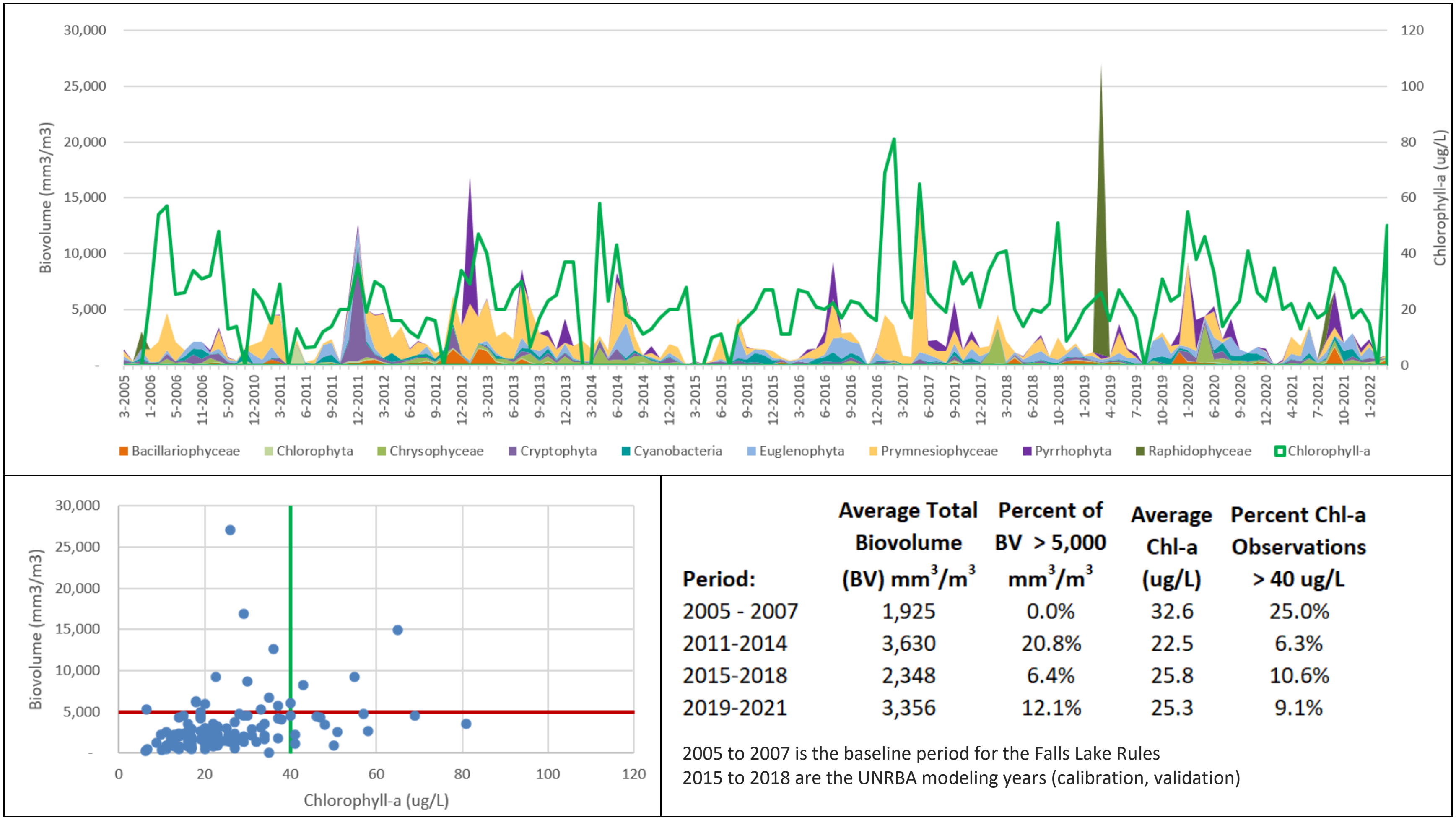
Figure D-2. Monthly Total (Stacked) Biovolume Estimates and Chlorophyll-a Concentrations at Station NEU013B as time series (top), scatter plot (bottom left), and period averages (bottom right)



Period:	Average Total Biovolume (BV) mm^3/m^3	Percent of BV > 5,000 mm^3/m^3	Average Chl-a (ug/L)	Percent Chl-a Observations > 40 ug/L
2005 - 2007	1,354	0.0%	33.6	8.3%
2011-2014	3,513	20.8%	31.1	20.8%
2015-2018	2,520	6.4%	32.5	17.0%
2019-2021	2,150	6.1%	33.1	21.2%

2005 to 2007 is the baseline period for the Falls Lake Rules
2015 to 2018 are the UNRBA modeling years (calibration, validation)

Figure D-3. Monthly Total (Stacked) Biovolume Estimates and Chlorophyll-a Concentrations at Station NEU018E as time series (top), scatter plot (bottom left), and period averages (bottom right)



Period:	Average Total Biovolume (BV) mm^3/m^3	Percent of BV > 5,000 mm^3/m^3	Average Chl-a (ug/L)	Percent Chl-a Observations > 40 ug/L
2005 - 2007	1,925	0.0%	32.6	25.0%
2011-2014	3,630	20.8%	22.5	6.3%
2015-2018	2,348	6.4%	25.8	10.6%
2019-2021	3,356	12.1%	25.3	9.1%

2005 to 2007 is the baseline period for the Falls Lake Rules
2015 to 2018 are the UNRBA modeling years (calibration, validation)

Figure D-4. Monthly Total (Stacked) Biovolume Estimates and Chlorophyll-a Concentrations at Station NEU019P as time series (top), scatter plot (bottom left), and period averages (bottom right)

Section 3: Comparison of Chlorophyll-a Concentrations to Secchi Depth

DWR collects water quality samples in Falls Lake as photic zone composite samples. The photic zone is the depth that sufficient light penetrates the water column to allow algae and plant growth. To estimate the depth of the photic zone, a Secchi disk is lowered into the water to the depth at which the disk is no longer visible, then raised to where it just becomes visible. The average of these two depths is recorded as the Secchi depth. The photic zone over which the composite sample is collected is approximated as twice the Secchi depth. This approximation has been confirmed for Falls Lake using a photosynthetically active radiation (PAR) meter which provides a more accurate measurement of photic depth (Section 4.7 of the UNRBA 2016 Annual Monitoring Report). DWR collects photic-zone composites for chlorophyll-a, nutrients, total solids, suspended solids, turbidity, and phytoplankton measurements.

The Secchi depth in Falls Lakes increases from the upper end of the lake toward the dam (Figure D-5). The five largest tributaries enter the lake at the upper end, upstream of Interstate 85. These tributaries deliver the majority of the nutrient and sediment loads to the lake, and the water is more turbid than downstream. The water depth at the upper end of the lake is shallow, and wind mixing and turbulence following high-flow events result in resuspension of sediment and little accumulation of sediment. These mixing processes become less dominant in the downstream direction as smaller tributaries enter the system and the water depth increases.

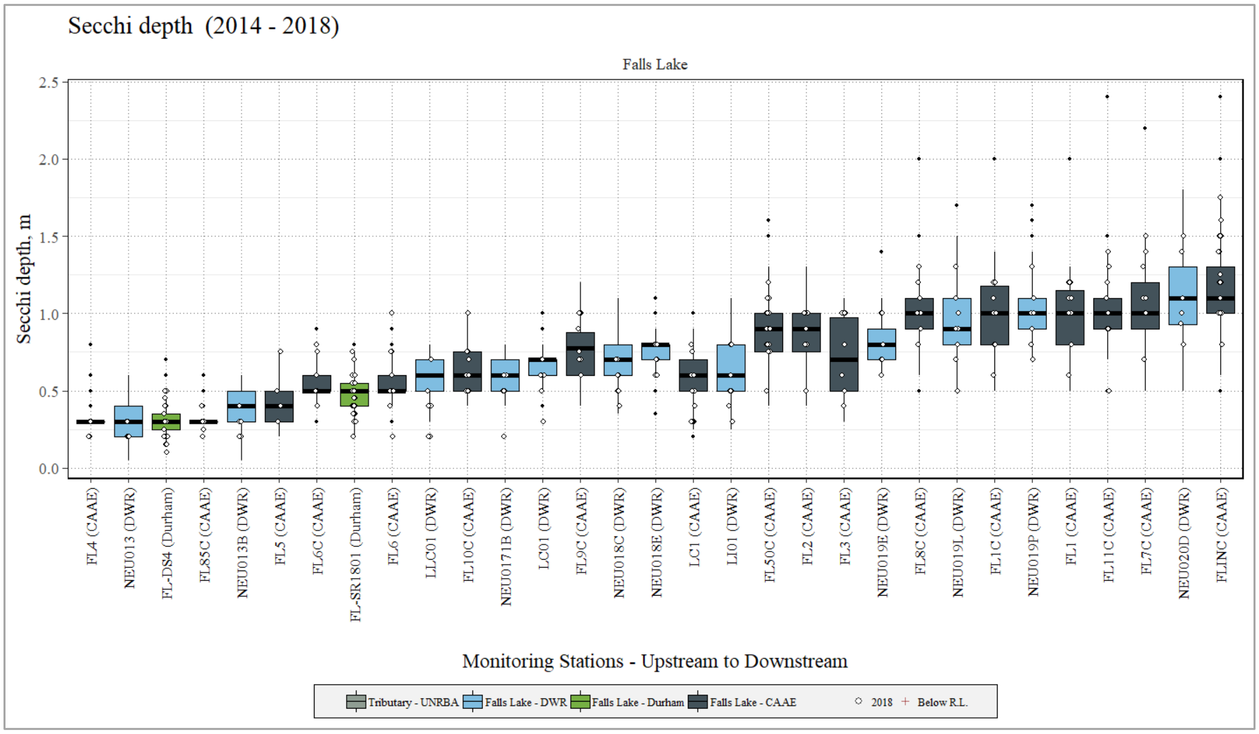


Figure D-5. Distribution of Secchi Depth Measurements in Falls Lake (2014 to 2018)

