Lake Hartwell – Eighteenmile Creek Lake Arm 2023 Nutrient Study

Final Report of the Field Program

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Executive Summary

In 2023, the South Carolina Department of Health and Environmental Control Bureau of Water completed a field study in the Eighteenmile Creek lake arm of Lake Hartwell to support future watershed and lake water quality TMDL model development. Eighteenmile Creek is designated as a priority restoration area in the State of South Carolina's 2020-2022 Integrated Report. Historically, wasteload allocations for oxygen demanding organic matter and total phosphorus have been determined from an interim TMDL established in 1992. Residential and commercial expansion in this area cannot be addressed using the existing TMDL.

The Eighteenmile Creek study focused on two existing DHEC ambient monitoring sites and established three new sites to enhance spatial resolution of the lake arm. The project's objectives were achieved through biweekly (every other week) water quality (nutrients, physical parameters, and total chlorophyll-a) sampling and vertical hydrographic profiling at routine lake sites. Further, two continuous monitoring systems were used to provide diel data of physical/hydrographic parameters and biological responses in the Eighteenmile Creek lake arm. The comprehensive dataset provided resolution into the links between hydrographic conditions, nutrients fluctuations, and algal responses such as phytoplankton biomass and toxin production.

This report discusses the successes and challenges of the field program and summarizes the data collected as part of the biweekly sampling and continuous monitoring project components. Generally, all field program objectives were achieved as nearly all targeted data were successfully collected.

Summary of observations:

- Response parameters such as dissolved oxygen and pH were influenced by both physical conditions and phytoplankton growth.
- Key differences were observed in the continuous monitoring records in the upper and mid-lake areas of the Eighteenmile Creek lake arm. Surface water temperature in the upper lake arm was subject to pulses of cooler stream water throughout the study. The upper lake arm also cooled more quickly in the fall than the mid-lake arm. The upper lake arm environment generally had a higher concentration of dissolved oxygen and higher pH possibly influenced by increased chlorophyll-a relative to the mid-lake arm.
- A chlorophyll-a gradient was evident in the lake arm with higher concentrations in the upper lake arm and lower concentrations near the confluence with the open lake.
- While nutrient concentrations were relatively low in the lake arm, a similar gradient to chlorophyll-a was apparent for both total phosphorus and total nitrogen.

Overview of the 2023 Eighteenmile Creek Lake Arm Study

Eighteenmile Creek is designated as a priority 2016-2022 restoration area in the State of South Carolina's 2020-2022 Integrated Report. Eighteenmile Creek receives treated wastewater effluent from several permitted municipal and industrial discharges: Pickens County/Eighteenmile Creek (SC0042994), Pickens County Middle Regional Wastewater Treatment Facility or WWTF (SC0047856), Milliken/Pendleton Plant (SC0000477), and Pendleton – Clemson Regional WWTF (SC0035700). Historically, wasteload allocations for oxygen demanding organic matter and total phosphorus in this area have been based on an interim TMDL established in 1992.

Eighteenmile Creek originates near Easley, SC, and flows southwest through the Pendleton and Clemson, SC, areas in Pickens and Anderson counties, below which Eighteenmile Creek forms the Eighteenmile Creek arm of Lake Hartwell. The stream and lake arm are completely contained within the Eighteenmile Creek 10-digit hydrologic unit (HU) watershed 03060101-06 (38,112 acres). This watershed is subdivided into two 12-digit subwatersheds: Upper Eighteenmile Creek (03060101-06-01; 22,158 acres) and Lower Eighteenmile Creek (03060101-06-02; 15,943 acres).

There is growing demand for residential and commercial expansion in this area that cannot be addressed using the existing TMDL. In addition, DHEC base monitoring site SV-268 located in the upper reaches of the Eighteenmile Creek lake arm is listed as impaired for total nitrogen, total phosphorus, and turbidity in the 2020-2022 Integrated Report. In 2019, SC DHEC established SV-374 two miles below SV-268 to further characterize water quality in this lake arm.

In 2023, the South Carolina Department of Health and Environmental Control (DHEC) Bureau of Water (BOW) completed the Lake Hartwell Eighteenmile Creek lake arm study. The study focused on the two existing DHEC ambient monitoring sites and established three new sites to enhance spatial resolution of the lake arm. The objectives of the project were to:

- Support updated nutrient evaluation of the Lake Hartwell Eighteenmile Creek arm and better define the spatial distribution of nutrients and nutrient-related parameters across the lake arm,
- Understand bottom water dynamics through oxygen demand and nutrient flux from the sediments in the lake arm,
- Develop a continuous record of key physical and biological parameters in the lake arm,
- Understand vertical hydrographic structure and light availability in the water column, and
- Support future watershed nutrient loading and nutrient TMDL determinations.

This study is one component of a comprehensive plan to investigate the Eighteenmile Creek watershed and lake arm. Other aspects include increased watershed monitoring, a United States Environmental Protection Agency led sediment oxygen demand and nutrient flux study, and forthcoming wet-weather synoptic sampling. Taken together, these studies will provide important insights into the relationships and spatial/temporal variations among nutrient inputs and watershed loading, physical conditions (e.g., temperature, total suspend solids, turbidity, etc.), algal activity, and metabolically driven water column response variables (e.g., dissolved oxygen and pH). The comprehensive results of these studies will provide guidance and source data for future system modeling/TMDL development. This report summarizes the results of the 2023 Eighteenmile Creek lake arm study.

Nutrient Study Project/Task Description

Field Logistics

The Eighteenmile Creek field study spanned 31 weeks from the beginning of April through the end of October 2023. The study focused on a series of five strategic locations in the lake to meet the objectives described above (Table 1, Figures 1,2):

1. SV-268 – Lake Hartwell – Eighteenmile Creek Arm at S-04-1098 (lake arm site with stream/wetland characteristics)
2. SV-838 – Eighteenmile Creek Upper Area Lake Arm Area (lake arm site)
3. SV-839 – Eighteenmile Creek Mid-Lake Arm Area (lake arm site)
4. SV-374 – Lake Hartwell – Eighteenmile Creek Arm ~227 Yards SW of Eighteenmile Creek Boat Landing (lake arm site)
5. SV-840 – Lake Hartwell off Eighteenmile Creek Lake Arm (open lake site)

Site coordinates are provided in Table 1 and site locations are presented in Figure 1.

Table 1. Field program site coordinates and descriptions.

Site ID	Lat./Long.	County	Site Description
SV-268	34.59720 / -82.82178	Anderson	Eighteenmile Creek Arm at S-04-1098
SV-838	34.58697 / -82.82471	Anderson	Eighteenmile Creek Upper Lake Arm
SV-839	34.57821 / -82.83203	Anderson	Eighteenmile Creek Mid-Lake Arm
SV-374	34.57214 / -82.82994	Anderson	Eighteenmile Creek Arm ~227 Yards SW of Boat Landing
SV-840	34.56460 / -82.83284	Anderson	Lake Hartwell off Eighteenmile Creek arm

Figure 1. Site locations in the Eighteenmile Creek lake arm area of Lake Hartwell. Blue squares indicate routine sampling sites and red squares indicate routine sampling sites with continuous monitoring systems.

Biweekly (every other week) surface (0.3 m) grab sampling was conducted at all sites. Continuous monitoring systems were installed at SV-838 and SV-839 and were serviced every other week. Routine surface grab sample parameters included:

- 5-day biochemical oxygen demand,
- Turbidity,
- Ammonia-nitrogen,
- Nitrate/nitrite-nitrogen,
- Total Kjeldahl Nitrogen,
- Total phosphorus,
- Orthophosphate,
- Total suspended solids,
- Total and filtered total organic carbon,
- Total chlorophyll-a,
- Cyanotoxins (microcystins)

Field surface sensor measurements were recorded at each grab sample site along with vertical profiles using a YSI EXO2 and photosynthetically active radiation (PAR) penetration using a LI-COR light meter:

- Water temperature,
- Dissolved oxygen (DO),
- pH,
- Turbidity,

- Specific conductivity,
- Chlorophyll-a fluorescence,
- Phycocyanin fluorescence

Continuous monitoring systems recorded surface measurements (~0.5 m) at 30-minute intervals at SV-838 and SV-839. Continuous parameters are the same as the field sensor measurements listed above.

Sensor Data

Surface Parameters

Surface physical parameters were collected at a depth of 0.3 m at each stream and lake site using a calibrated YSI EXO2. These measurements accompany routine grab sampling. Sampling was conducted from mid-morning through early afternoon (0930-1300). Routine physical parameters included pH (SU), optical dissolved oxygen (DO, mg/L), water temperature (°C), specific conductivity (µS/cm), and turbidity (FNU) (Table 2).

Table 2. Range (surface minimum and surface maximum) for each primary field parameter over the 4/5/2023 – 10/17/2023 period at the lake sites. Generally, each range consists of 15 sampling events.

Site	Field pH (SU)	Field DO (mg/L)	Water Temp. (°C)	Spec Cond. (µS/cm)	Turbidity (FNU)
SV-268	6.68 - 7.31	6.20 - 9.05	12.03 - 24.63	65.9 - 126.3	12.65 - 81.33
SV-838	7.02 - 8.81	8.62 - 11.23	18.64 - 31.86	44.7 - 77.0	2.47 - 24.27
SV-839	7.08 - 8.48	7.80 - 10.37	19.46 - 31.23	37.7 - 59.1	1.71 - 10.77
SV-374	6.94 - 8.64	7.07 - 10.51	19.40 - 30.95	37.1 - 51.9	1.33 - 7.17
SV-840	6.83 - 7.87	6.35 - 10.14	18.66 - 30.59	33.9 - 43.5	0.14 - 4.34

An expanded suite of surface measurements was also collected at each lake site including sensor-based chlorophyll-a (RFU) and phycocyanin (RFU) (Table 3). In addition, upper water column features were measured such as penetration depth of photosynthetically active radiation (PAR, 400-700 nm wavelength, µmol m^{-2} s^{-1}) using a LI-COR light meter and a LI-1400 data logger and water clarity expressed as secchi depth (m). PAR depth was determined as the depth in which PAR decays to 1% of its ambient value. The chlorophyll-a and phycocyanin maximums were determined from the vertical profile downcast and described as either a discrete depth or vertical band where pigment fluorescence was highest.

Table 3. Range (minimum and maximum) for additional field parameters at the lake sites over the 4/5/2023 – 10/17/2023 study period. Generally, each range consists of 15 sampling events. Only surface measurements were collected from SV-268 due to depth and stream-like nature of the lake at this location.

Site	Chl-a (RFU)	Chl-a Max Depth (m)	Phycocyanin (RFU)	Phycocyanin Max Depth (m)	PAR Depth (m)	Secchi Depth (m)
SV-268	0.27 - 5.75	-	0.04 - 0.55	-	-	-
SV-838	1.45 - 6.51	0.3 - 1.5	0.26 - 1.23	0.3 - 2.2	1.0 - 2.8	0.5 - 1.3
SV-839	0.87 - 4.12	0.3 - 3.3	0.13 - 0.61	0.3 - 4.4	2.5 - 4.7	0.9 - 1.9
SV-374	0.49 - 2.55	1.3 - 5.0	0.08 - 0.35	1.3 - 5.2	3.5 - 6.3	1.0 - 2.3
SV-840	0.36 - 1.22	1.8 - 7.0	0.01 - 0.24	1.8 - 9.4	3.8 - 7.5	1.1 - 3.0

Vertical Profile

Vertical profiles were collected at each lake site visit using a YSI EXO2. The casts were conducted manually, but data were logged by the instrument every second. The sonde was gradually lowered through the water column (downcast) until contact was made with the lake bottom and then retrieved at a similar rate of ascent. An Excel tool was used to process raw vertical profile data. The tool extracts the downcast from the profile record by identifying when instrument descent was initiated and when retrieval began after contacting the lake bottom. The bottom depth for the profile was manually adjusted, if necessary, to remove the effects of sediment resuspension on the sensor measurements. Subsequently, the program averages the downcast data in half meter intervals. Eight parameters were processed for each profile: water temperature, DO concentration, DO percent saturation, pH, turbidity, specific conductivity, chlorophyll-a fluorescence, and phycocyanin fluorescence.

