UNC Nutrient Management Study - In Situ Observational Study of Falls Lake Year 1 Report

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1. Background and Objectives

Falls Lake is a man-made reservoir, constructed by the US Army Corps of Engineers (USACE) in the late 1970s. The lake is 28 miles long from the confluence of the Eno, Little and Flat Rivers to the dam. Highway 50 divides the lake's volume approximately in half; the upper section is shallower and wider in comparison to the deeper, narrower lower section that follows the historical river channel (**FIGURE 1**). The main stem of the lake is segmented by six bridge causeways: railroad, I85, Fish Dam Rd, Hwy 50, New Light Rd, and Hwy 98 from upstream to downstream. Net flow through the lake is principally determined by watershed inputs and the outflow over the dam. The lake has at least 18 tributaries, of which five, the Flat River, Eno River, Little River, Knap of Reeds Creek, and Ellerbe Creek, contribute an average of 78 percent of the annual inflow. No other tributary delivers more than 3 percent of the annual inflow (Final UNRBA Monitoring Report for Supporting the Re-Examination of the Falls Lake Nutrient Management Strategy, June 2019). All five of the major tributaries enter the lake upstream of the Interstate 85 crossing. Outflow from the lake is controlled by the USACE to achieve downstream flood control and to maintain a reasonably stable lake level and adequate drinking water supply for surrounding communities.

The NC Division of Water Quality (DWQ) has collected water quality data in the lake since its opening. Chlorophyll-a concentrations in excess of 40 micrograms per liter in portions of the lake prompted a modeling study in the 2000s to help identify nutrient reduction targets and the establishment of strategies in 2010 to reduce nutrient input to the lake. To supplement DWQ efforts, in 2014 the Upper Neuse River Basin Association (UNRBA) initiated an extensive data collection and analysis program in the lake and its tributaries (UNRBA 2019) and a re-modeling of the lake (Basic Evaluation of Model Performance Special Study SS.LR.8, August 2016). Water quality data has also been collected in the lake by the City of Durham and by the NC State University Center for Applied Aquatic Ecology (CAAE).