Based on NC DEQ's algal composition data (collected monthly at three stations in Falls Lake), Prymnesiophytes and euglenoids frequently dominate the algae biovolume composition. Prymnesiophytes and some euglenoid algae are flagellates that are vertically mobile. The "third-party reviewers" suggested a comparison of chlorophyll-a concentrations to Secchi depth (a measure of water clarity where a higher Secchi depth indicates more clarity) to determine if algal organisms were concentrating near the lake surface, reducing the Secchi depth, and resulting in higher chlorophyll-a concentrations when these algae dominate. These comparisons are provided at 11 DWR lake modeling stations for the UNRBA study period (Section 3.2) and at 3 DWR stations for the extended record (Section 3.3) to correspond to the comparisons provided in Section 2:.

3.1 Model Layering Approach

The layer-averaging approach for comparing EFDC model results to photic zone composite samples collected in Falls Lake is based on water level. The EFDC model grid was developed with 10 Sigma-Zed vertical layers. This gridding approach allows for the number of layers to vary over the model domain. Each grid cell can use a different number of layers, though the number of layers for each cell is constant in time (i.e., shallower areas can have fewer layers). The thickness of each layer varies in time to accommodate the varying water levels. When the lake water level is below normal pool, the layers are approximately 0.75 meters thick. When the water level is above normal pool, the layers are approximately 1.25 meters thick. Table D-1 summarizes the layering approach used for EFDC model calibration which was approved by the UNRBA Path Forward Committee and Modeling and Regulatory Support Workgroup (MRSW) at their November 2021 and January 2022 meetings, respectively.

Table D-1. EFDC Layers to Average for Water Quality Calibration and Comparison to Photic Zone Composites

DWR Monitoring Stations	When water level is below normal pool	When water level is above normal pool
NEU013,13B	Top layer	Top layer
LLC01; LC01; LI01; NEU017B,18C,18E,19E,19L,19P	Top 2 layers	Top layer
NEU020D	Top 3 layers	Top 2 layers

For the WARMF Model, each lake segment (

Figure D-6) includes up to 40 model layers, and each layer is approximately 0.75 meters thick. Table D-2 summarizes the layering approach for the WARMF model which was approved by the UNRBA MRSW at their October 2021 meeting.

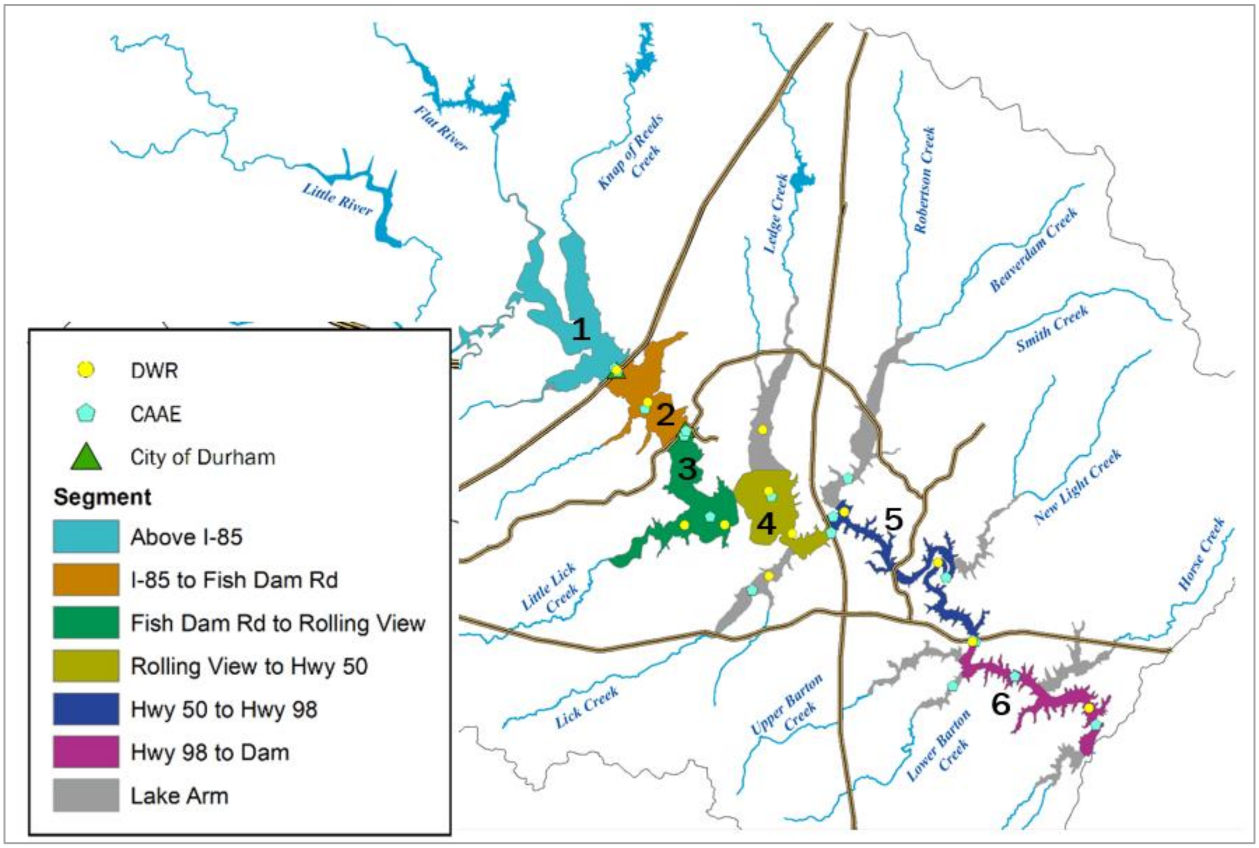


Figure D-6. WARMF Lake Segmentation

Table D-2. WARMF Layers for Water Quality Calibration and Comparison to Photic Zone Composite Data			
WARMF Lake Segment	Typical Secchi Depth (m)	Typical Photic Zone (m)	Top Layers to Average
1	0.4	0.8	1
2	0.6	1.2	1, 2
3	0.75	1.5	1, 2
4	1	2	1, 2, 3
5	1.1	2.2	1, 2, 3
6	1.25	2.5	1, 2, 3

3.2 EFDC Calibration Stations

As described in the UNRBA Modeling QAPP, the EFDC Falls Lake model is being calibrated at the DWR lake water monitoring stations. Comparisons of Secchi depth and chlorophyll-a concentrations are provided for three lake arm stations (Figure D-7 through Figure D-9) and eight main lake stations (Figure D-10 through Figure D-17). DWR does not currently monitor chlorophyll-a at station NEU013.

Sometimes when chlorophyll-a is high, Secchi depth is low (as expected because more algae reduces light penetration), but this is not always the case. Secchi depth is affected by turbidity and background color, and there is little correlation with chlorophyll-a concentrations during the UNRBA study period particularly upstream of Highway 50.