In total, 60 vertical profiles were collected as part of the 2023 Lake Program: fifteen biweekly profiles at each routine site except for SV-268. Because profiles are collected on an approximately biweekly schedule, the data can be used to illustrate the evolution of the water column over the course of the field program.

Continuous Monitoring

Continuous monitoring systems were deployed at SV-838 and SV-839 from 4/5/2023 through 11/1/2023. Each deployment was two weeks in duration with data recorded at 30-minutes intervals. End of deployment verifications for all variables were largely successful (Table 4).

Table 4. Percent of continuous monitoring deployments passing end of deployment verifications for each sensor. Assessment criteria are identified in the column headers. Note: 10% criterion for phycocyanin is not an approved accuracy rating but provides basic interpretation of sensor performance.

Station	Dissolved Oxygen (0.2 mg/L)	pH (0.2 SU)	Specific Conductivity (10%)	EXO2 Chlorophyll-a (10%)	EXO2 Phycocyanin (10%)	Turbidity (10%)
SV-838	87%	94%	100%	100%	100%	94%
SV-839	100%	100%	94%	100%	100%	94%

The following list summarizes deployment notes:

SV-838

- Due to shallowing of the lake, the record at SV-838 ended on 10/23/2023 as instrument was in contact with the sediment after that time.
- DO read above saturation for the 4/5/2023 verification. This is possibly due to laboratory temperature and pressure issues related to dehumidifiers.
- Possible electrical or Bluetooth connection issue for DO verification of the 7/11/2023 record. Comparison with the SV-839 record showed no deviation or drift. The record was deemed usable.
- The pH sensor for the 9/5/2023 record did not meet end of day verification. This may be related to the temperature of the instrument or sensors. The sensor was verified the following morning and passed verification.

SV-839

- Unusual battery drain was observed on the 7/11/23 deployment. Specific conductivity sensor did not meet verification standards. The record was consistent with prior and subsequent records and was deemed usable.

Fluorometer-Based Chlorophyll-a

A total of 75 lake samples were collected for fluorometer-based total chlorophyll-a. Samples were collected at the surface (0.3 m) at all sites during all visits. All samples were successfully analyzed.

Cyanotoxins

Samples for microcystins analysis were collected at the surface along with each total chlorophyll-a sample. A total of 75 samples were collected. One sample was lost (SV-838 on 9/5/2023) and one analyzed sample did not pass laboratory quality control (SV-840 on 10/17/2023).

Water Quality

Grab samples for water quality occurred biweekly from 4/5/2023-10/17/2023. Each site was sampled 15 times over the course of the field program. Completeness of the water quality grab sampling component was 100% as no sample event was omitted due to field team decision or error. In total, 120 grab samples at 75 site visits were successfully collected. The total includes 45 subsurface grab samples collected at SV-839 (one subsurface sample per visit) and SV-374 (two subsurface samples per visit). Lake sampling followed a biweekly schedule and samples were evenly distributed over the course of the study.

Water quality sampling notes:

- Laboratory errors were reported for turbidity samples from SV-839 (4.0 m) and SV-374 (9.0 m and 16.5 m) on 4/18/2023.
- Laboratory analytical issues were reported for ammonia and Total Kjeldahl Nitrogen for SV-374 on three occasions: 16.5 m on 7/11/2023, 8.0 m on 7/25/2023, and 15.0 m on 8/8/2023.

Summary of Findings

The following discussion presents observations of key parameters investigated as part of the 2023 Eighteenmile Creek study. The discussion is not meant to be exhaustive of all data collected during the study but highlights seasonal trends and features of the system. The vertical profile data discussion centers on the structure of the water column over the course of the field program at SV-374. Continuous monitoring data focuses on key features at SV-838 and SV-839. Summary statistics for total chlorophyll-a, microcystins, total phosphorus, total nitrogen, and total organic carbon are presented for all sites and all available depths. Additional site figures are presented in Appendix A (vertical profile) and B (continuous monitoring).

Vertical Profile

Section plots for temperature, dissolved oxygen, pH, and chlorophyll-a fluorescence for SV-374 are presented in Figures 2-5. Phycocyanin fluorescence, specific conductivity, and turbidity plots for SV-374 along with section plots for SV-838, SV-839, and SV-840 are presented in Appendix A. The section plots were interpolated from the 15 vertical profiles collected on a biweekly basis at each station. Because the profiles were collected at approximately two-week intervals at roughly the same time of day, the

interpolated data illustrate the seasonal evolution of the water column physical and biological parameters at each site.

In April, average water column temperatures at SV-374 (average total depth = 17.5 m) were 15-17°C with differences between surface and bottom of 6-7°C. Specifically, surface temperatures at this point in the season were 19-20°C and bottom temperatures were 13-14°C (Figure 2). Average water column temperatures increased to ~27°C in August and September before decreasing to ~22°C in mid-October. Surface temperatures in August and September were 30-31°C with bottom temperatures of 18-21°C. The highest temperature differences between surface and bottom were ~12°C in July. By August, warmer temperatures were present in the deeper reaches of the water column. Vertical mixing of the water column occurred in mid-October as surface temperatures cooled to ~22°C (Figure 2).

Throughout the project, DO at the surface ranged from 7-10.5 mg/L (Figure 3). Higher surface water DO concentrations were observed early in the project (April and May) and decreased through the summer and early fall. Bottom water DO concentrations of <2.0 mg/L emerged at the end of May and gradually expanded to encompass the water column below 8 m by mid-July. After July, this low DO feature gradually contracted over the remainder of summer. By mid-September, minimum water column DO concentrations were >4 mg/L. Vertical mixing in October largely homogenized DO concentrations throughout the water column resulting in ~0.5 mg/L differences between the surface and bottom waters (Figure 3).

Surface water pH was highest from late May through late summer with lower values in the spring and early fall (Figure 4). Measured pH in surface waters throughout the project did not mirror DO which suggests that DO and pH may be influenced more by physical processes than phytoplankton growth in this area of the lake arm. Surface water chlorophyll-a fluorescence may support this observation as higher values were measured in the later stages of the project (late August through mid-September) (Figure 5).

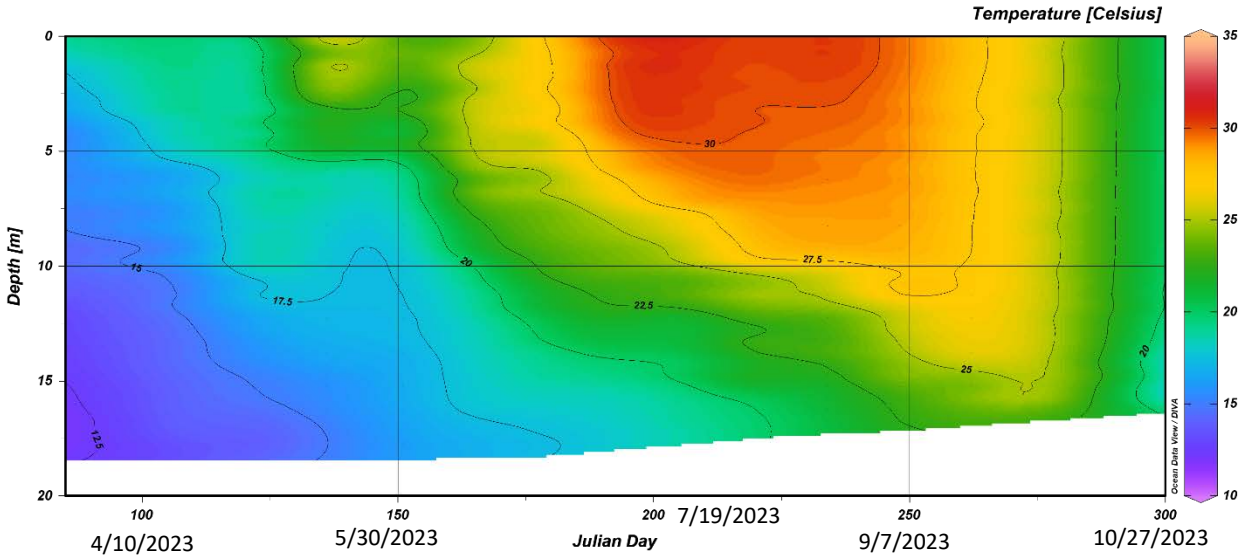


Figure 2. Temperature (°C) section plot for SV-374. Corresponding calendar dates are listed next to Julian Day labels.

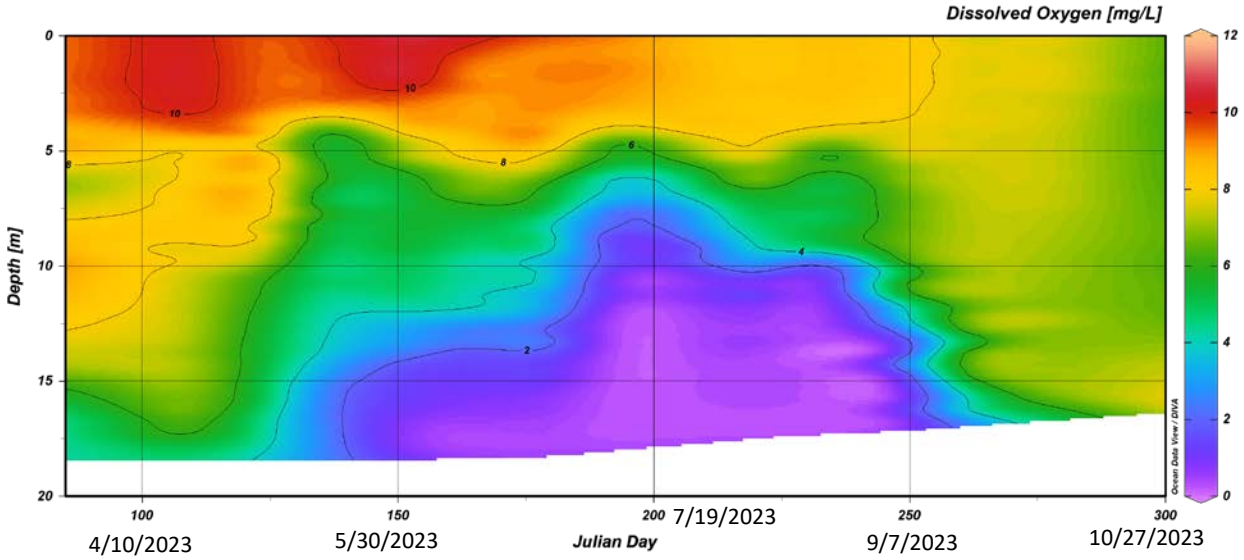


Figure 3. Dissolved oxygen (mg/L) section plot for SV-374. Corresponding calendar dates are listed next to Julian Day labels.