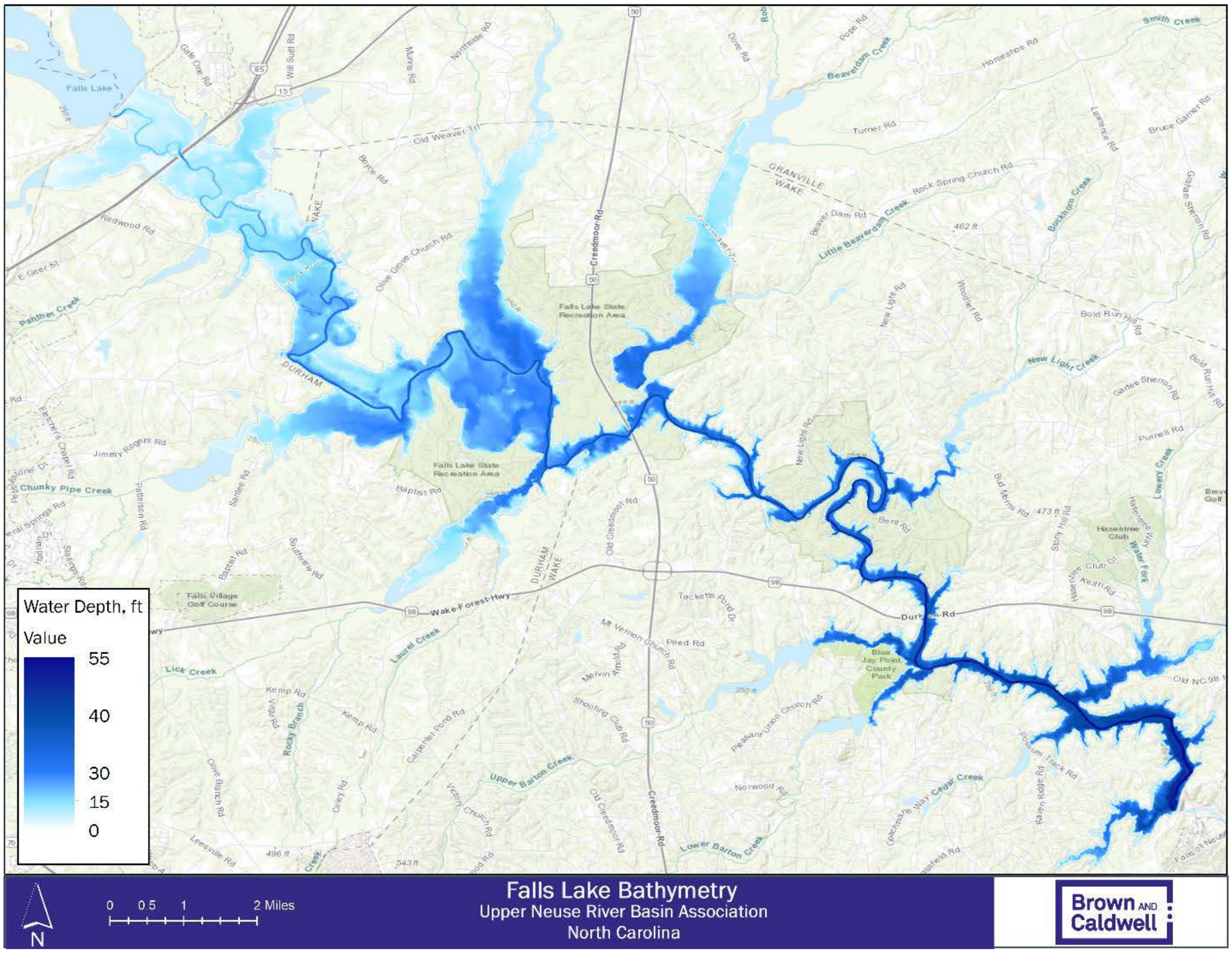

Figure 1. Falls Lake Bathymetry, data collected 2017, (UNRBA 2019)

Lake water quality is determined by multiple factors, including the movement of water and associated constituents (nutrients, sediments, algae, etc.) through the system. Residence time provides a lake-wide average assessment of water movement. From August 2014 – November 2018, the UNRBA found residence times (computed as 15-day average lake volume divided by the 15-day average outflow over the dam) varied from as little as 20 days to nearly 2.5 years, with long residence times occurring when the USACE reduced outflow for downstream flood control (UNRBA 2019). To better document the lake's response to high-flow conditions (which are infrequent but account for a significant portion of the volume inflow to the lake), the UNRBA also sponsored one hour long flow measurements at the I85 and Hwy 50 causeways, on four days in January and October 2016. Results were converted to daily average discharge and appeared to track predictions based on a mass balance that included changes in lake surface elevation, rainfall, tributary inflows, and evaporation estimates (UNRBA Monitoring Program Annual Report May 2016; UNRBA Monitoring Program Annual Report May 2017). While water quality is strongly dependent on the inflows to and outflow from the lake and the associated average transport through the lake, the timescales of nutrient uptake, primary productivity and algal growth are fast compared to average transport timescales, even through sub-segments of the lake. Indeed, the relationship between short-term hydrodynamics and productivity processes have been identified as having important implications for the lake's water quality model (UNRBA Special Study Plan, November 2015).

This study is designed to address the important gap in present knowledge of water movement and exchange in the lake over the range of timescales from hourly to seasonal. While at long time scales (e.g., monthly to seasonal) established residence time and long term average calculations may adequately capture lake-wide conditions, minimal information exists on flow variability in the lake compared to these lake-wide averages and on the role played by physical flow drivers other than tributary inflows and outflow at the dam in effecting flow characteristics. Thus we have been conducting data collection to identify movement and exchange over a broad range of time scales at several key locations in the lake to help quantify processes that may be important for affecting water quality in the lake.

2. Data Collection Plan and Methodology

2.1 Water Circulation and Exchange

Acoustic Doppler current profilers (ADCPs) were deployed to measure water velocities through the water column at four locations along the lake, I85 bridge, Fish Dam/Cheek Road bridge, Highway 50 Bridge and Highway 98 bridge, (red dot and circles in Figure 2). Each ADCP is mounted on a bottom stand with the instrument pointed upward (Figure 3) sampling the water column above. They were programmed to store 3-minute averaged water velocities every 10 minutes, with a vertical resolution of 0.5 m. The instruments were deployed on November 19, 2019 and recovered / redeployed in June