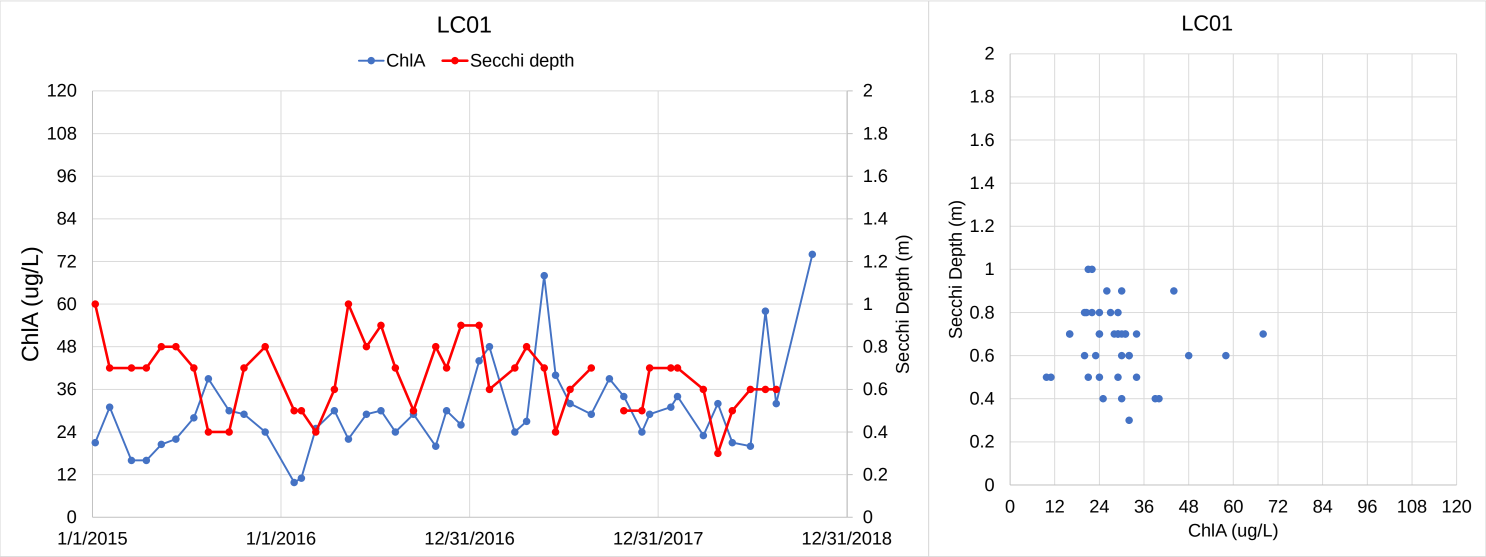


Figure D-7. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station LC01 as Time Series (left) and Scatter Plot (right)

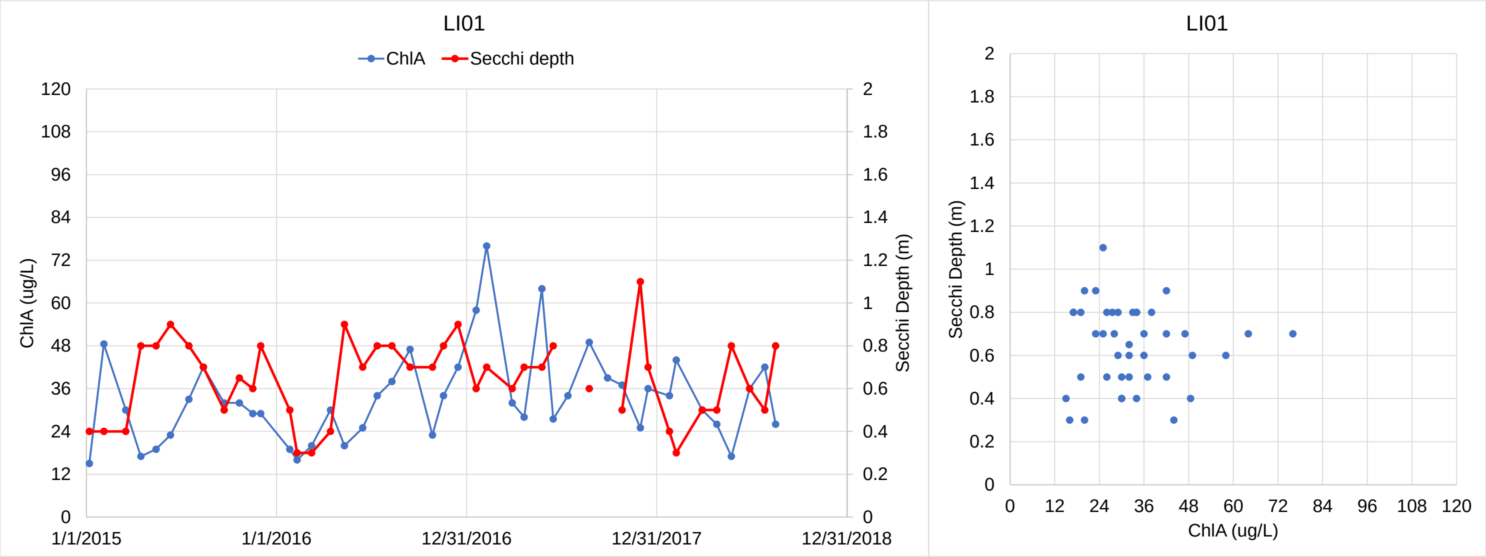


Figure D-8. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station LI01 as Time Series (left) and Scatter Plot (right)

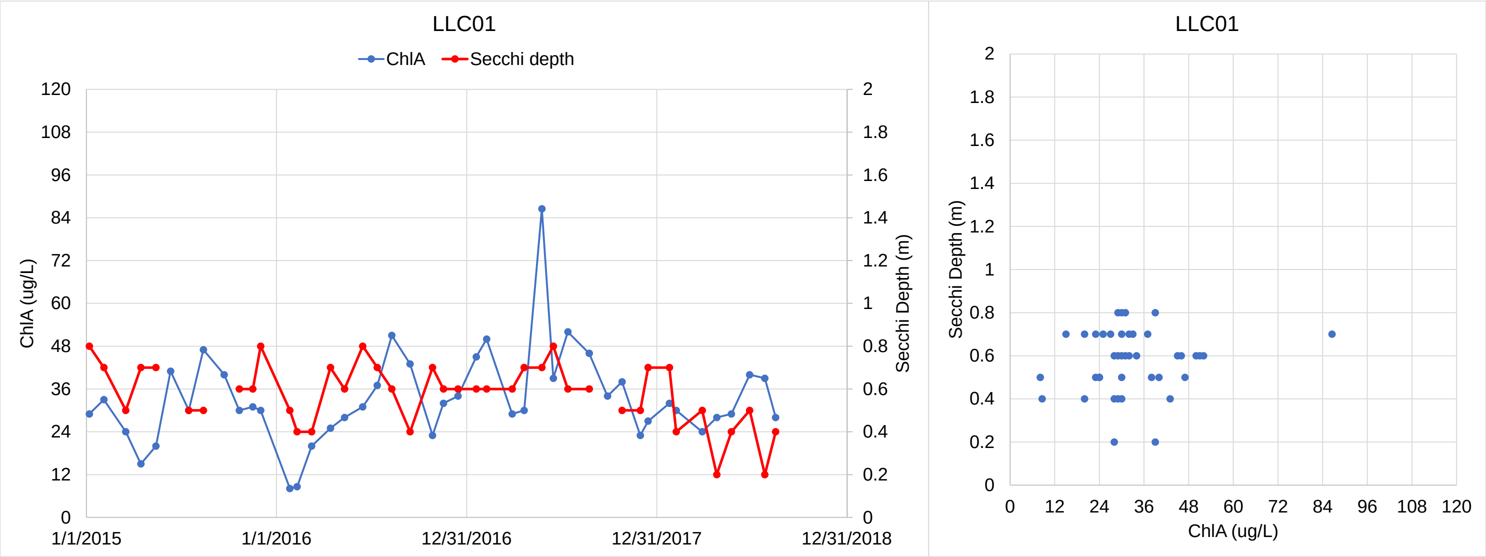


Figure D-9. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station LLC01 as Time Series (left) and Scatter Plot (right)

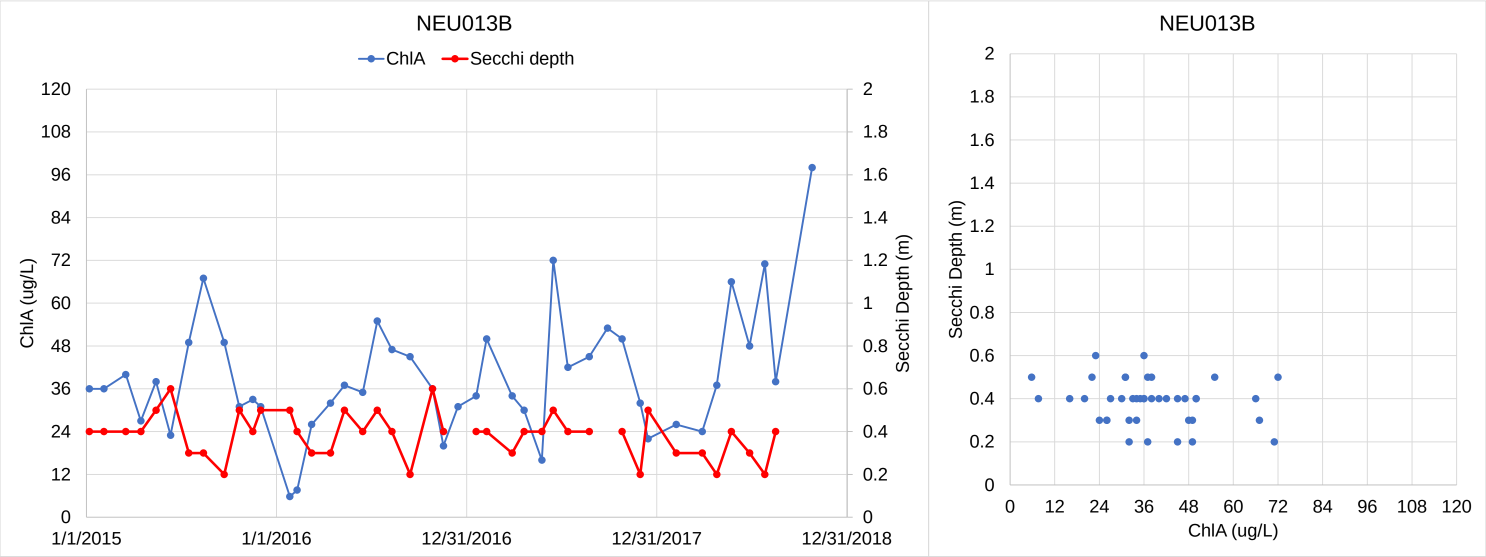


Figure D-10. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU013B as Time Series (left) and Scatter Plot (right)