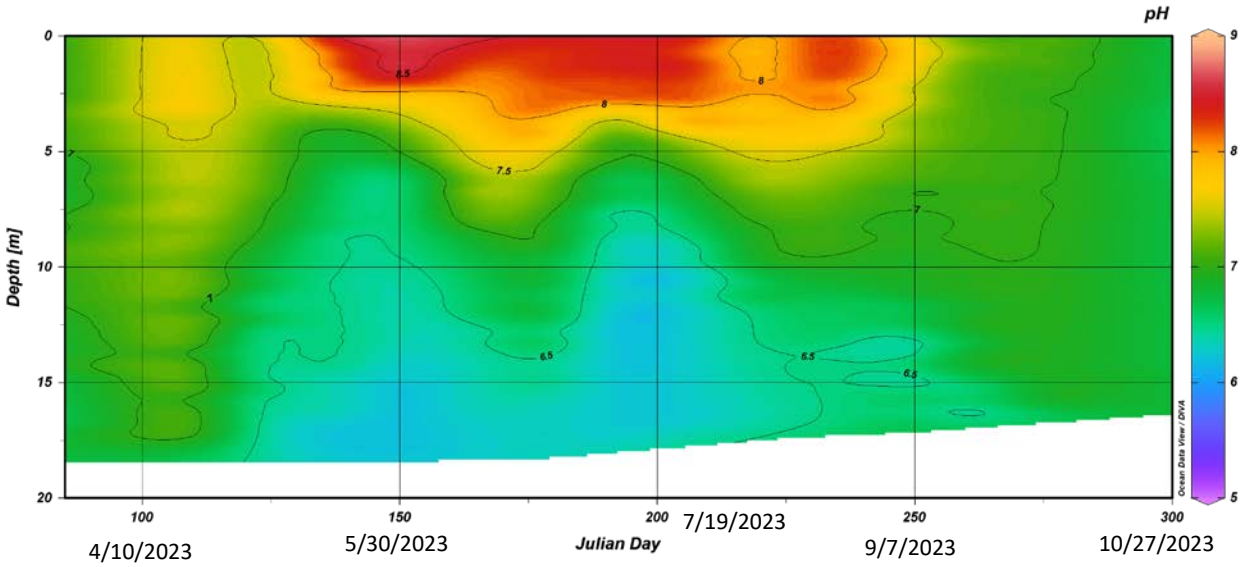


Figure 4. pH (SU) section plot for SV-374. Corresponding calendar dates are listed next to Julian Day labels.

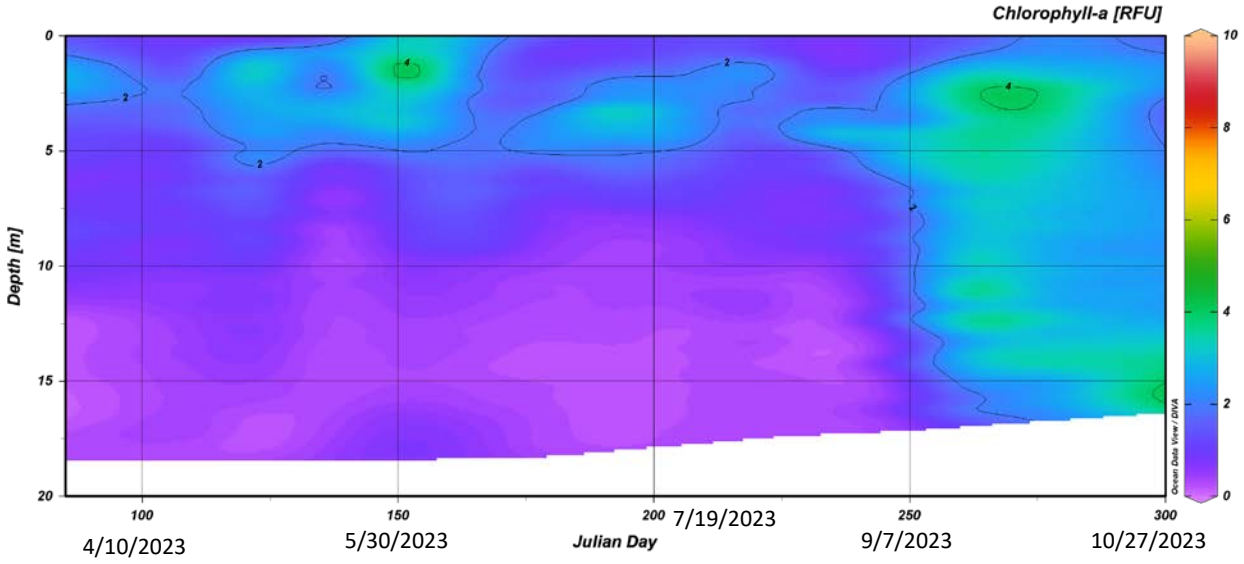


Figure 5. Chlorophyll-a fluorescence (RFU) for SV-374. Corresponding calendar dates are listed next to Julian Day labels.

Continuous Monitoring

Continuous monitoring in the surface water environment filled in data gaps between biweekly surface measurements and vertical profiles. The following discussion focuses on the temperature and chlorophyll-a fluorescence time-series for SV-838 and SV-839 along with hourly average histograms of DO, pH, and chlorophyll-a fluorescence which provided insights into daily progressions for these parameters. Additional continuous monitoring plots are presented in Appendix B.

In April, surface water temperatures at SV-838 and SV-839 (Figure 6) averaged ~19-20°C consistent with the surface component of the vertical profiles collected at these sites (Appendix A) and SV-374 (Figure 2). SV-838 was subject to larger temperature fluctuations than SV-839, likely to due to greater influence from Eighteenmile Creek. Daily maximum average temperatures of ~33°C occurred on 7/28/2023 at both sites. Seasonal cooling of surface water began in mid-September at both sites. SV-838 cooled more quickly than SV-839 to a minimum average temperature of 17-18°C by the third week of October when the data record ended. SV-839 reached minimum temperatures of ~22°C near the conclusion of the time-series near the end of October (Figure 6).

Dissolved oxygen concentrations were generally higher at SV-838 than SV-839 with maximum daily concentrations occurring in the 1800 hour at both sites (Figure 7). Daily minimum DO concentrations typically occurred in the morning (0800 hour at SV-838 and 0700 at SV-839). There were several differences between SV-838 and SV-839 when comparing monthly average DO data. On a monthly basis, the average daily maximum DO concentrations occurred in June at SV-838 (13.7 mg/L) and May at SV-839 (11.2 mg/L) (Table 5). August was the lowest DO month at SV-838 for both minimum (8.0 mg/L) and maximum (12.5 mg/L) daily average concentrations. At SV-839, DO was lowest in September for daily average minimum (7.8 mg/L) and maximum (9.11 mg/L) concentrations. The highest range in DO (ΔDO) occurred in October at SV-838 though the record for that month ended on 10/21/23. The highest range in DO at SV-839 occurred in May.

As with DO, pH exhibited a diel cycle with higher values in the early evening and lower values mid-morning (Figure 8). Hour-by-hour pH was generally higher at SV-838 than SV-839. Hourly average minimum and maximum pH values are the same as DO. For SV-838, average daily maximum pH was highest in July (9.0 SU) while June was highest for SV-839 (8.9) (Table 5). For the 201-day time-series at SV-838, the maximum daily pH exceeded the state standard of 8.5 on 160 days (80%). Fewer exceedances were observed at SV-839. At this site, pH exceeded 8.5 on 132 days of 209-day record (63%).

Continuous chlorophyll-a fluorescence was on average higher at SV-838 than SV-839 (Figures 9 and 10). While magnitudes of fluorescence were different, both sites exhibited similar features. Moderately high fluorescence values (4-5 RFU) were observed from April through late June or early July. Lower chlorophyll-a fluorescence values (2-4 RFU) were characteristic of the July through mid-September period. Higher fluorescence values occurred from mid-September through the end of the time-series. The late season chlorophyll-a fluorescence pattern at SV-838 was characterized by a sharp increase, which peaked in early October (25 RFU), followed by sharp decline. At SV-839, chlorophyll-a fluorescence gradually increased then maintained relatively high levels (5-7 RFU) until the time-series concluded at the end of October. Maximum average chlorophyll-a fluorescence occurred in the 2000 hour for both sites (Figure 11), an approximate 2-hour delay from maximum average DO and pH. Minimum average fluorescence occurred at 0600 for SV-838 while the minimum average fluorescence for SV-839 didn't occur until the 1400 hour.

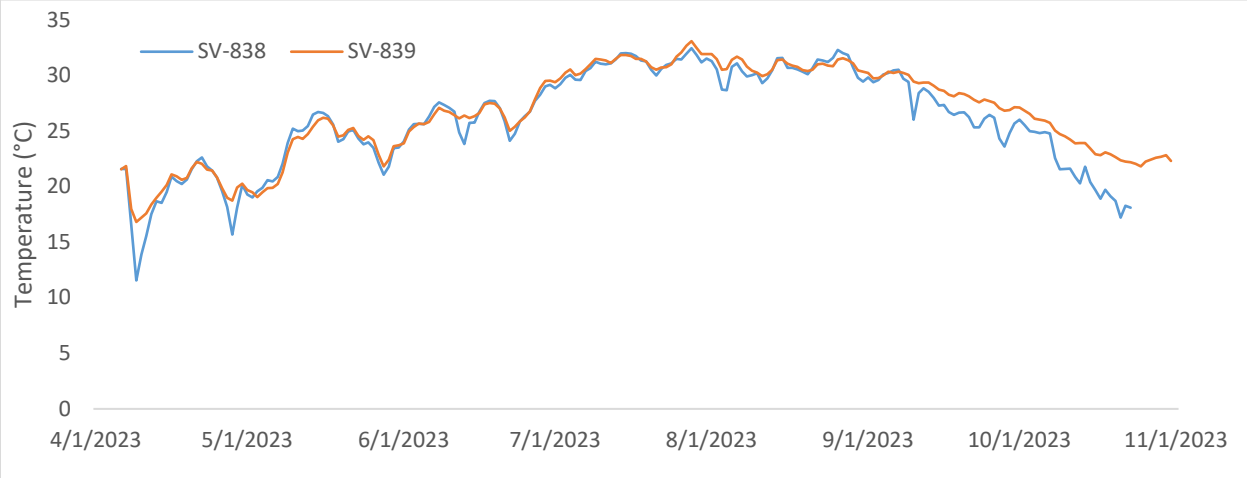


Figure 6. Average daily surface water temperature at SV-838 and SV-839.

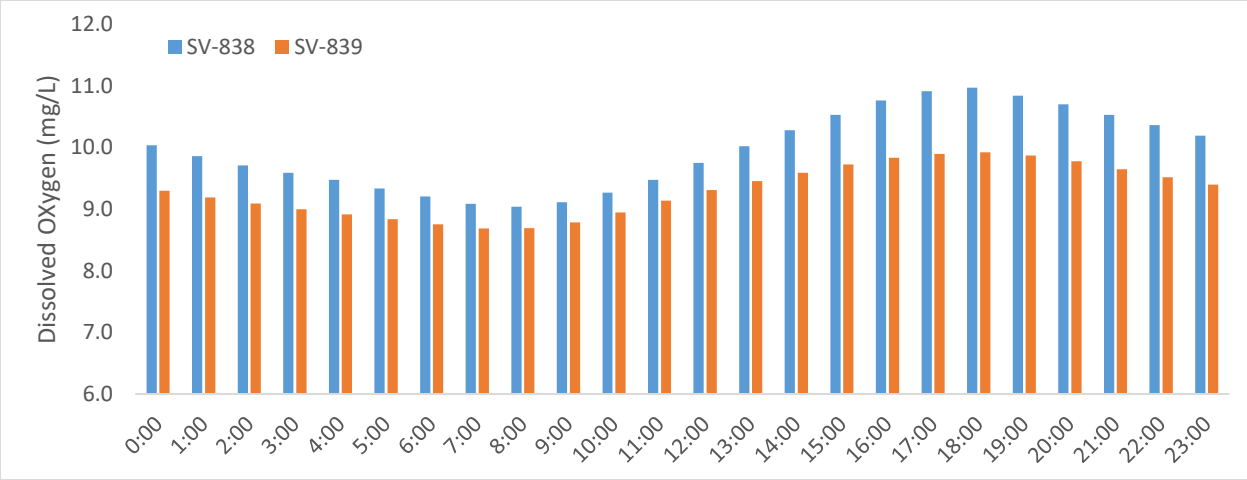


Figure 7. Hourly average dissolved oxygen concentrations (mg/L) at SV-838 and SV-839.