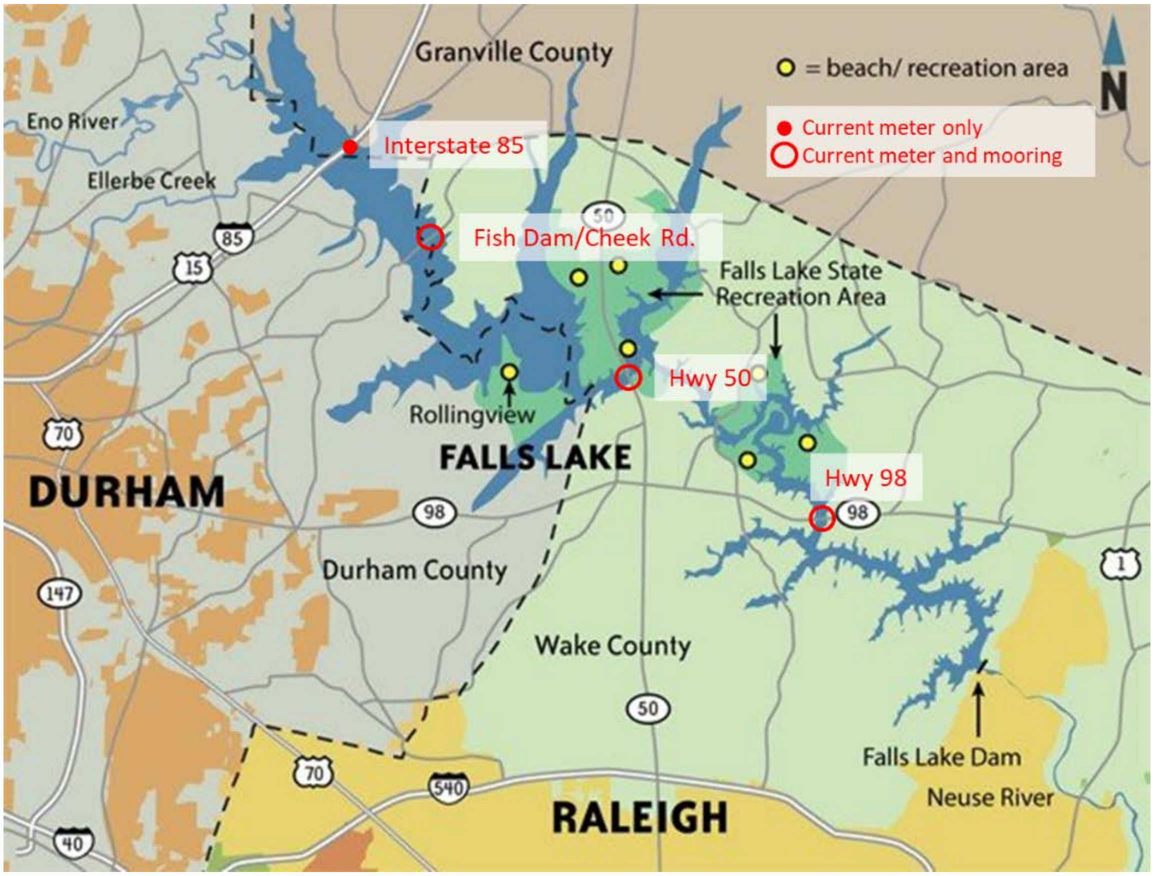

Figure 2. Locations for ADCPs and thermistor string moorings in Falls Lake

2020, see Section 3. Recovery and redeployment involves pulling up each instrument, bringing it to shore, downloading data, reprogramming, and redeploying it, typically the following day.

Figure 3. Acoustic Doppler Current Profiler (ADCP) in a typical mounting stand.

2.2 *In Situ* Water Quality Parameters

Near the three downriver ADCPs we deployed moorings to measure temperature, irradiance, conductivity and water depth to aid in understanding thermal stratification and light extinction. (The I85 site was not included due to shallow water, difficulty of access, and the co-location of a vertical profiler station operated by the NCSU CAAE.) Each mooring consists of two parts, one suspended below a surface float and the other attached to the bottom using a taught line and submerged float, (**FIGURE 4**). This arrangement allowed the full water column to be sampled while allowing for a possible change in lake level of as much as 19 ft. Each mooring contained approximately 20 HOBO temperature sensors (**FIGURE 4**) spanning the water column at 0.5 m intervals. A conductivity sensor was included at 2.2 m below the surface and the upper few HOBOs also included light sensors. Pressure sensors were included on top of the surface float (to measure atmospheric pressure) and at the top and bottom of the surface and bottom mooring components to determine total water depth and position of the sensors over depth as total water depth varied with lake level. Data were collected every 6 – 12 minutes. Due to fouling of the light and conductivity sensors, the part of the mooring attached to the surface float was intended to be recovered and cleaned monthly. At that time, vertical profiles of photosynthetically active radiation (PAR), (Li-Cor model LI-193 spherical sensor) and water quality indicators (Endeco-YSI multi-parameter probes models 6600 or EX02) were collected from the attending boat to assist with calibration of the moored sensors and further enhance the data set. Temperature data from all sensors on each mooring have been aggregated to provide information on temperature over depth and time and mapped onto a grid every 6 minutes for subsequent analysis. The pressure measurements were used to track the relative depths of the surface and bottom moorings.