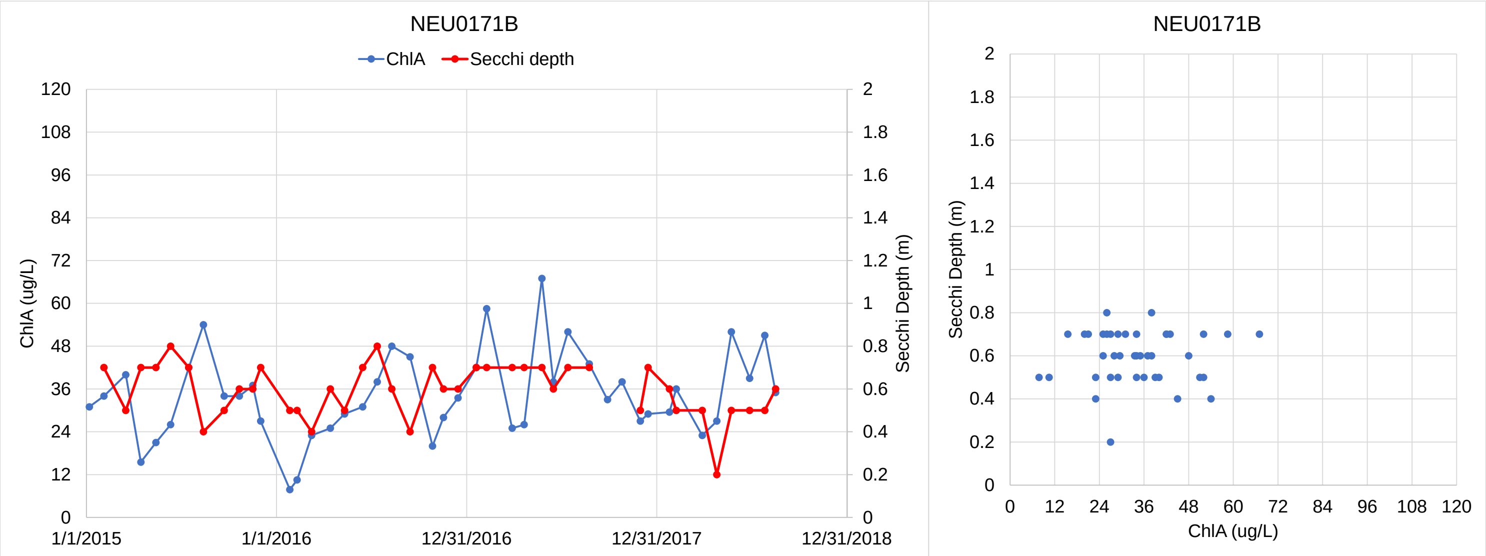


Figure D-11. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU017B as Time Series (left) and Scatter Plot (right)

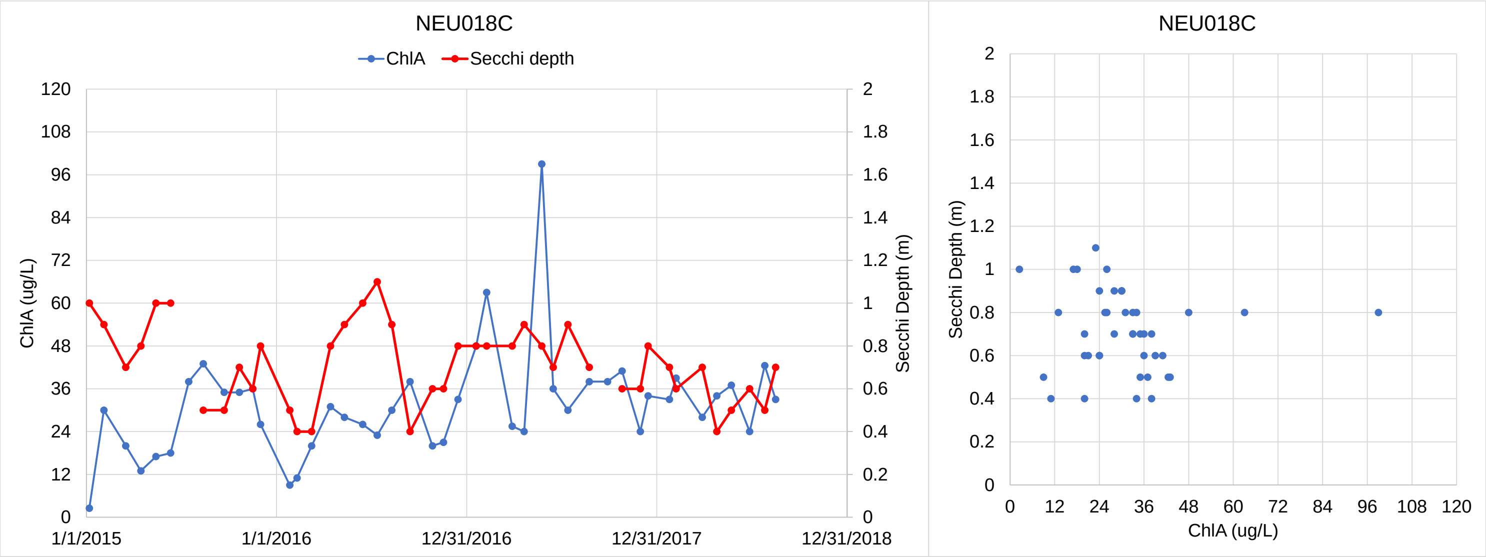


Figure D-12. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU018C as Time Series (left) and Scatter Plot (right)

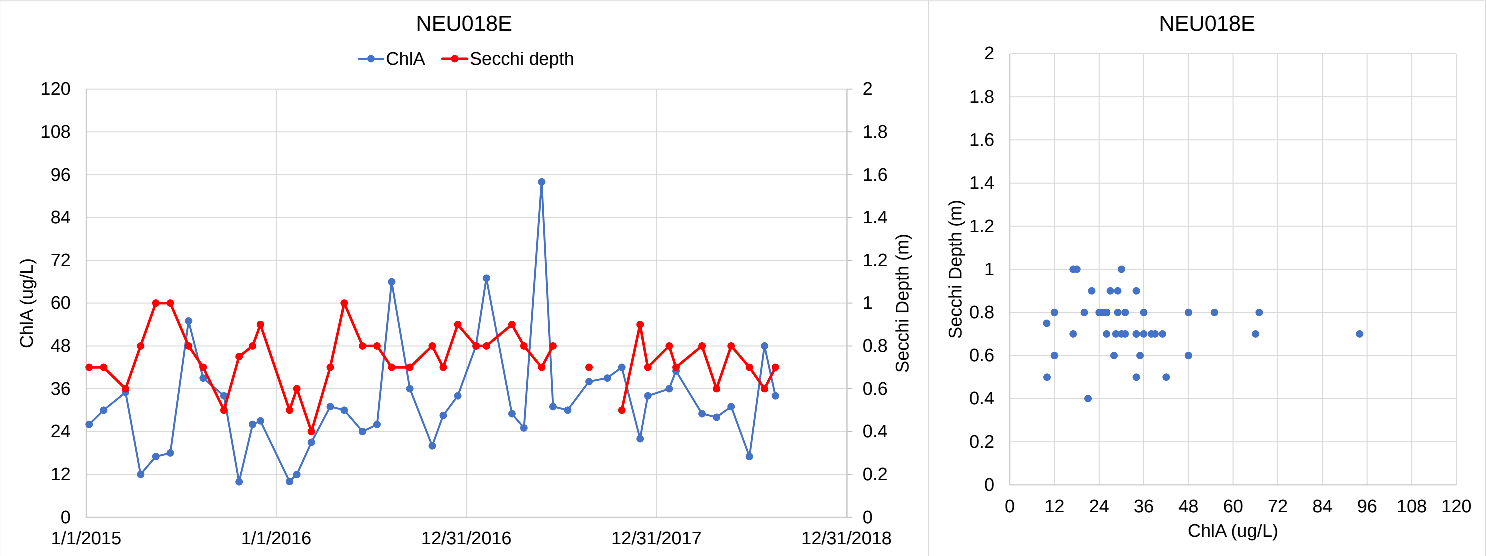


Figure D-13. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU018E as Time Series (left) and Scatter Plot (right)