Table 5. Month by month average minimum and maximum dissolved oxygen concentration along with average daily range in recorded values SV-838 and SV-839. The period of record begins on 4/6/2023 for both sites. The record for SV-838 ends on 10/23/2023 and the record for SV-839 ends on 10/31/2023. All units in mg/L.

Month	Site	Avg. Daily Minimum DO	Avg. Daily Maximum DO	Avg. Δ DO	n
April	SV-838	9.34	13.02	1.82	25
	SV-839	9.24	10.79	1.55	25
May	SV-838	9.42	13.24	2.15	31
	SV-839	9.27	11.21	1.94	31
June	SV-838	9.31	13.66	2.37	30
	SV-839	9.42	11.07	1.65	30
July	SV-838	9.04	13.21	2.71	31
	SV-839	8.40	10.07	1.67	31
August	SV-838	8.01	12.52	2.81	31
	SV-839	7.95	9.45	1.50	31
September	SV-838	8.29	12.97	2.81	30
	SV-839	7.81	9.11	1.30	30
October	SV-838	8.15	13.49	3.45	23
	SV-839	7.91	9.26	1.35	31

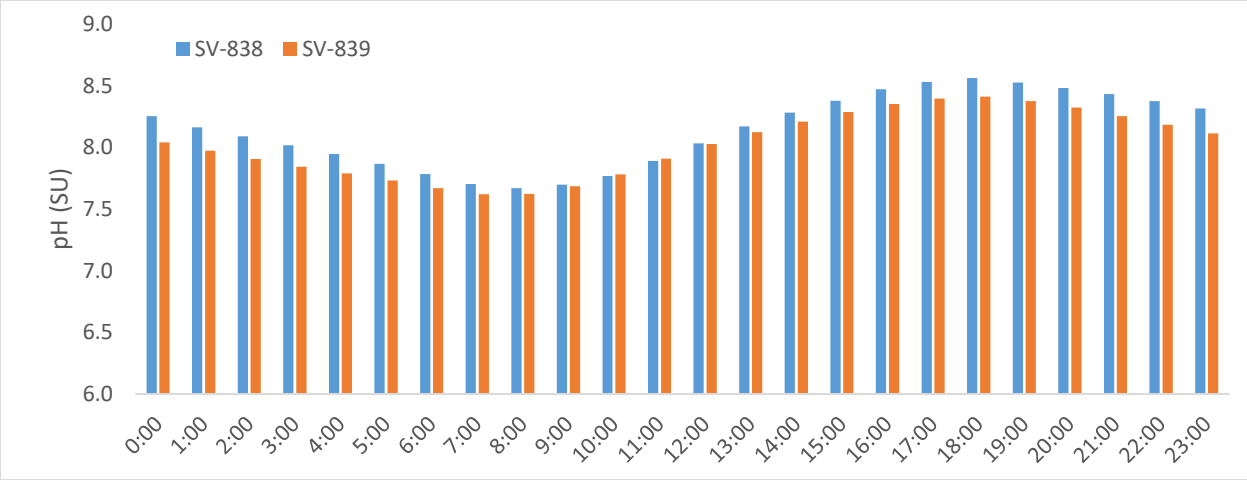


Figure 8. Hourly average pH (SU) at SV-838 and SV-839.

Table 6. Month by month average minimum and maximum pH (SU) along with average daily range in recorded values and the number of daily maximum values that exceeded 8.5 for SV-838 and SV-839. The period of record begins on 4/6/2023 for both sites. The record for SV-838 ends on 10/23/2023 and the record for SV-839 ends on 10/31/2023.

Month	Site	Avg. Daily Minimum pH	Avg. Daily Maximum pH	Avg. Δ pH	Max. > 8.5	n
April	SV-838	7.05	7.87	0.82	6	25
	SV-839	7.15	8.02	0.86	4	25
May	SV-838	7.40	8.54	1.14	22	31
	SV-839	7.44	8.62	1.18	24	31
June	SV-838	7.97	8.93	0.96	28	30
	SV-839	8.14	8.91	0.77	27	30
July	SV-838	8.01	9.03	1.01	30	31
	SV-839	7.92	8.84	0.92	31	31
August	SV-838	7.60	8.97	1.37	30	31
	SV-839	7.66	8.68	1.02	26	31
September	SV-838	7.47	8.99	1.51	29	30
	SV-839	7.36	8.42	1.06	12	30
October	SV-838	7.14	8.68	1.55	15	23
	SV-839	7.10	7.95	0.85	8	31

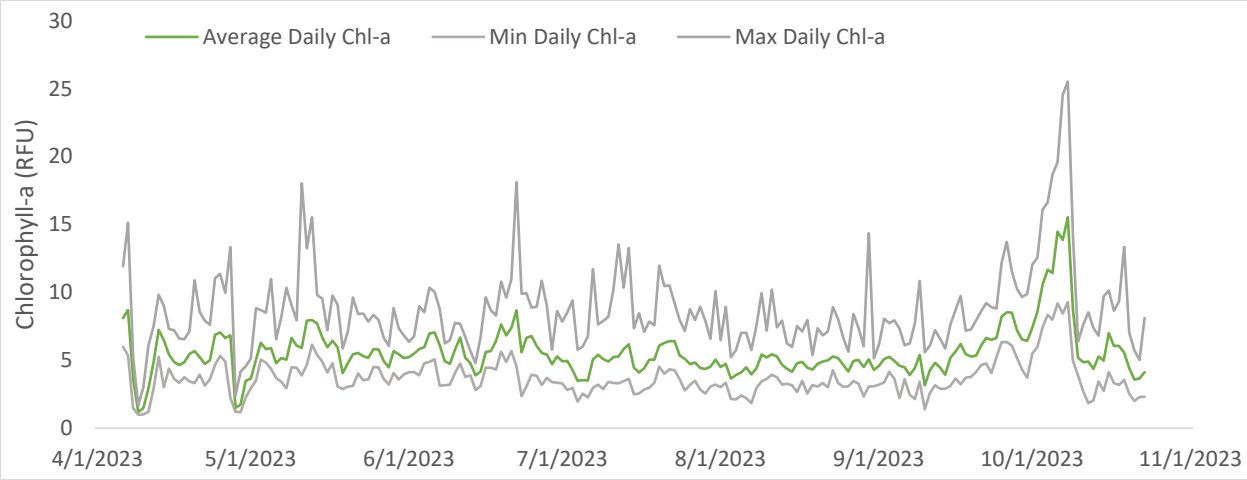


Figure 9. Daily average, daily minimum, and daily maximum YSI EXO2 chlorophyll-a fluorescence (RFU) at SV-838. Note: Y-axis scaled to dataset.

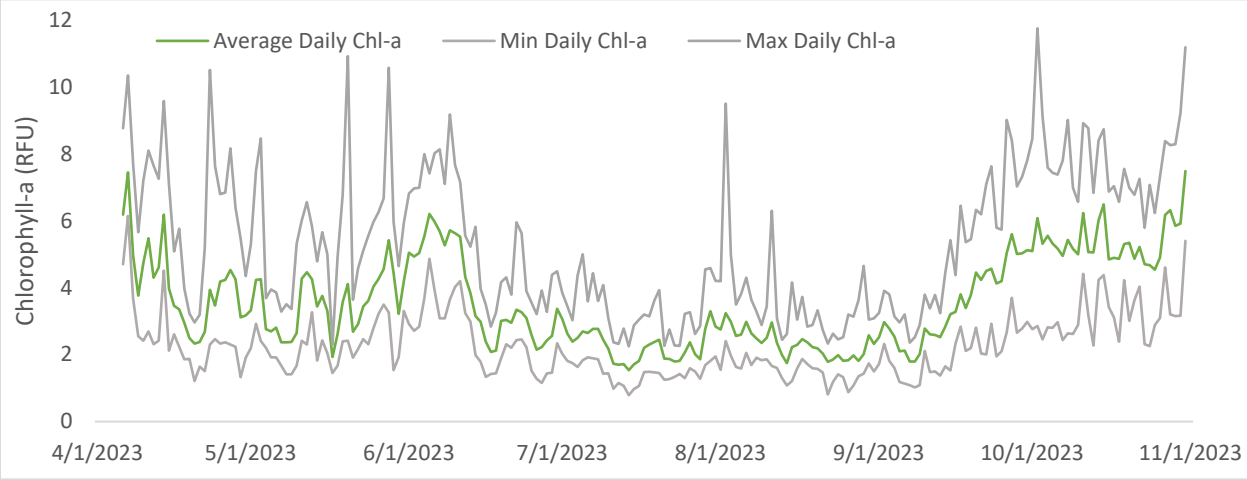


Figure 10. Daily average, daily minimum, and daily maximum YSI EXO2 chlorophyll-a fluorescence (RFU) at SV-839. Note: Y-axis scaled to dataset.

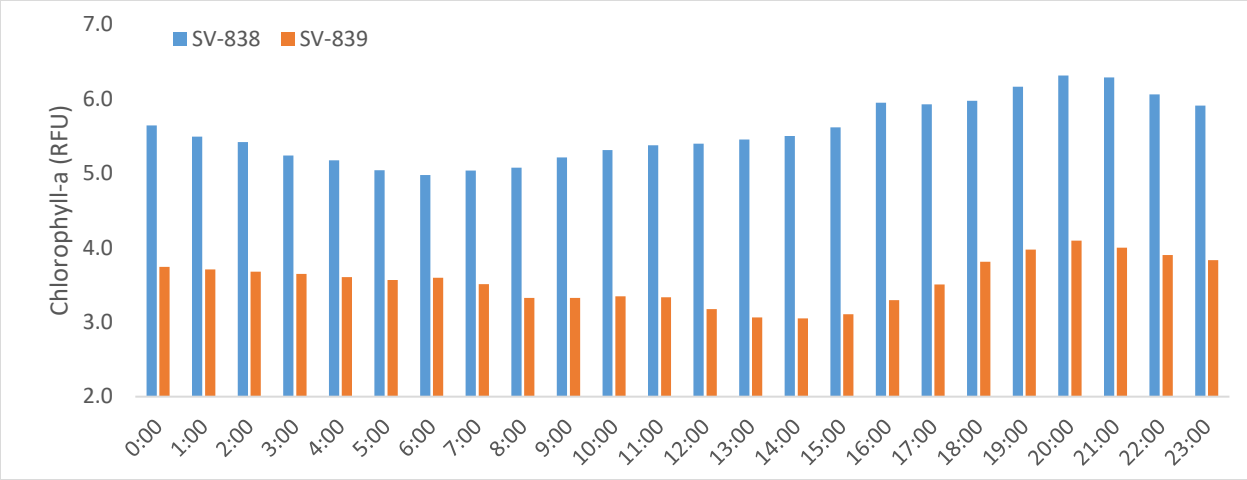


Figure 11. Hourly average chlorophyll-a fluorescence (RFU) at SV-838 and SV-839.

Fluorometer-Based Chlorophyll-a

Total chlorophyll-a was highest at SV-838 with a progressive decrease in average values down the lake arm into the open lake environment (Table 7, Figure 12). Average total chlorophyll-a was also relatively low at SV-268. There were no exceedances of the State 40 µg/L ecoregional standard for chlorophyll-a at any site. SV-838 exceeded 35 µg/L on three occasion in the early and late stages of the project (Figures 12 and 13). In general, higher total chlorophyll-a concentrations were observed early and late in the growing season while mid-season concentrations were lower (Figure 13). Similar features were observed in the continuous chlorophyll-a fluorescence time-series as noted above (Figure 9 and 10). Further, fluorometric total-chlorophyll-a concentrations and corresponding surface water field measurements of chlorophyll-a fluorescence indicate good agreement (Figure 14). This relationship provides insights into the ranges and magnitudes of total chlorophyll-a over the daily cycle at SV-838 and SV-839.