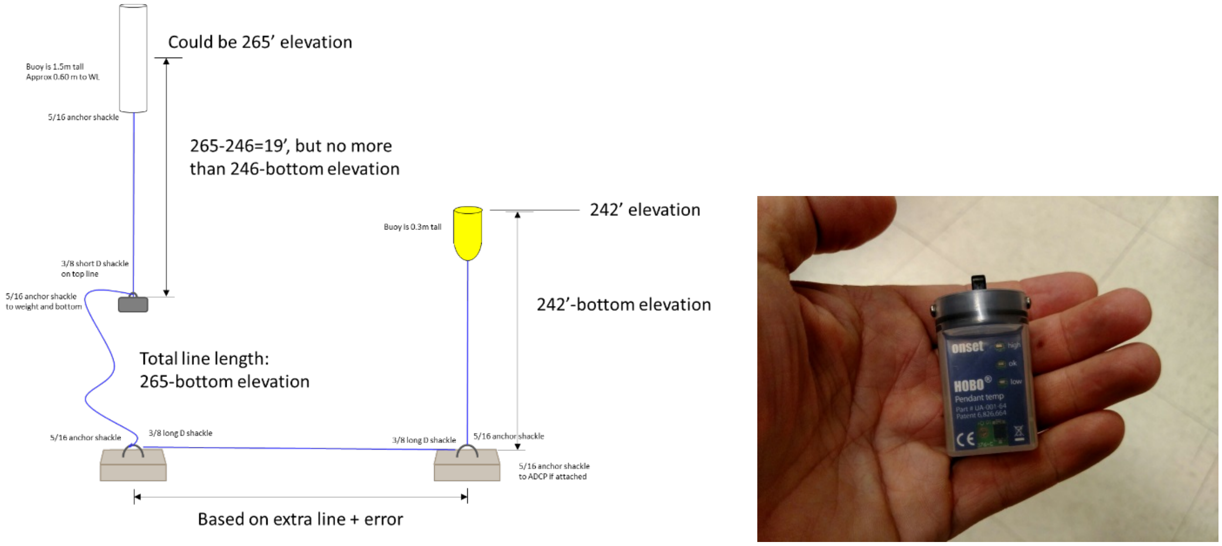

Figure 4. Moorings and typical Hobo sensor

3. Results

Data from surface section of the moorings were planned to be downloaded and the instruments cleaned on a monthly basis. To date there have been four visits: January 23, February 26, May 7, and June 22-23. March and April were missed due to travel restrictions due to the SARS-CoV-2 pandemic. No data were lost on account of the extended delay. While originally scheduled for recovery in May, due to delays associated with the pandemic, we were unable to recover / redeploy the bottom sections of the moorings and the ADCP current meters until the June visit. Pressure sensors attached to the ADCP frames and the bottom mooring sections filled their memory on May 18 leaving a data gap between that date and the June servicing. The ADCPs were programmed with expected battery depletion at approximately the same time in May, however conservative estimates of battery life allowed them to collect data through to the June recovery. Results from the surface data have been analyzed and are presented below; analyses of the data from the bottom sections of the moorings and from the current meters are still in progress.

The five most significant rivers and creeks in terms of discharge are gaged and, as mentioned earlier, contribute approximately 78% of the input. Apart from minor losses including water which is drawn for municipal uses and losses due to evaporation, the outflow from the lake goes through the dam and therefore the lake level is largely controlled by varying discharge from the dam. The target water level for the lake is 251.5 ft. (NGVD 29) above sea level. Conditions during this deployment are shown in **FIGURE 5** with plots in the top panel of the total inflow from the five gaged inputs in green and the outflow over the dam in dark gray. Inflows are episodic and correspond with local rainfall, however multiple reservoirs upstream (e.g. Lake Michie and Little River Lake which provide water for the city of Durham) mitigate the episodic flows. Lake levels (shown in the middle panel) were low from the time of deployment in November to January, which is often the case in autumn, consequently there was minimal outflow from the dam during that time. Once lake levels reached their target, as they did in January, outflow followed inflow in order to maintain the target lake level while balancing other factors such as flood control. Considerable rainfall in early February caused the lake levels to rise more than six feet above normal; release at the dam throughout the remainder of February brought the lake back to normal levels in March.