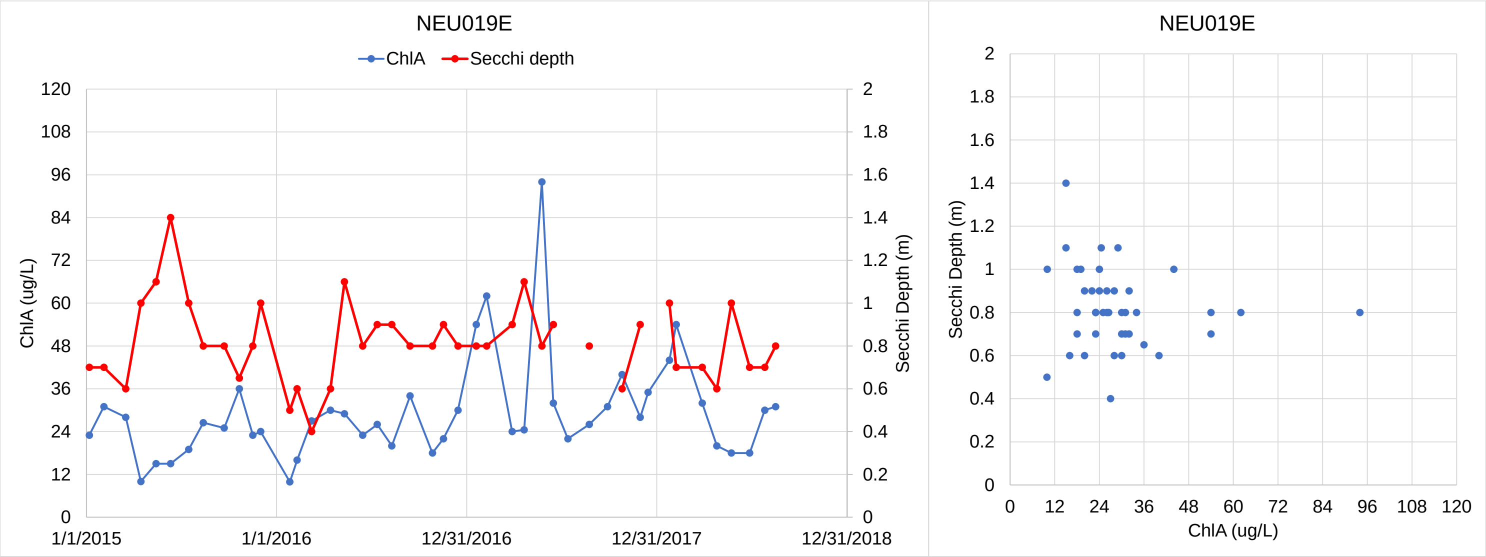


Figure D-14. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU019E as Time Series (left) and Scatter Plot (right)

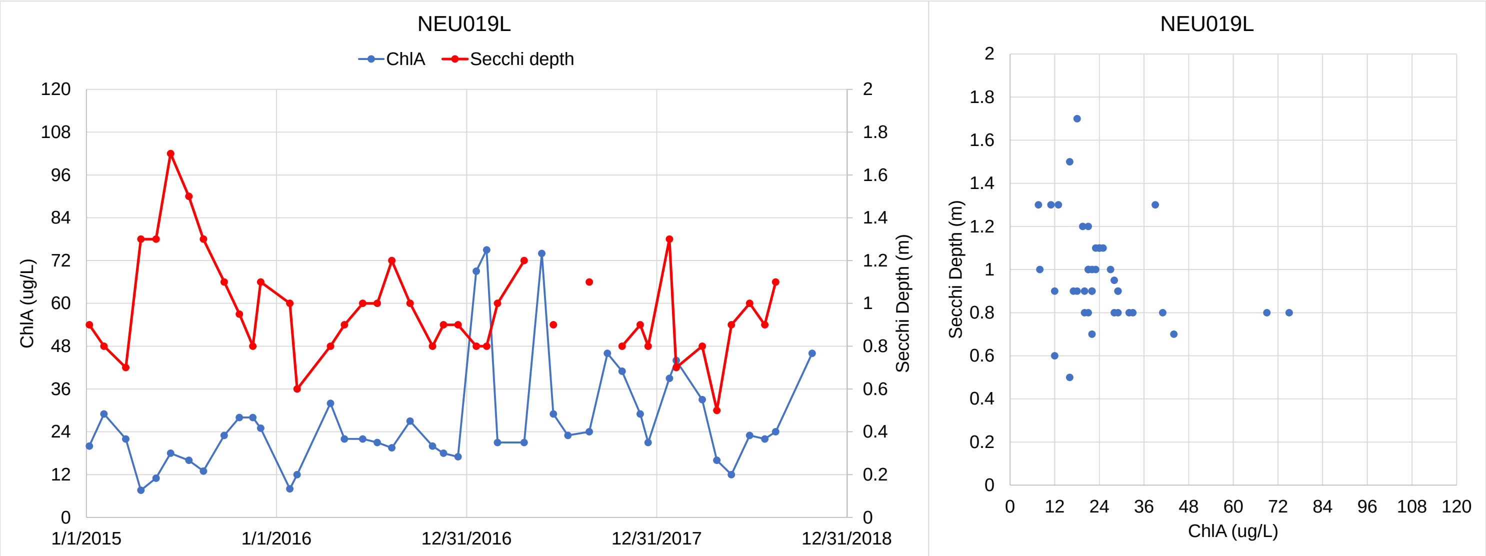


Figure D-15. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU019L as Time Series (left) and Scatter Plot (right)

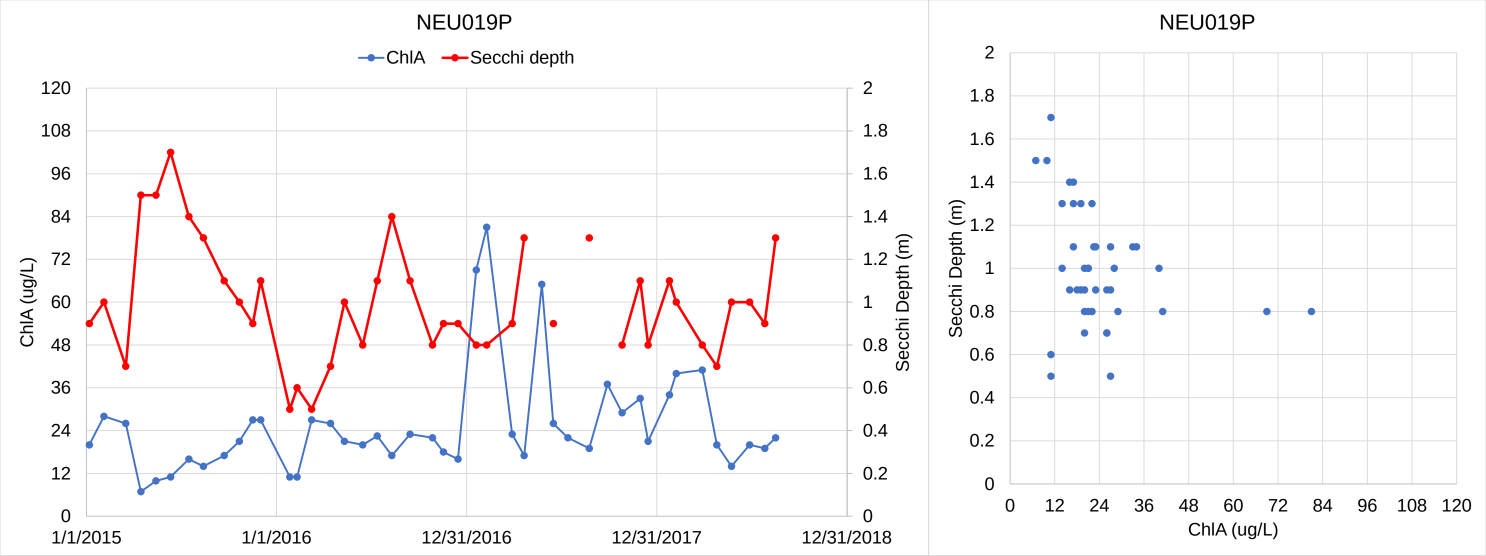


Figure D-16. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU019P as Time Series (left) and Scatter Plot (right)