Table 7. Surface (0.3 m) total chlorophyll-a summary statistics for each lake site. Average is presented as ± 1σ. All total chlorophyll-a units in µg/L.

Site	Avg. T. Chl-a	Minimum	Maximum	n
SV-268	7.4 ± 8.0	1.2	28.6	15
SV-838	24.1 ± 8.6	12.4	38.9	15
SV-839	15.4 ± 7.4	7.5	31.3	15
SV-374	10.7 ± 4.3	5.6	18.7	4
SV-840	6.1 ± 1.8	3.4	8.6	4

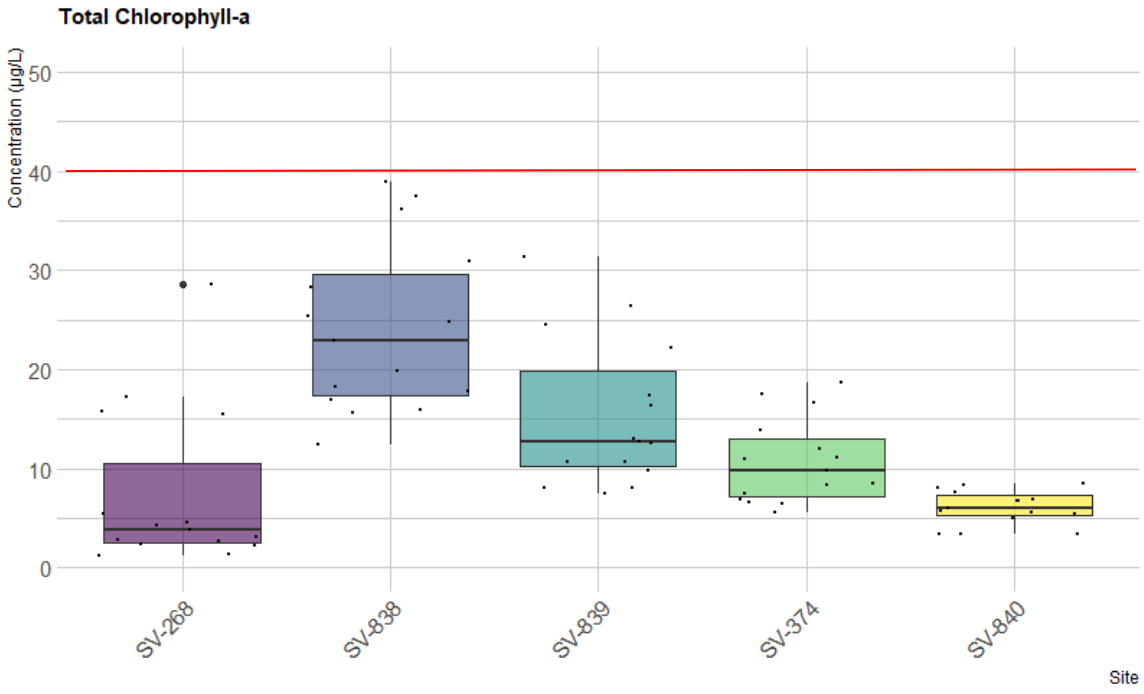


Figure 12. Box plot summary of surface (0.3 m) total chlorophyll-a concentrations (µg/L) for each lake site. Box plots include median, first (lower) and third (upper) quartiles, and ranges (minimum and maximum) for the data. Data points accompanied by a black dot are deemed outliers. The red line denotes the 40 µg/L ecoregional total chlorophyll-a standard.

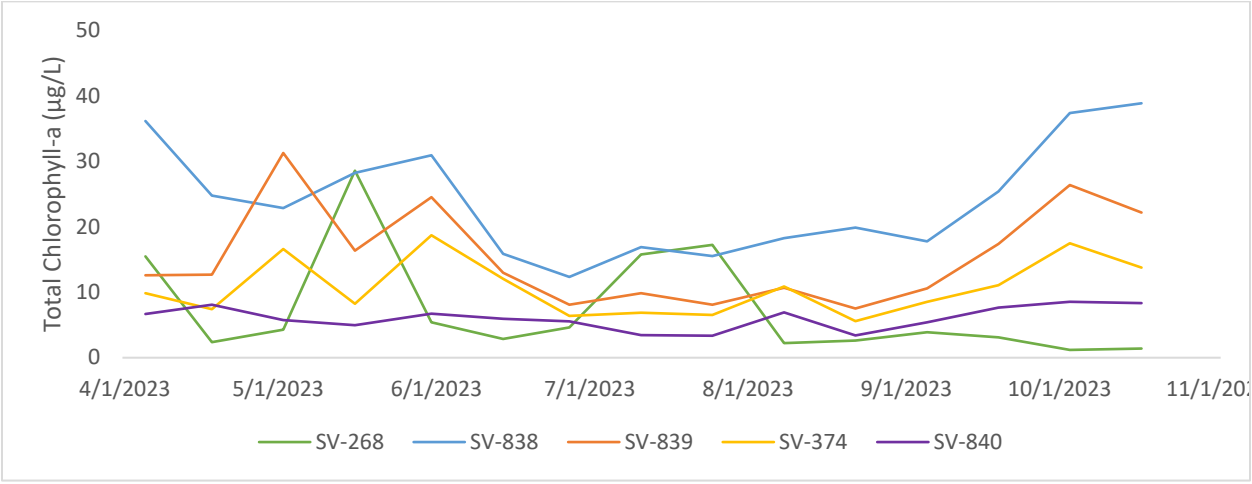


Figure 13. Total chlorophyll-a measurements (µg/L) at the biweekly lake stations. All values are surface samples (0.3 m).

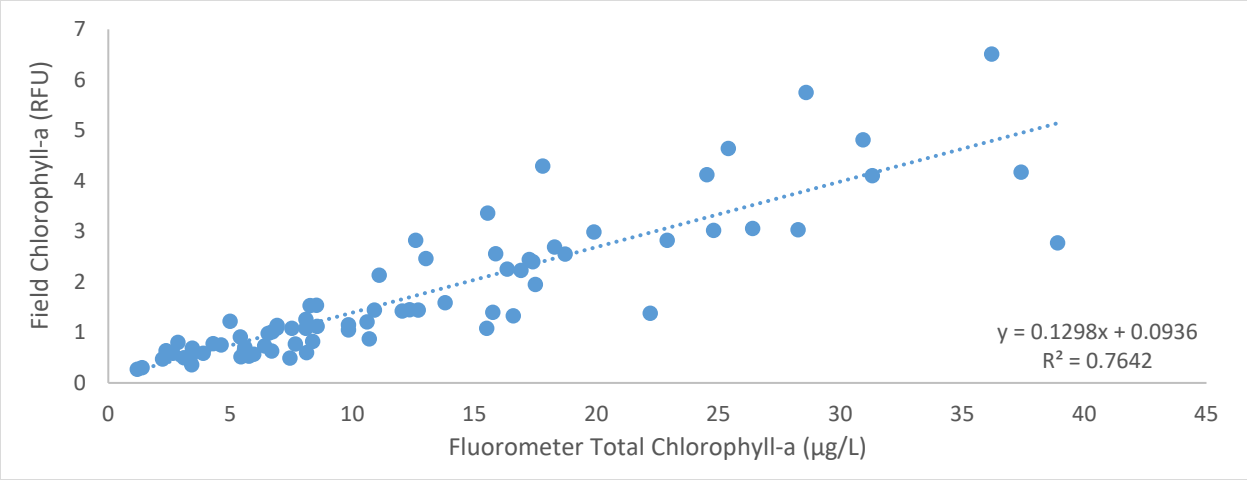


Figure 14. Relationship between laboratory fluorometer total chlorophyll-a (µg/L) and corresponding surface water chlorophyll-a fluorescence (RFU).

Cyanotoxins

Concentrations of microcystins were generally low at all sites and below the United States Environmental Protection Agency recreational health advisory value and DHEC recreational standard of 8 µg/L.[1,2] For more information related to cyanotoxin distributions within South Carolina waters, refer to DHEC Bureau of Water Technical Report No. 005-2023.[3]

Table 8. Surface (0.3 m) microcystins summary statistics for each lake site. Average is presented as ± 1σ. Dashes (-) indicate a concentration below analytical detection limit (0.016 µg/L). Values below detection limit are assumed ½ detection limit (0.008 µg/L) for the site average. All total concentrations in µg/L.

Site	Avg. Microcystins	Minimum	Maximum	n
SV-268	0.038 ± 0.098	-	0.393	15
SV-838	0.040 ± 0.028	-	0.102	14
SV-839	0.051 ± 0.026	-	0.098	15
SV-374	0.057 ± 0.033	-	0.132	15
SV-840	0.044 ± 0.025	-	0.086	14

Water Quality - Nutrients

The following discussion summarizes grab sample results for total phosphorus (TP) and total nitrogen (TN), two nutrient parameters regulated in lakes by the State, as well as total organic carbon (TOC). This section also includes subsurface grab samples from SV-839 and SV-374. Regulatory assessment of these parameters occurs only for surface samples. Note that TN is not explicitly measured but reported as the

[1] U.S. Environmental Protection Agency. 2019. Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin. U.S. Environmental Protection Agency, Office of Water, EPA- 822-R-19-001.

[2] South Carolina Department of Health and Environmental Control. Regulations 61-68 Water Classifications and Standards.

[3] South Carolina Department of Health and Environmental Control. 2021. 2021 South Carolina Cyanotoxin Distribution Project. Bureau of Water Technical Report No. 005-2023. June 2023.

sum of Total Kjeldahl Nitrogen (TKN, sum of ammonia/ammonium and organic nitrogen) and nitrate/nitrite.

Total phosphorus and total nitrogen concentrations were on average highest at SV-268 (Tables 10 and 11, Figures 15 and 16). Nutrient concentrations at the surface generally decrease from the upper reaches of the lake arm to the downstream area and open lake. Ten of 15 TP measurements at SV-268 exceeded the state ecoregional standard of 0.06 mg/L. One TP exceedance was measured at SV-838 and all other surface measurements were <0.06 mg/L throughout the study area. Only one TN surface standard exceedance (state standard = 1.5 mg/L) was recorded at SV-268. Subsurface nutrient concentrations were generally higher than surface values at SV-839 and SV-374 (Figures 15 and 16). TOC concentrations were largely similar site-by-site with average and median values of ~2-3 mg/L (Figure 17).

Table 9. Total phosphorus summary statistics for all sites and depths. 'SV-839-bottom' sample depths range from 2.5–4.5 m depending on total water column depth. 'SV-374-mid' includes all mid-water column samples at the site and range from 8–9 m depending on total water column depth. 'SV-374-bottom' includes all bottom water samples ranging from 15–16.5 m depending on total water column depth. For concentrations below the analytical detection limit (0.02 mg/L), a value of one-half the detection limit was substituted (0.01 mg/L). All units in mg/L.