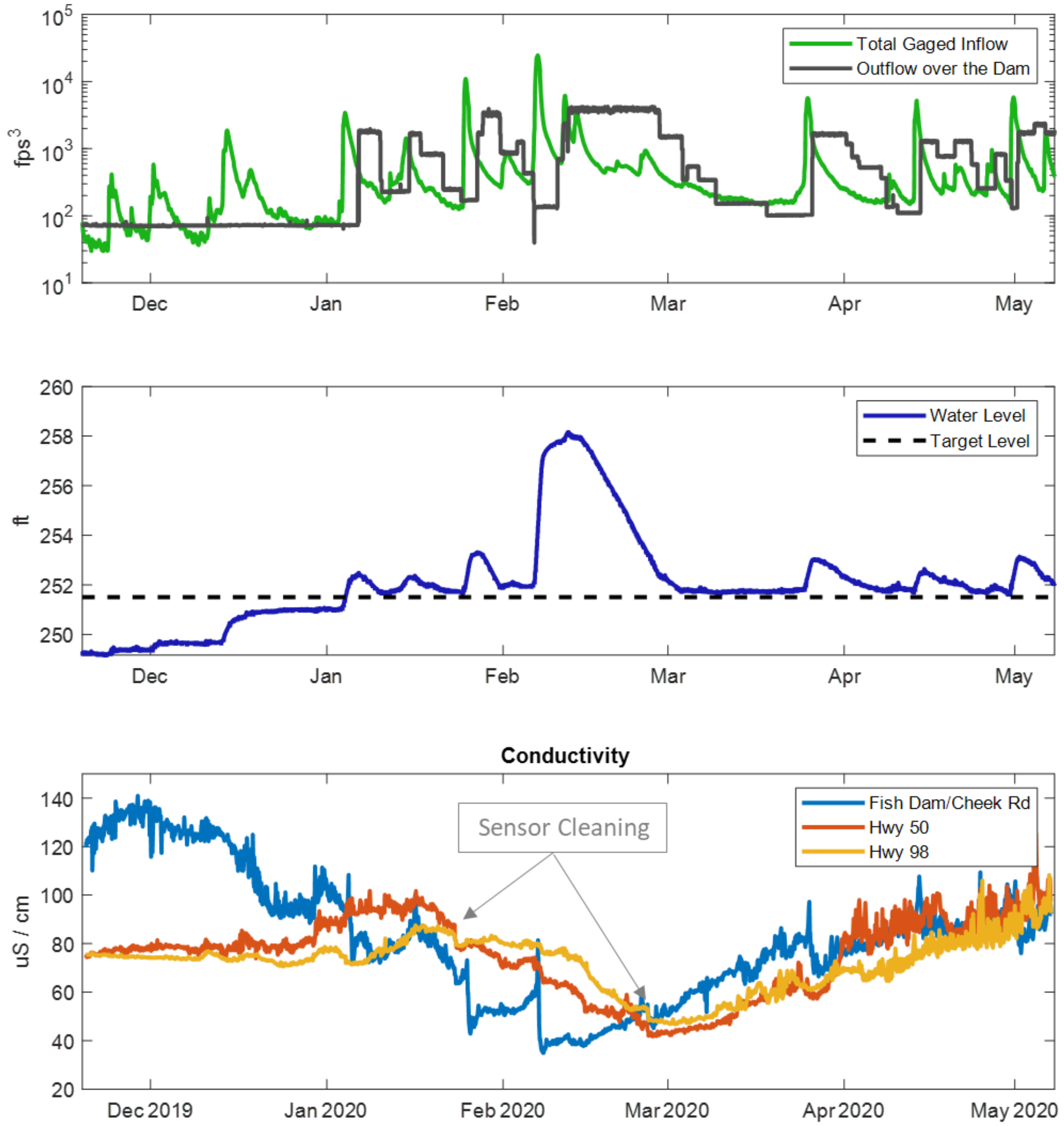

Figure 5. The top panel shows total gaged input to the lake in green and outflow over the dam in black. The bottom panel shows water level in ft. above sea level in blue and the target level is shown with a dashed black line.

The effects of the freshwater inputs can be seen in the data from the conductivity sensors (FIGURE 5 bottom panel). Input totals above approximately 2000 cubic ft per second (green lines in top panel of FIGURE 5) are reflected in the conductivity at the Fish Dam/Cheek Rd site as quick *increases* in conductivity followed by rapid and longer lasting reductions in conductivity. Sites further downriver do not show the initial rapid rise and fall in conductivity associated with significant fresh water inputs, although all sites show a longer term conductivity decrease followed by a gradual conductivity increase as the effects of the freshwater runoff dissipate. The difference between the Fish Dam/Cheek Rd conductivity and the downriver sites in November and December are worth noting as it appears that outflow from the dam, which begins in early January, may significantly control the advancement of the freshwater input.