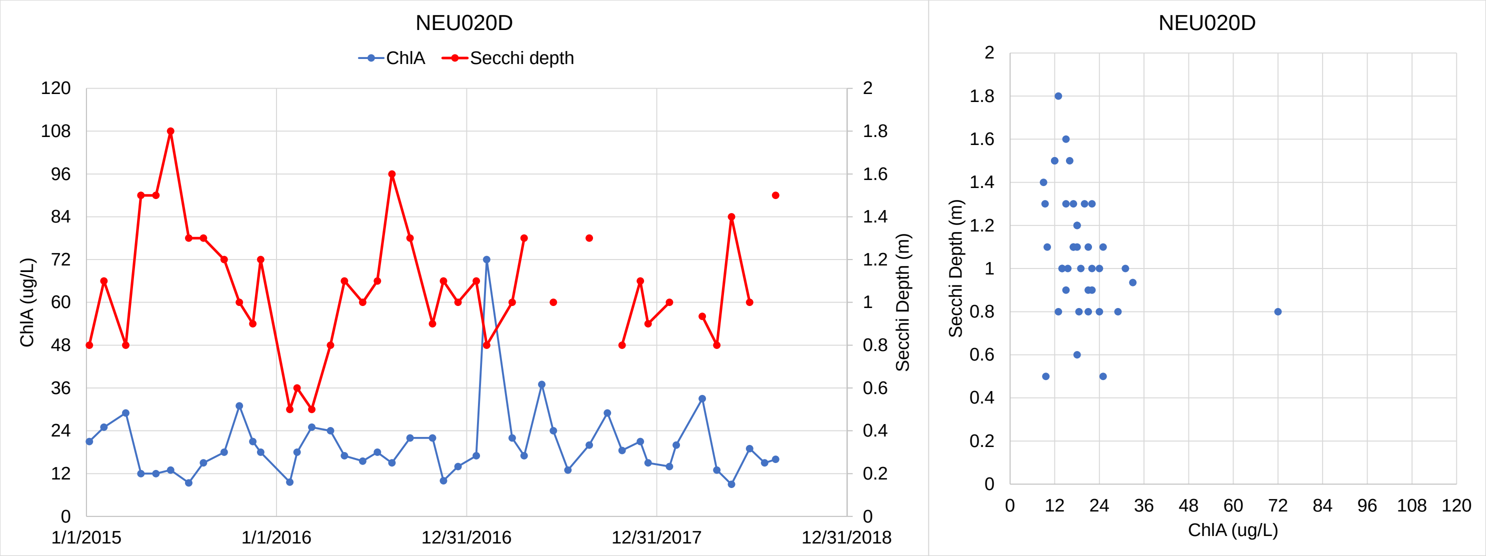


Figure D-17. Comparison of Monthly Chlorophyll-a Concentrations and Secchi Depths at Station NEU020D as Time Series (left) and Scatter Plot (right)

3.3 Extended Record for Three Stations

To correspond with the data presented in Section 2:, an extended comparison of Secchi depth and chlorophyll-a was developed for stations NEU013B, NEU018E, and NEU019P. Figure D-18 shows scatter plots for these stations with consistent scales for the x and y axes.

At the upper station (NEU013B), Secchi depth is generally low with little variability compared to chlorophyll-a. This station is near the upper part of the lake where the five largest tributaries enter the system, and therefore this area recieves a lot of sediment from the watershed. Thus, the turbidity is relatively high and Secchi depth is generally low. At the station closest to the dam (NEU019P), there is generally less turbidity and Secchi depth is more variable. Here the data show a pattern where higher Secchi depth corresponds with lower chlorophyll-a concentrations. The middle station (NEU018E) has a pattern that is more similar to the upper lake station, but the Secchi depth is generally one-half meter higher.

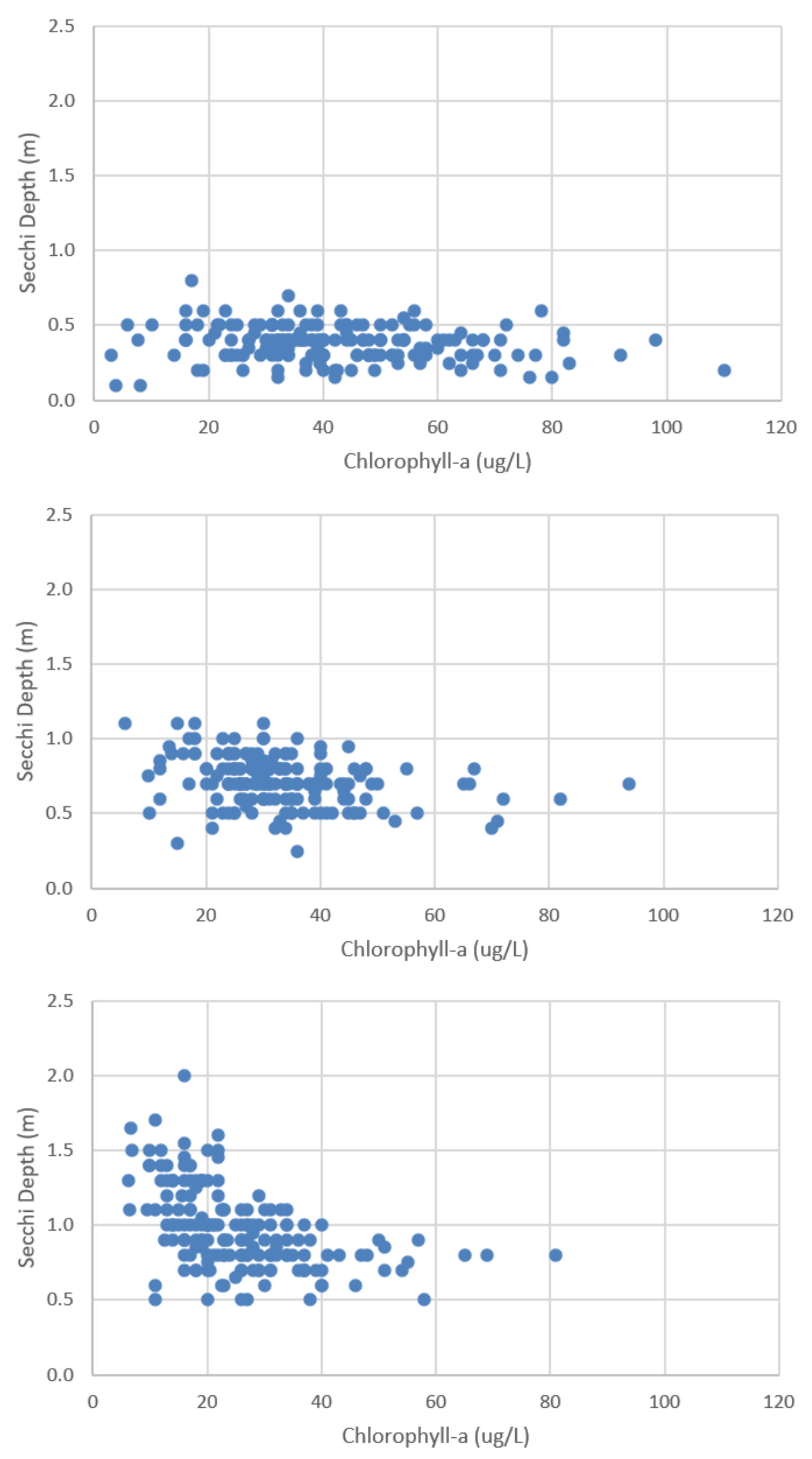


Figure D-18. Secchi Depth versus Chlorophyll-a at Stations NEU013B (top), NEU018E (middle), and NEU019P (bottom) based on DWR Falls Lake Monitoring Data (2001 to 2020)

Section 4: Jordan Lake Profile Fluorescence Data

As noted in Section 3:, the "third-party reviewers" noted that Prymnesiophytes are flagellates that are vertically mobile. To evaluate how vertical mobility may affect chlorophyll-a concentrations throughout the water column, they suggested a review of fluorescence data collected in Jordan Lake. Following review of the fluorescence figures provided by Luettich et al., (2019), the "third-party reviewers" suggested a focus on the Haw River arm of the lake during July 17 to 21, 2017 (Figure D-19). While Dr. Luettich also conducted studies on Falls Lake, the profiler fluorescence measurements were not part of that study.