Site	Avg. Total Phosphorus	Minimum	Maximum	n
SV-268	0.08 ± 0.02	0.04	0.12	15
SV-838	0.04 ± 0.01	0.01	0.06	15
SV-839	0.02 ± 0.01	0.01	0.05	15
SV-839-bottom	0.02 ± 0.01	0.01	0.05	15
SV-374	0.01 ± 0.00	0.01	0.03	15
SV-374-mid	0.02 ± 0.02	0.01	0.10	15
SV-374-bottom	0.02 ± 0.01	0.01	0.04	15
SV-840	0.01 ± -	0.01	0.01	15

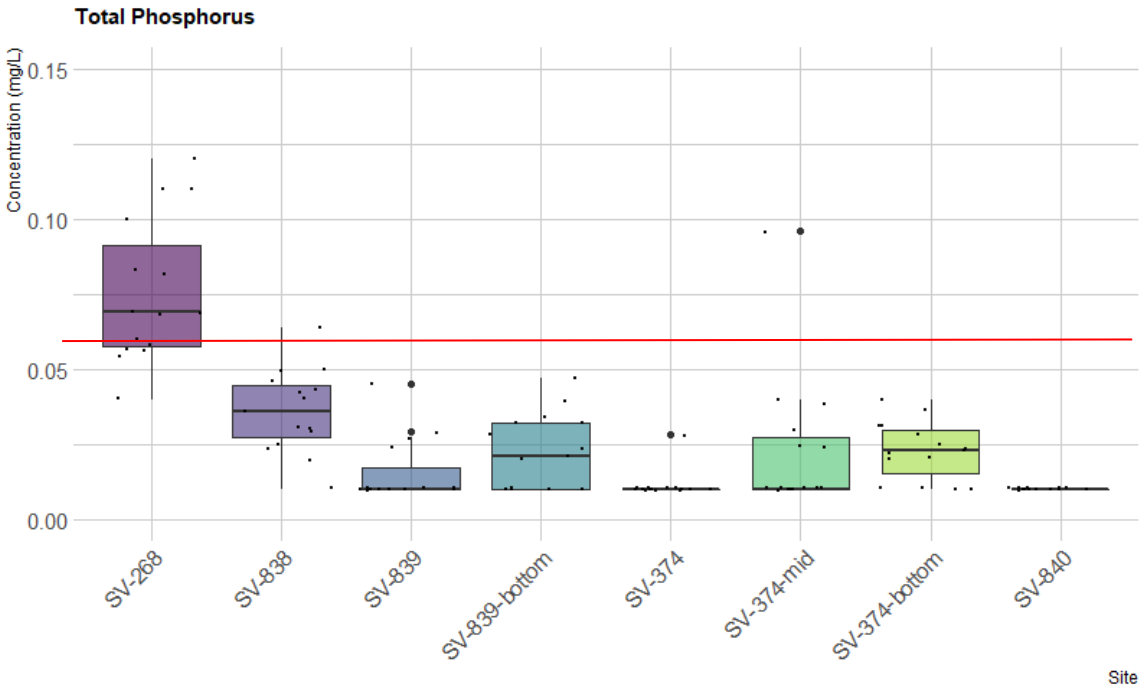


Figure 15. Box plot summary of total phosphorus concentrations (mg/L) measured at each lake site. 'SV-839-bottom' sample depths range from 2.5–4.5 m depending on total water column depth. 'SV-374-mid' includes all mid-water column samples at the site and range from 8–9 m depending on total water column depth. 'SV-374-bottom' includes all bottom water samples ranging from 15–16.5 m depending on total water column depth. For concentrations below the analytical detection limit (0.02 mg/L), a value of one-half the detection limit was substituted (0.01 mg/L). Box plots include median, first (lower) and third (upper) quartiles, and ranges (minimum and maximum) for the data. The red line denotes the 0.06 mg/L lake ecoregional total phosphorus standard.

Table 10. Total nitrogen summary statistics for all sites and depths. 'SV-839-bottom' sample depths range from 2.5–4.5 m depending on total water column depth. 'SV-374-mid' includes all mid-water column samples at the site and range from 8–9 m depending on total water column depth. 'SV-374-bottom' includes all bottom water samples ranging from 15–16.5 m depending on total water column depth. For concentrations below the analytical detection limit (0.1 mg/L for TKN and 0.02 mg/L for nitrate/nitrite), a value of one-half the detection limit was substituted (0.05 mg/L for TKN and 0.01 mg/L for nitrate-nitrite). All units in mg/L.

Site	Avg. Total Nitrogen	Minimum	Maximum	n
SV-268	1.00 ± 0.26	0.66	1.61	15
SV-838	0.44 ± 0.28	0.09	0.91	15
SV-839	0.27 ± 0.16	0.06	0.56	15
SV-839-bottom	0.34 ± 0.20	0.06	0.60	15
SV-374	0.28 ± 0.18	0.06	0.62	15
SV-374-mid	0.46 ± 0.23	0.06	0.86	14
SV-374-bottom	0.80 ± 0.31	0.15	1.21	13
SV-840	0.22 ± 0.14	0.06	0.46	15

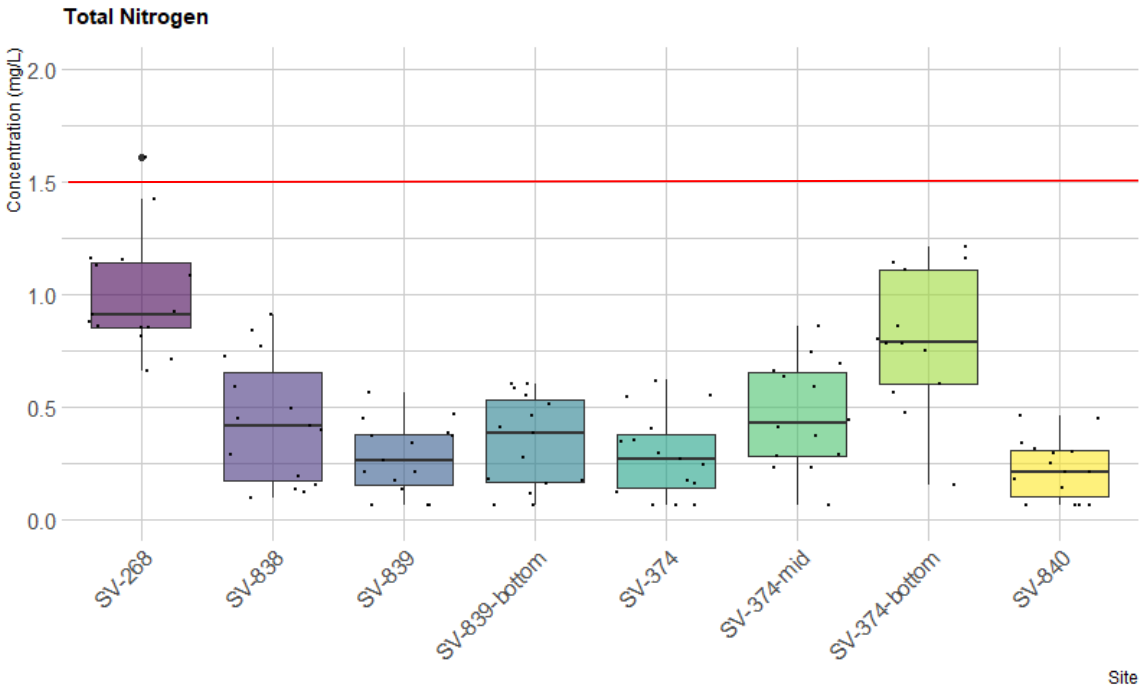


Figure 16. Box plot summary of total nitrogen concentrations (mg/L) measured at each lake site. Total nitrogen is reported as the sum of Total Kjeldahl Nitrogen and nitrate-nitrite. 'SV-839-bottom' sample depths range from 2.5–4.5 m depending on total water column depth. 'SV-374-mid' includes all mid-water column samples at the site and range from 8 –9 m depending on total water column depth. 'SV-374-bottom' includes all bottom water samples ranging from 15–16.5 m depending on total water column depth. For concentrations below the analytical detection limit (0.1 mg/L for TKN and 0.02 mg/L for nitrate/nitrite), a value of one-half the detection limit was substituted (0.05 mg/L for TKN and 0.01 mg/L for nitrate-nitrite). Box plots include median, first (lower) and third (upper) quartiles, and ranges (minimum and maximum) for the data. The red line denotes the 1.5 mg/L lake ecoregional total nitrogen standard.

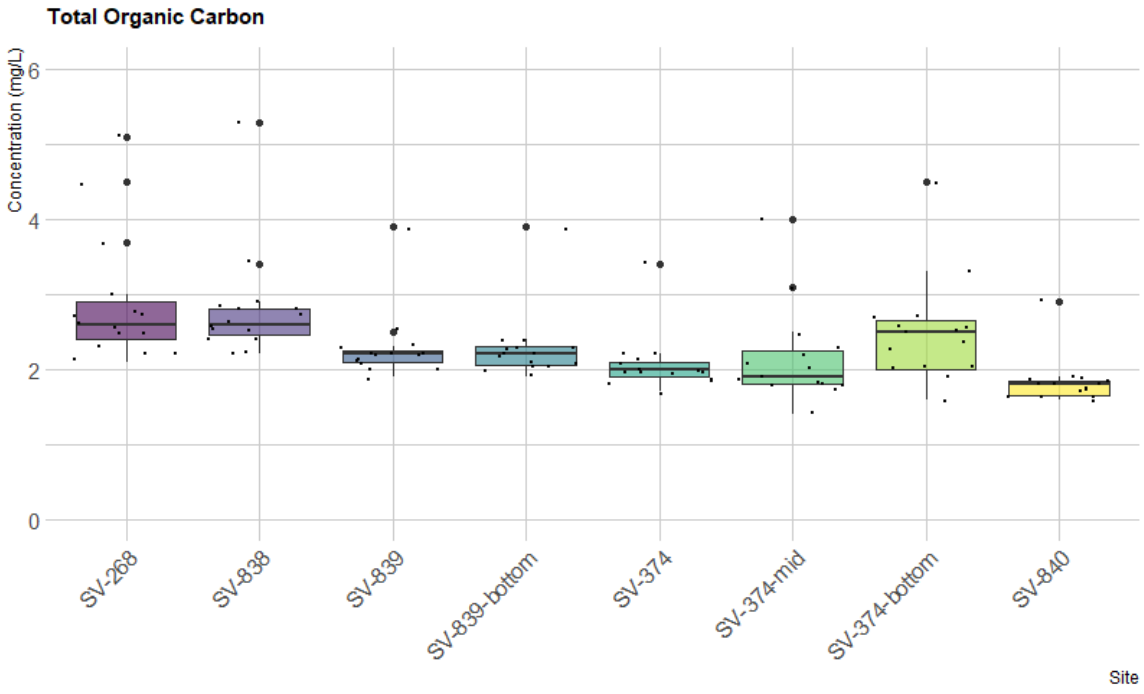


Figure 17. Box plot summary of total organic carbon concentrations (mg/L) measured at each lake site. 'SV-839-bottom' sample depths range from 2.5–4.5 m depending on total water column depth. 'SV-374-mid' includes all mid-water column samples at the site and range from 8–9 m depending on total water column depth. 'SV-374-bottom' includes all bottom water samples ranging from 15–16.5 m depending on total water column depth. Box plots include median, first (lower) and third (upper) quartiles, and ranges (minimum and maximum) for the data.