Given that the majority of the freshwater inputs are upriver from the Fish Dam/Cheek Rd site, the majority of the sediment influx associated with runoff and high river flow also enters the system upriver. In addition, the upriver half of the lake is wider and shallower (c.f. bathymetry in FIGURE 1). This has profound consequences on turbidity and light penetration. Data from the light sensors on the moorings are shown in FIGURE 6. The horizontal lines represent points at which there are valid data. The values are shown as a log10 scale in lux. Data were interpolated/extrapolated vertically. Areas with a white background contain extrapolated values if there was enough data to do so. Although there was a significant amount of missing data due to failed sensors – especially at the Fish Dam/Cheek Rd site – sufficient data were collected to clearly show the increase in light penetration downriver. Light penetration can be expressed as an extinction coefficient based on an exponential decay function with depth. These extinction values can be rewritten to show the euphotic zone depth where 1% of the available light remains. Histograms of euphotic zone depths are shown in FIGURE 7. While the limited availability of data at the Fish Dam/Cheek Rd site results in a sparse histogram at that location, the median values of each describe the same trend with 1% light levels of 1.9m, 2.4m, 3.2m from Fish Dam/Cheek Rd, Highway 50, and Highway 98 respectively. Data from the shipboard profiles collected

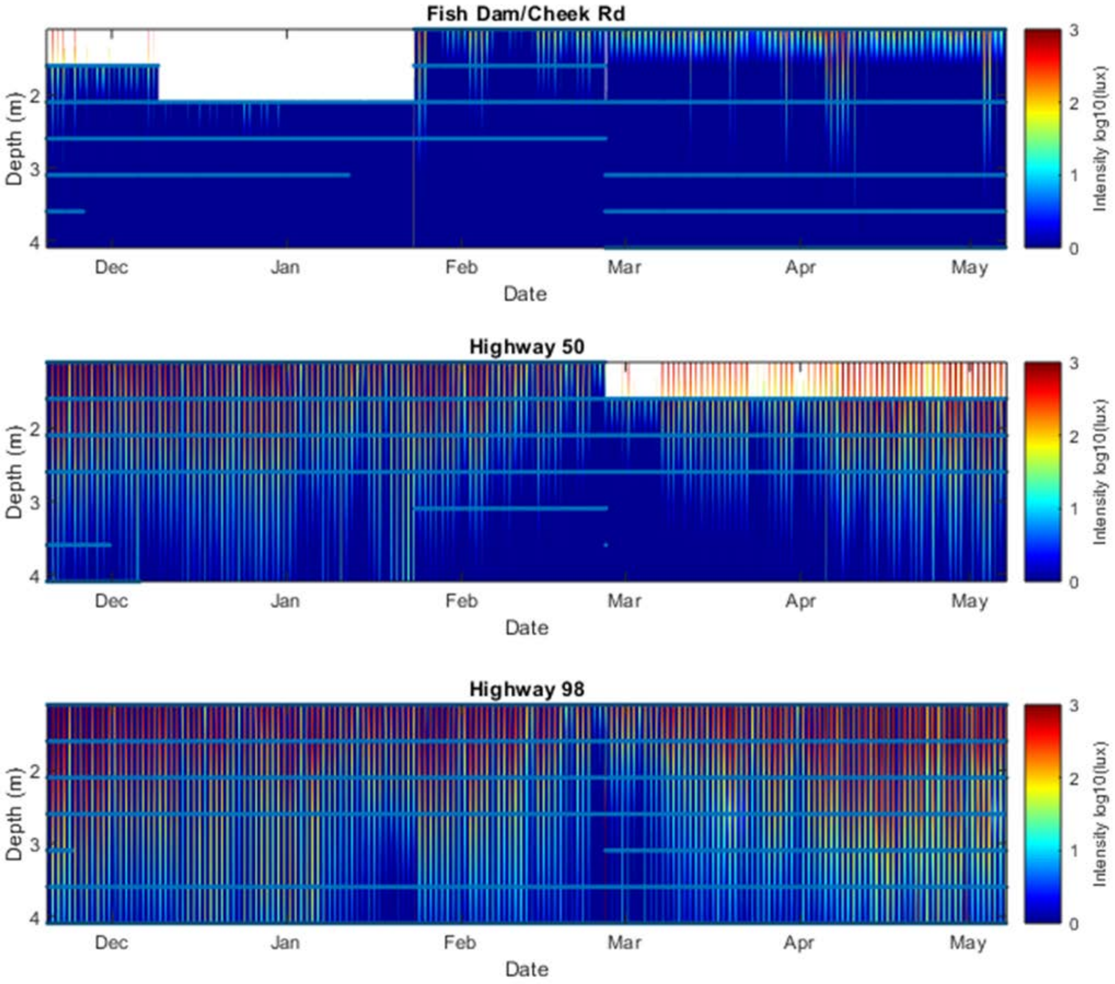

Figure 6. Light sensor data in log10(lux) from each of the three sites. Top panel is Fish Dam/Cheek Rd. Middle panel is Highway 50. Bottom Panel is Highway 98. Areas with a white background have been extrapolated. Horizontal lines represent existing data.

during field site visits also help to confirm the trend, **FIGURE 8**. Turbidity values during each visit were greatest at Fish Dam/Cheek Rd, followed by Highway 50, then Highway 98.