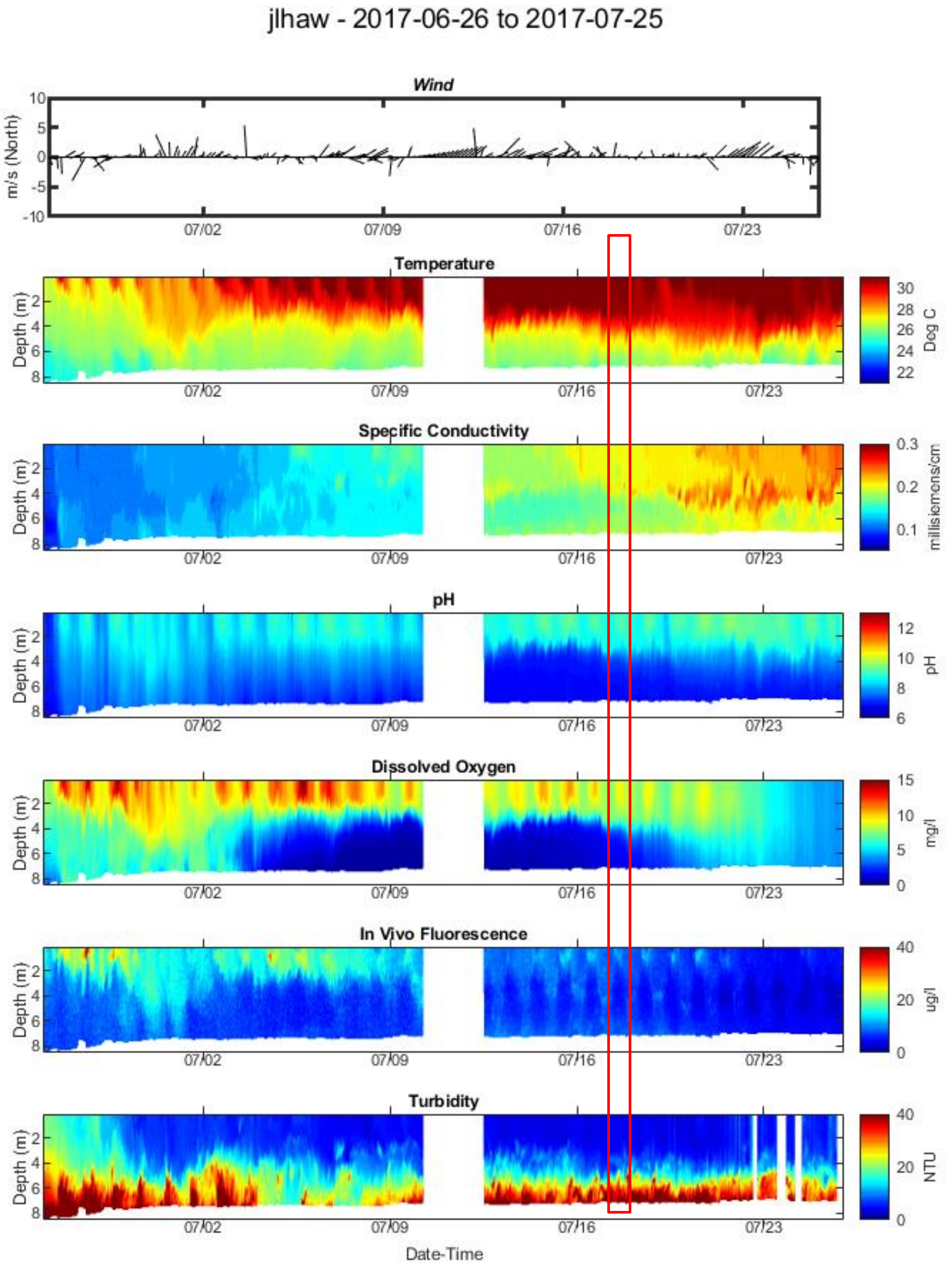
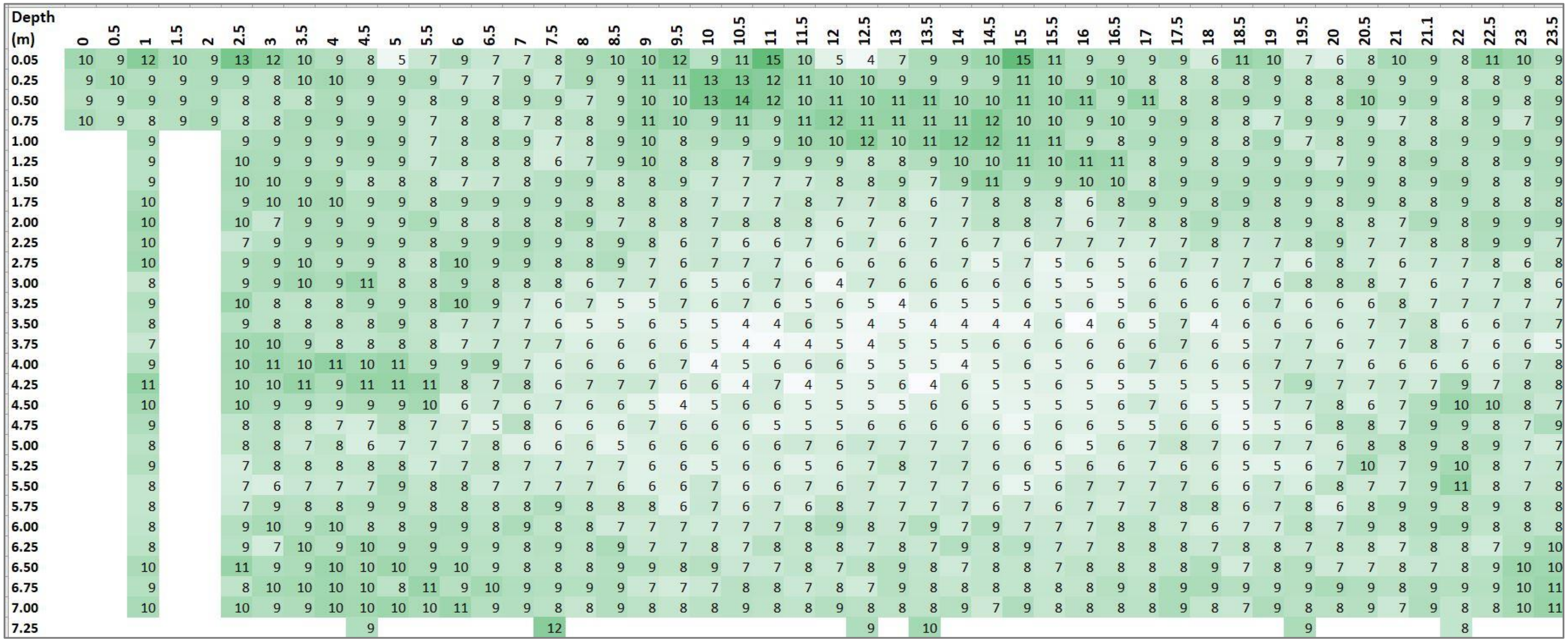


Figure D-19. Wind velocity, temperature, specific conductivity, pH, in vivo fluorescence, and turbidity at the Haw River Arm in Jordan Lake for July 2017 (from Luettich et al., 2019) (red box indicates July 17th)

Jordan Lake Haw River arm Sampling Location (Luettich et al., 2019

In vivo fluorescence is an efficient method of estimating algal biomass. It is less accurate than laboratory analyses and not used for regulatory purposes. Because it can be incorporated into a field-deployed meter, much more frequent recordings are possible with this method. Dr. Luettich's final report (Luettich et al., 2019) described the Jordan Lake data collection method as follows: "Water quality and meteorological data were also measured in a semi-continuous manner using two Autonomous Vertical Profilers (AVP), Figure 6. This floating platform has a computer-controlled winch system that allows it to remotely raise and lower a multi-parameter probe and collect vertical profiles of key water quality properties including water temperature, conductivity, in vivo fluorescence, dissolved oxygen concentration, turbidity, and pH. The AVPs were programmed to perform profiles every 30 minutes and data were collected with a vertical resolution of approximately 4 cm." Each day of monitoring yields over 17,000 measurements.

To provide a visualization of the vertical changes in fluorescence observed over the course of a day, data from July 17th were extracted from the data set. The profiler moves from the surface (0.05 meters) toward the bottom of the lake (up to 7.25 meters) at the beginning of each half hour, and each half-hour interval records up to 405 measurements. To provide a visual summary of the July 17th data (Figure D-20), data are displayed for each 0.25-meter increment (down the rows) and at each half hour (across the column). Higher fluorescence measurements are indicated by increased levels of green shading. During nighttime on July 17th (0 to 7 and 19 to 23.5), the relative fluorescence is evenly distributed throughout the water column. However, there was a noticeable peak in fluorescence that occurred at the top of the thermocline (Figure D-20). In Figure D-19, similar nighttime peaks along the top of the thermocline are apparent throughout the period July 15 to July 20. During the daylight hours of July 17th (7.5 to 18.5), the upper 1.5 meters of the water column have higher fluorescence readings compared to the deeper waters (Figure D-20). This pattern of higher near-surface fluorescence in daytime is observed throughout this period of July (Figure D-19). Daytime fluorescence maxima near the surface followed by either vertically homogenous or deep-water maxima at night are depth-distribution patterns that are consistent with the diel vertical migration behaviors of flagellated phytoplankton (Hall et al. 2015; Hall and Paerl 2009). This pattern indicates a higher concentration of vertically mobile algal organisms near the surface and indicates that flagellates contributed a substantial fraction of total phytoplankton biomass during July 2017 at this Jordan Lake location.