Conclusion

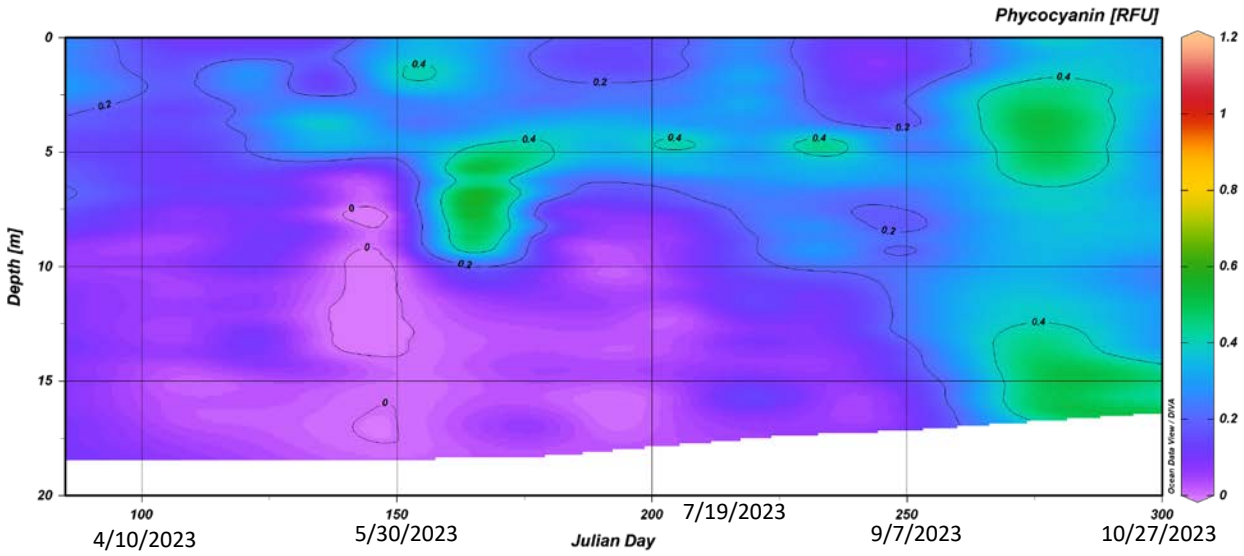
The results of this project revealed important features in the vertical structure of the water column in the Eighteenmile Creek lake arm. Response parameters such as dissolved oxygen and pH may be influenced by both physical conditions and phytoplankton growth. Key differences were observed in the continuous monitoring records at SV-839 and SV-839. Temperature in the upper lake arm (SV-838) was subjected to pulses in cooler stream water. The upper lake arm also cooled more quickly in the fall than the mid-lake arm area (SV-839). The upper lake arm was also a higher dissolved oxygen and pH environment, possibly influenced by higher phytoplankton biomass. The lake arm demonstrated a chlorophyll-a gradient with higher concentrations in the upper lake arm and lower values nearer the open lake. While nutrient concentrations were relatively low in the lake arm, a similar gradient was apparent for both total phosphorus and total nitrogen. The aggregated results of this study and accompanying watershed nutrient loading studies will provide a robust data set to develop, calibrate, and validate coupled watershed loading and lake water quality models to inform TMDLs for this area of Lake Hartwell.

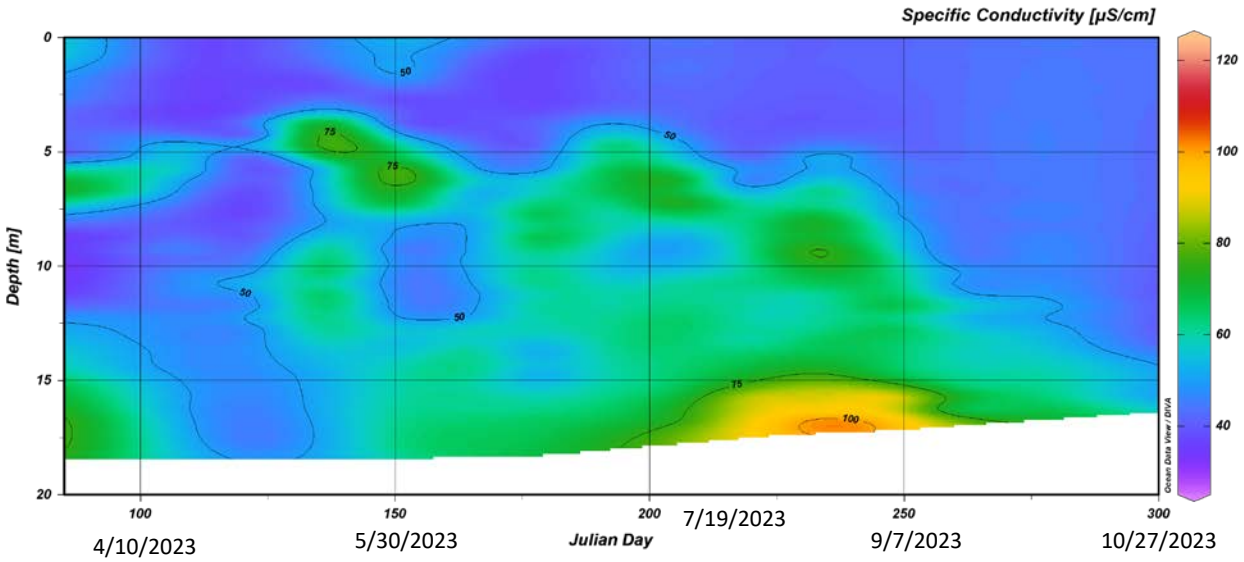
Acknowledgments

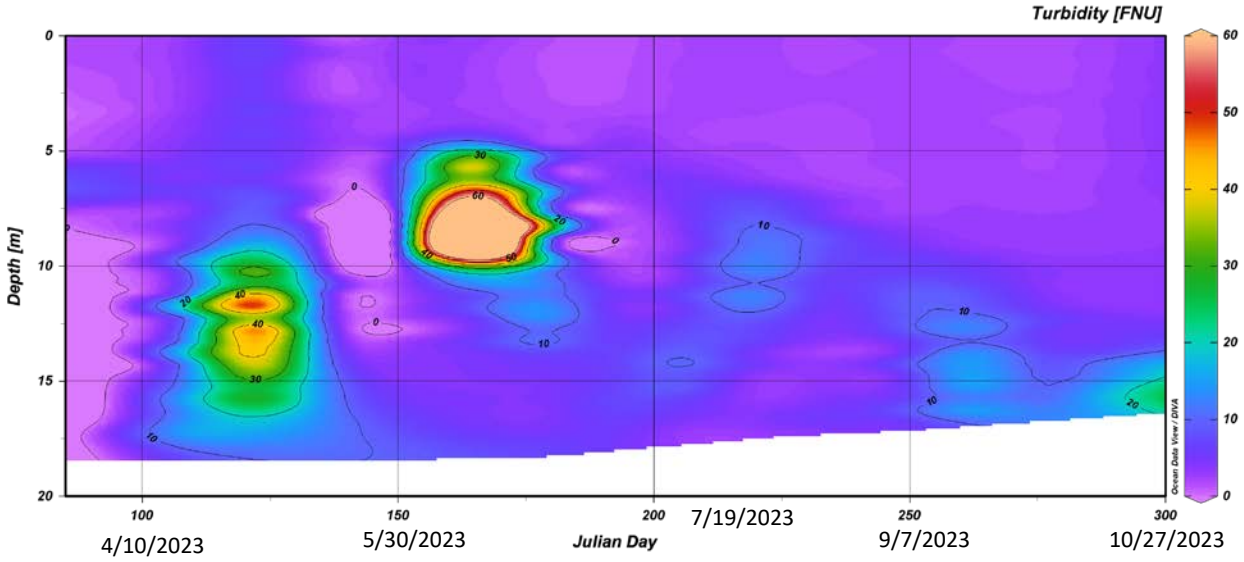
This project was made possible through support from DHEC Bureau of Water (BOW) TMDL group as well as Quality Assurance programs from the DHEC BOW and Bureau of Environmental Health Services (BEHS). The BEHS laboratory processed and analyzed water quality samples. Total chlorophyll-a and cyanotoxin samples were processed and analyzed by the BOW Aquatic Science Programs (ASP). Field sampling was conducted by personnel from the BOW TMDL and ASP groups.

Appendix A – Vertical Profile Section Graphs

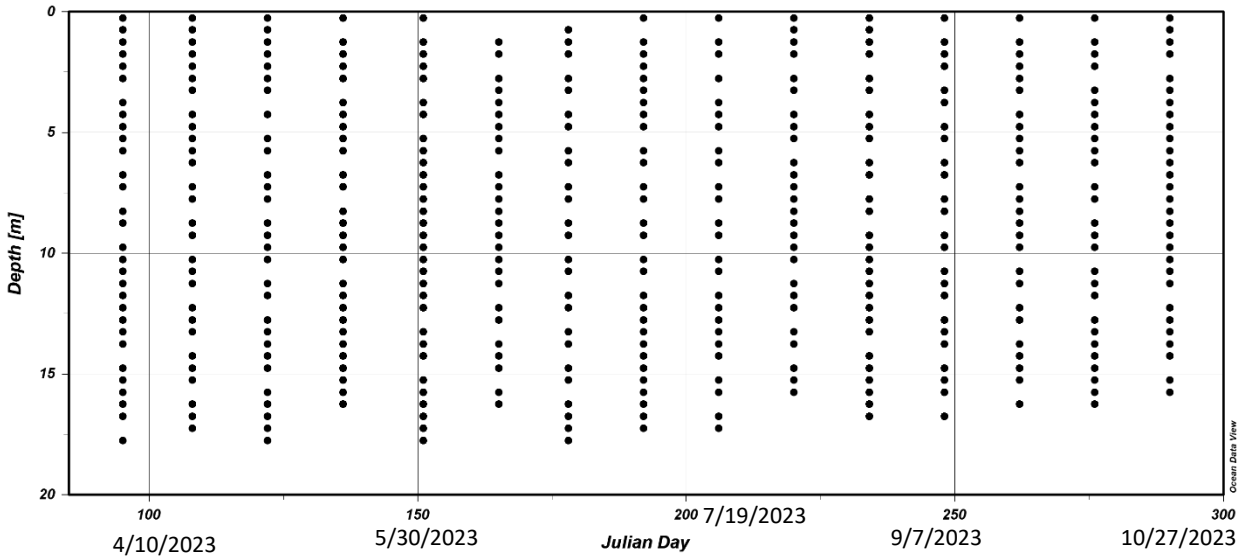
S-374 – additional section plots – average total depth = 17.5 m