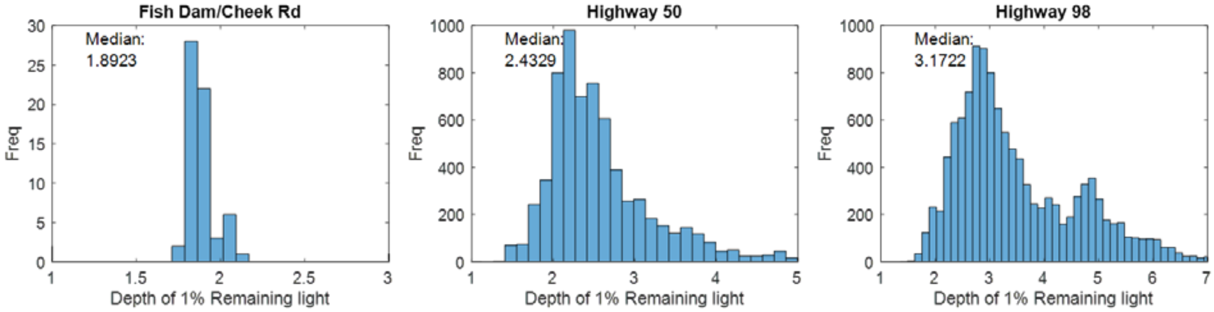

Figure 7. Histograms of light extinction expressed as the depth at which light intensity falls to 1% of the surface value.

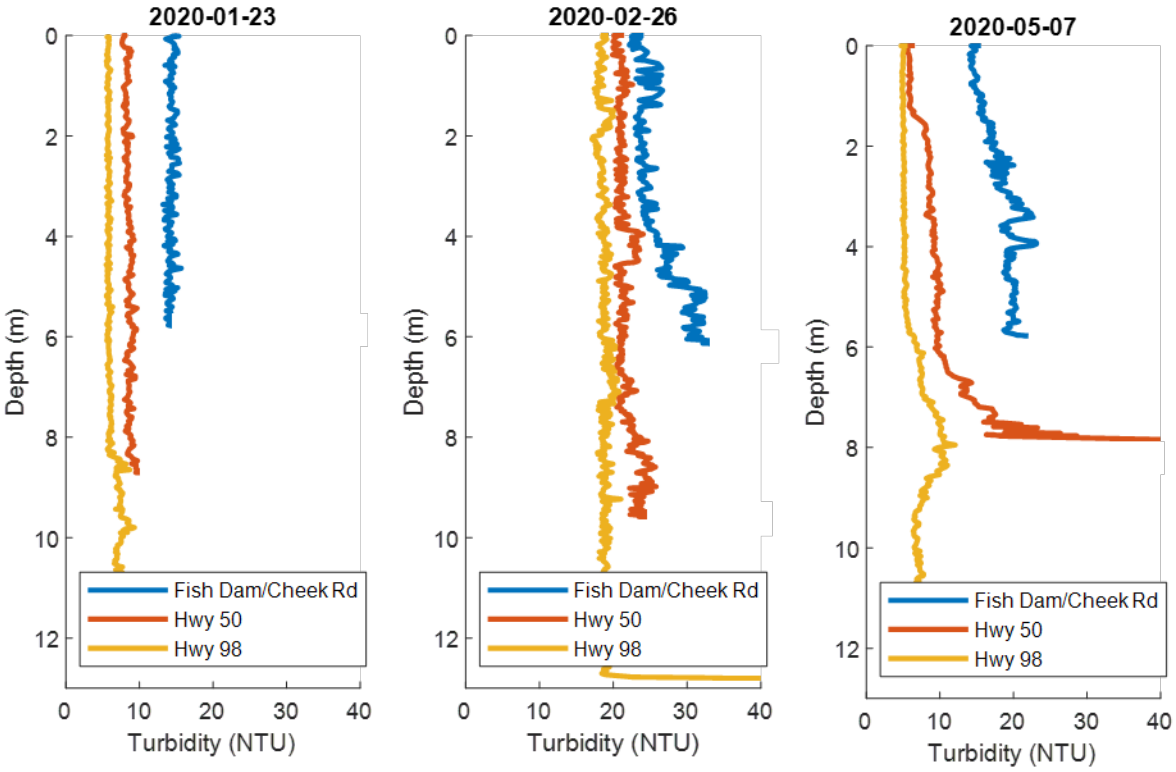

Figure 8. Turbidity data from shipboard Sonde casts during field site visits.