Depth (m)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.1	22	22.5	23	23.5
0.05	10	9	12	10	9	13	12	10	9	8	5	7	9	7	7	8	9	10	10	12	9	11	15	10	5	4	7	9	9	10	15	11	9	9	9	9	6	11	10	7	6	8	10	9	8	11	10	9
0.25	9	10	9	9	9	9	8	10	10	9	9	9	7	7	9	7	9	9	11	11	13	13	12	11	10	10	9	9	9	9	11	10	9	10	8	8	8	8	9	8	8	9	9	9	8	8	9	8
0.50	9	9	9	9	9	8	8	8	9	9	9	8	9	8	9	9	7	9	10	10	13	14	12	10	11	10	11	11	10	10	11	10	11	9	11	8	8	9	9	8	8	10	9	9	8	9	8	9
0.75	10	9	8	9	9	8	8	9	9	9	9	7	8	8	7	8	8	9	11	10	9	11	9	11	12	11	11	11	11	12	10	10	9	10	9	9	8	8	7	9	9	9	7	8	8	9	7	9
1.00			9			9	9	9	9	9	9	7	8	8	9	7	8	9	10	8	9	9	9	10	10	12	10	11	12	12	11	11	9	8	9	9	8	8	9	7	8	9	8	8	9	9	9	9
1.25			9			10	9	9	9	9	9	7	8	8	8	6	7	9	10	8	8	7	9	9	9	8	8	9	10	10	11	10	11	11	8	9	8	9	9	9	7	9	8	9	8	8	9	9
1.50			9			10	10	9	9	8	8	8	7	7	8	9	9	8	8	9	7	7	7	7	8	8	9	7	9	11	9	9	10	10	8	9	9	9	9	9	9	9	8	9	9	8	8	9
1.75			10			9	10	10	10	9	9	8	9	9	9	9	8	8	8	8	7	7	7	8	7	7	8	6	7	8	8	8	6	8	9	9	8	9	8	9	8	9	8	8	9	8	8	8
2.00			10			10	7	9	9	9	9	9	8	8	8	8	9	7	8	8	7	8	8	8	6	7	6	7	7	8	8	7	6	7	8	8	9	8	8	9	8	8	7	9	8	9	9	9
2.25			10			7	9	9	9	9	9	8	9	9	9	9	8	9	8	6	7	6	6	7	6	7	6	7	6	7	6	7	7	7	7	7	8	7	7	8	9	7	7	8	8	9	9	7
2.75			10			9	9	10	9	9	8	8	10	9	9	8	8	9	7	6	7	7	7	6	6	6	6	6	7	5	7	5	6	5	6	7	7	7	7	6	8	7	6	7	7	8	6	8
3.00			8			9	9	10	9	11	8	8	9	8	8	8	6	7	7	6	5	6	7	6	4	7	6	6	6	6	6	5	5	5	6	6	6	7	6	8	8	8	7	6	7	7	8	6
3.25			9			10	8	8	8	9	9	8	10	9	7	6	7	5	5	7	6	7	6	5	6	5	4	6	5	5	6	5	6	5	6	6	6	6	7	6	6	6	8	7	7	7	7	7
3.50			8			9	8	8	8	8	9	8	7	7	7	6	5	5	6	5	5	4	4	6	5	4	5	4	4	4	4	6	4	6	5	7	4	6	6	6	6	7	7	8	6	6	7	7
3.75			7			10	10	9	8	8	8	8	7	7	7	7	6	6	6	6	5	4	4	4	5	4	5	5	5	6	6	6	6	6	6	7	6	5	7	7	6	7	7	8	7	6	6	5
4.00			9			10	11	10	11	10	11	9	9	9	7	6	6	6	6	7	4	5	6	6	6	5	5	5	4	5	6	5	6	6	7	6	6	6	7	7	7	6	6	6	6	6	7	8
4.25			11			10	10	11	9	11	11	11	8	7	8	6	7	7	7	6	6	4	7	4	5	5	6	4	6	5	5	6	5	5	5	5	5	5	7	9	7	7	7	7	9	7	8	8
4.50			10			10	9	9	9	9	9	10	6	7	6	7	6	6	5	4	5	6	6	5	5	5	5	6	6	5	5	5	5	6	7	6	5	5	7	7	8	6	7	9	10	10	8	7
4.75			9			8	8	8	7	7	8	7	7	5	8	6	6	6	7	6	6	6	5	5	5	6	6	6	6	6	5	6	6	5	5	6	6	5	5	6	8	8	7	9	9	8	7	9
5.00			8			8	8	7	8	6	7	7	7	8	6	6	6	5	6	6	6	6	6	7	6	7	7	7	7	6	6	6	5	6	7	8	7	6	7	7	6	8	8	9	8	9	7	7
5.25			9			7	8	8	8	8	8	7	7	8	7	7	7	7	6	6	5	6	6	5	6	7	8	7	7	6	6	5	6	6	7	6	6	5	5	6	7	10	7	9	10	8	7	7
5.50			8			7	6	7	7	7	9	8	8	7	7	7	7	6	6	6	7	6	6	7	6	7	7	7	7	6	5	6	7	7	7	7	6	6	7	6	8	7	7	9	11	8	7	8
5.75			8			7	9	8	8	9	9	8	8	8	8	9	8	8	8	6	7	6	7	6	8	7	7	7	7	6	7	6	7	7	7	8	8	6	7	8	6	8	9	9	8	9	8	8
6.00			8			9	10	9	10	8	8	9	9	8	9	8	8	7	7	7	7	7	7	8	9	8	7	9	7	9	7	7	7	8	8	7	6	7	7	8	7	9	8	9	9	8	8	8
6.25			8			9	7	10	9	10	9	9	9	9	8	9	8	9	7	7	8	7	8	8	8	7	8	7	9	8	9	7	7	8	8	8	7	8	8	7	8	8	7	8	8	7	9	10
6.50			10			11	9	9	10	10	10	9	10	9	8	8	8	9	9	8	9	7	7	8	7	8	9	8	7	8	8	7	8	8	8	8	9	7	8	9	7	7	8	7	8	9	10	10
6.75			9			8	10	10	10	10	8	11	9	10	9	9	9	9	7	7	7	8	8	7	8	7	9	8	8	8	8	8	8	9	8	9	9	9	9	9	9	9	8	9	9	9	10	11
7.00			10			10	9	9	10	10	10	10	11	9	9	8	8	9	8	8	8	9	8	8	9	8	8	8	9	7	9	8	8	8	8	9	8	7	9	8	8	9	7	9	8	8	10	11
7.25										9						12										9		10												9					8			

Figure D-20. Fluorescence Data (Luettich et al., 2019) collected at 0.25-meter Depth Increments (rows) at Each Half Hour (columns) in the Haw River Arm of Jordan Lake on July 17th

Section 5: Conclusions

Mechanistic models are typically capable of simulating repeatable, predictable patterns (e.g., increased nutrients leading to increased algal biomass and therefore increased chlorophyll-a concentrations). These models use the simulation of algal groups and their assumed chlorophyll-a content (chlorophyll-a to carbon ratio) to simulate chlorophyll-a concentrations.

The comparisons of algal biovolume, chlorophyll-a, and Secchi depth along with evaluation of the fluorescence data collected in the Haw River arm of Jordan Lake illustrate the challenges of calibrating the mechanistic models for Falls Lake when consistent/predictable patterns in the data are not being observed or the processes are not addressed within the functionality of the models:

- Elevated chlorophyll-a concentrations (even over 70 µg/L) do not always correspond to blooms of algae (as determined by biovolume)
- Chlorophyll-a spikes are often due to the presence of “other” algal groups such as Prymnesiophytes and Euglenoids, but the magnitude of observed chlorophyll-a does not always correlate to the observed biovolume; i.e., sometimes blooms of Prymnesiophytes correspond to elevated chlorophyll-a, and sometimes they do not
- Prymnesiophytes are vertically mobile and when dominant, may concentrate chlorophyll-a at the surface of the lake. With their current programming, neither WARMF Lake nor EFDC are able to simulate the vertical mobility of algal groups.
- Model parameters to accurately simulate algal growth are not available for some of the “other” groups of algae that are abundant in Falls Lake
- Water clarity appears strongly affected in the upper lake by sediments with more correlation to chlorophyll-a concentration in the lower lake. The photic zone composite samples are twice the Secchi depth, and this relationship has been confirmed for Falls Lake. Output from each model layer that is typically within the photic zone is compared to observed data. When blooms of vertically mobile algae occur, the chlorophyll-a concentration may be concentrated near the surface and not equally distributed over the photic depth or the representative model layers.

While there are limitations with the simulation of chlorophyll-a using mechanistic models (chlorophyll-a is a measure of the green pigment and is only an indicator of algal growth, laboratory measurements are not exact, and the chlorophyll-a to carbon ratio likely varies in the natural environment), these models are the best scientific tools available in terms of predicting algal response to nutrient inputs.

During discussions with the UNRBA modeling team, the “third-party reviewers” and DWR modelers expressed that they do not expect that the mechanistic models of Falls Lake would simulate isolated peaks in chlorophyll-a concentrations, especially when such peaks do not correspond to clear physical drivers. They noted that mechanistic models are not capable of simulating all peaks because of their limitations in accounting for the physical, chemical, and biological processes and their inability to simulate anomalous events. The reviewers indicated that they expect the models to predict the general trends in nutrient and chlorophyll-a concentrations (e.g., trends associated with seasonality and varying hydrologic inputs) and that the performance results should be evaluated in the context of the model limitations.

Section 6: References

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