As noted previously, only the temperature data from the top half of the split mooring (cf. **FIGURE 4**) have been processed to date. Thus, the temperature data presented in **FIGURE 9** represent only the upper portion of the water column. These temperatures ranged from approximately 5-25 deg. C and stratification can be seen to form at all sites during periods of warming. During periods of cooling such as in November, the upriver section cools more quickly than the deeper downriver section. The increased density of the cooler water can lead to along-lake density driven currents.

Analyses of data from Falls Lake that was recovered in June as well as that collected during the remainder of this calendar year will be presented in the Year 2 report.

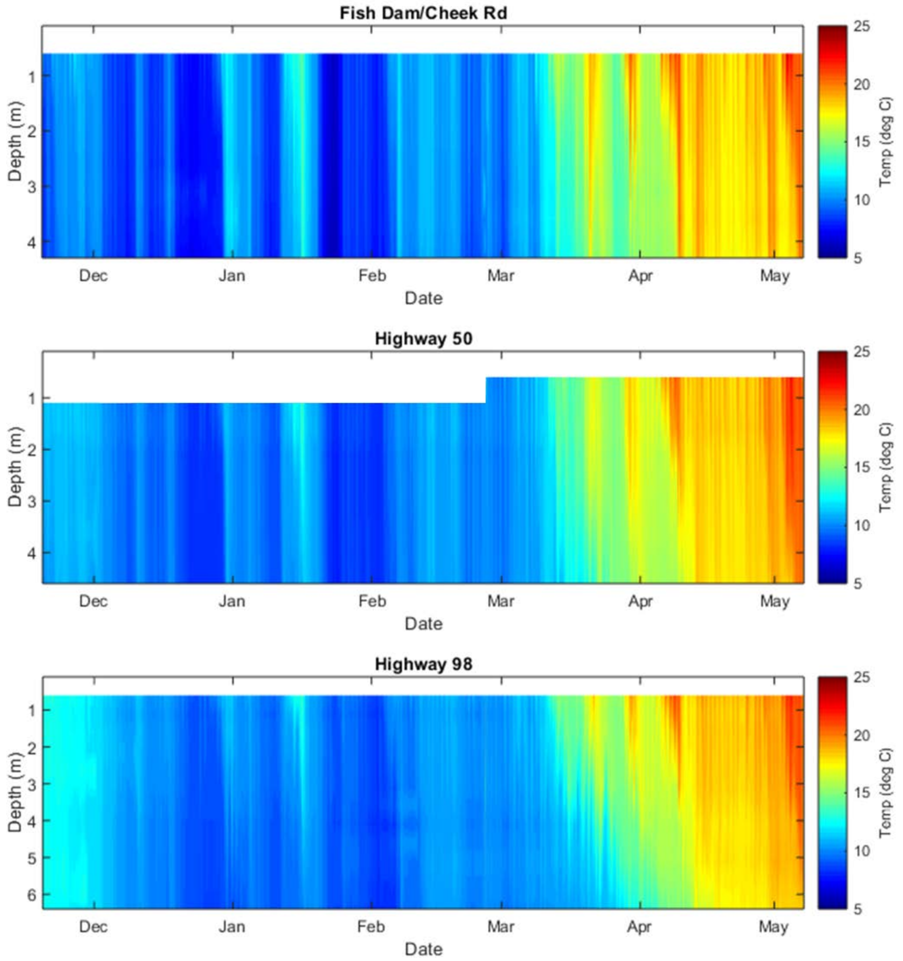

Figure 9. Temperature data taken from the top section of each split mooring.

4. Jordan Lake

Two autonomous vertical profilers (AVPs) have remained in place since their deployment during the study period dedicated to Jordan Lake (See UNC Nutrient Management Study - In Situ Observational Study of Jordan Lake Final Report). The AVPs have been collecting water quality data nearly continuously, including vertical profiles of water temperature, conductivity, in vivo fluorescence, dissolved oxygen concentration, turbidity and pH. Daily plots of the data collected by the AVPs are available at the website jordanlakeobservatory.unc.edu.

5. Data Archive

Data from the Jordan Lake observational study are available at the Jordan Lake project on Hydroshare https://www.hydroshare.org/. This project will be expanded to cover data from both Jordan and Falls Lake during the coming year.