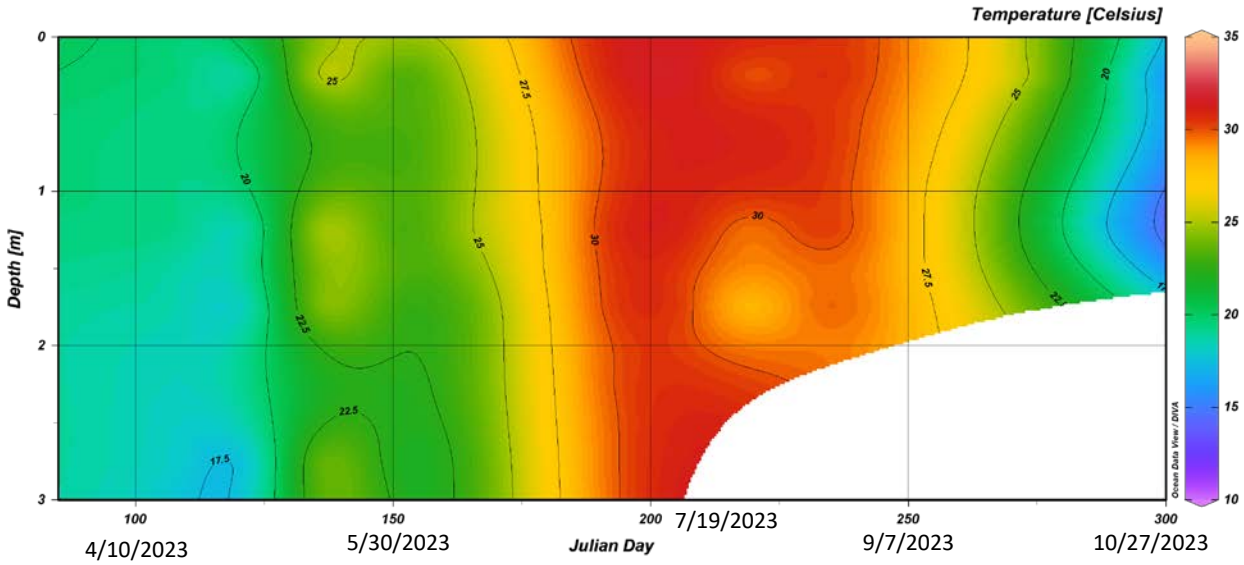


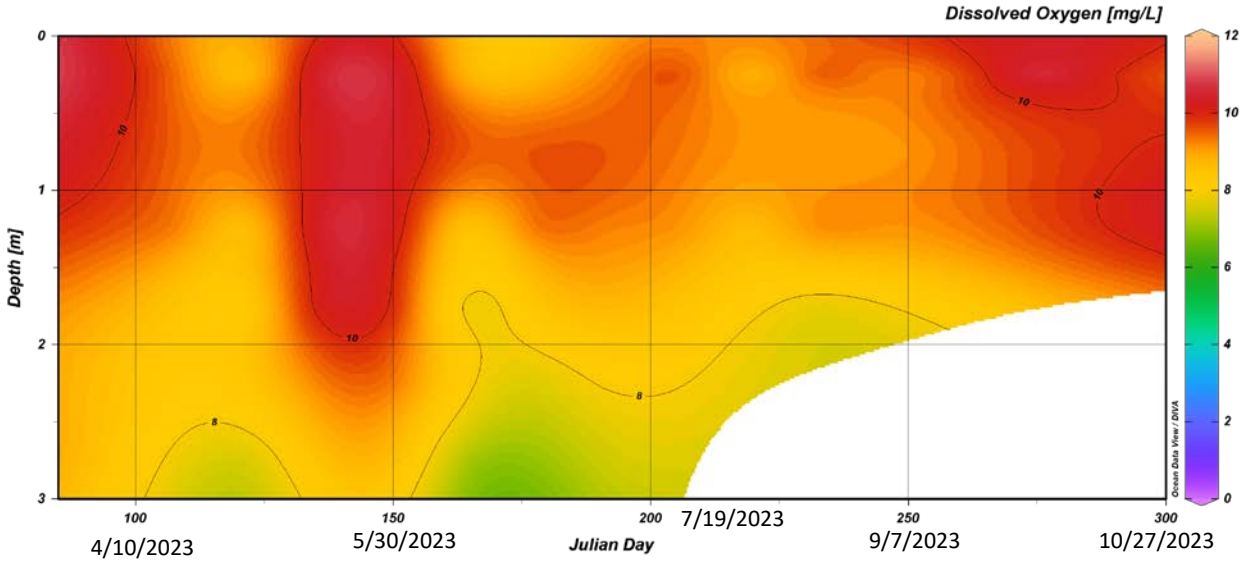


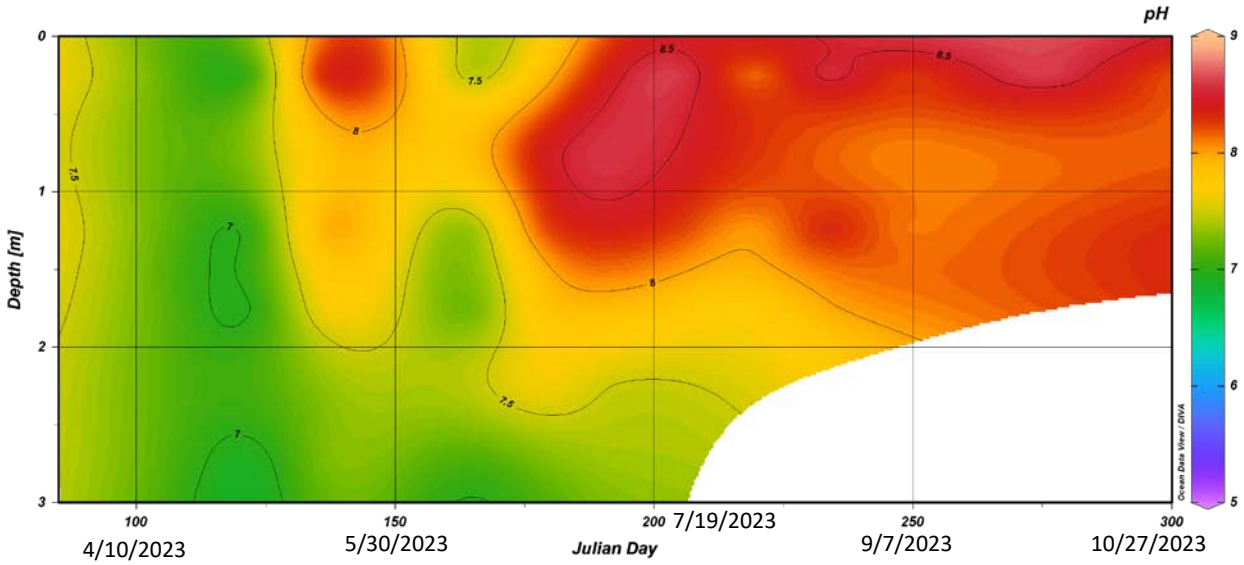
Off-scale turbidity spike on 6/14/2023 (depth ~6-9 m). Maximum values in this band were ~130 FNU.



S-838 – average total depth = 2.3 m



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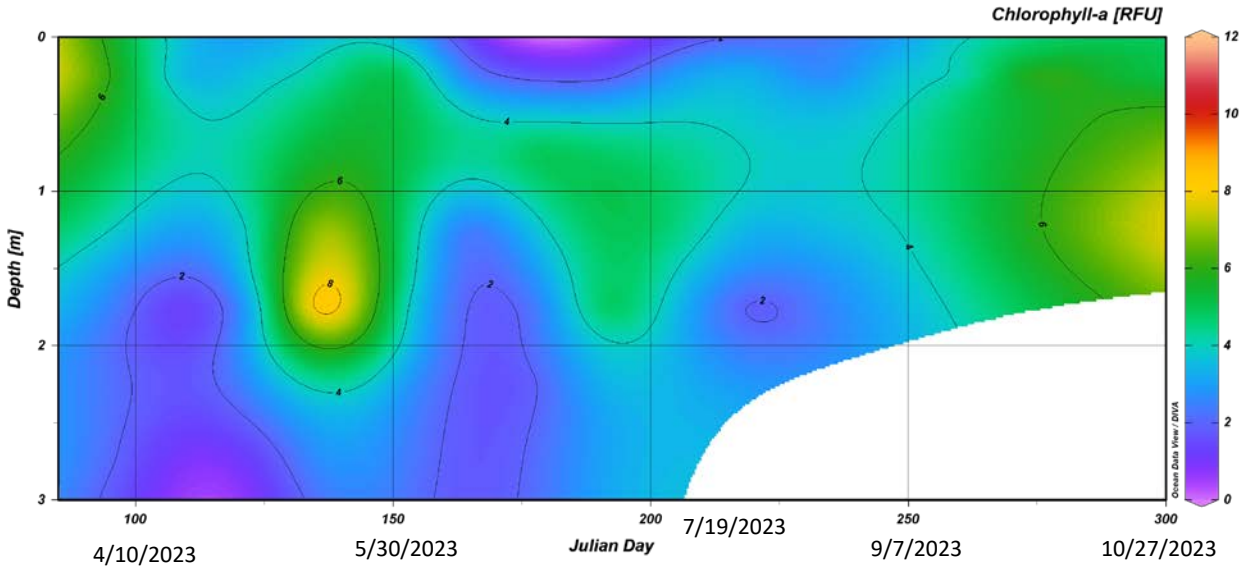
5/30/2023
7/19/2023
9/7/2023
10/27/2023


Chlorophyll-a [RFU]
Depth [m]
Julian Day
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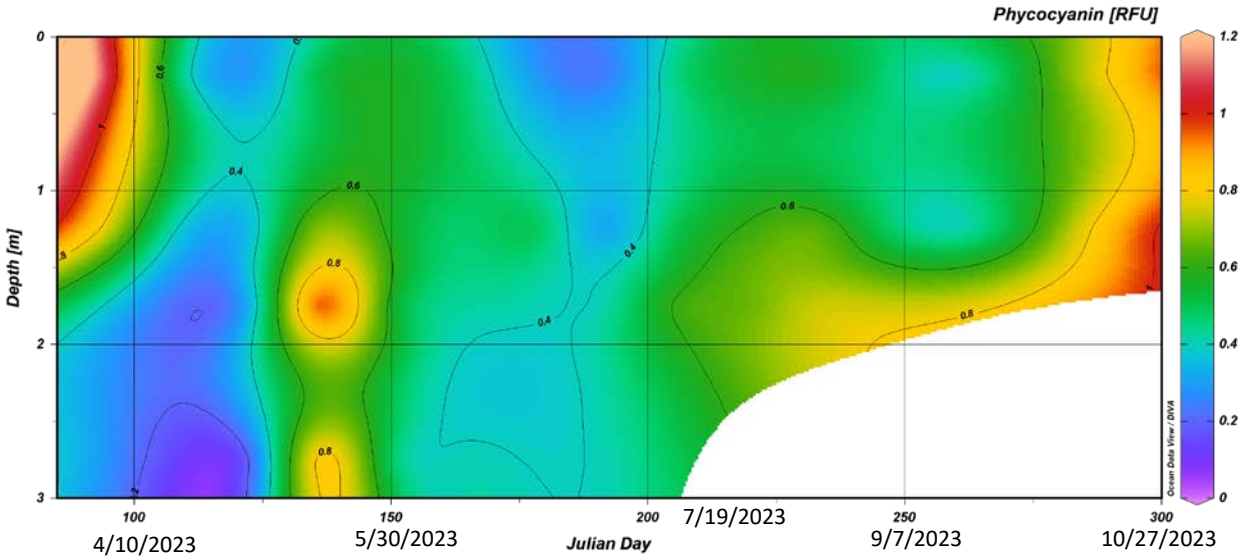
9/7/2023
10/27/2023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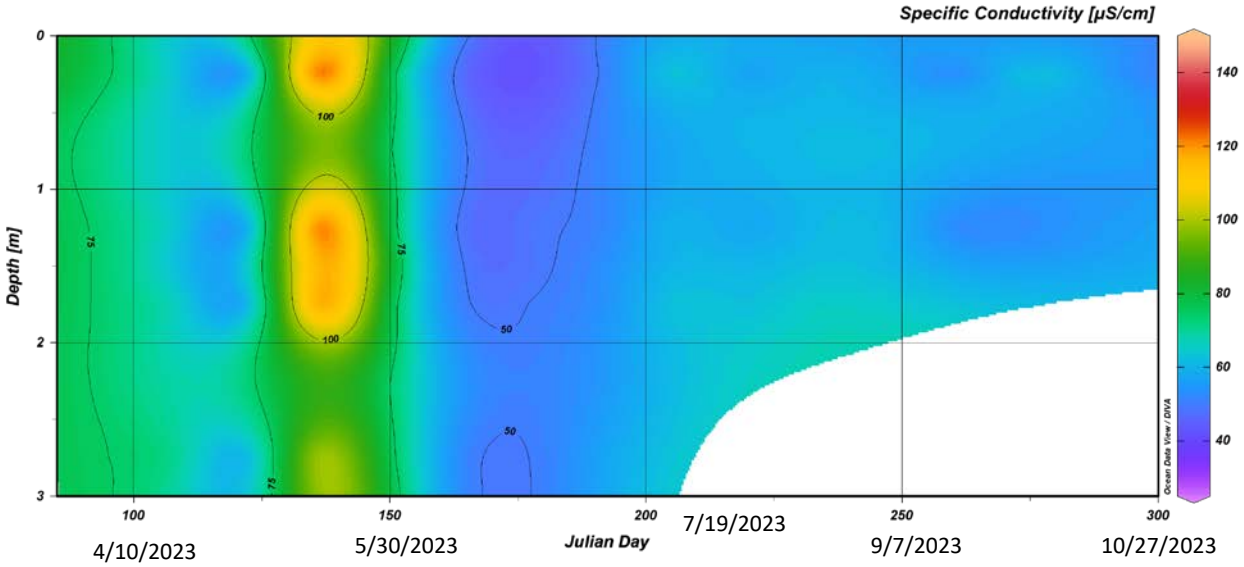
Ocean Data View / DIVA


Specific Conductivity [µS/cm]
Depth [m]
Julian Day
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5/30/2023
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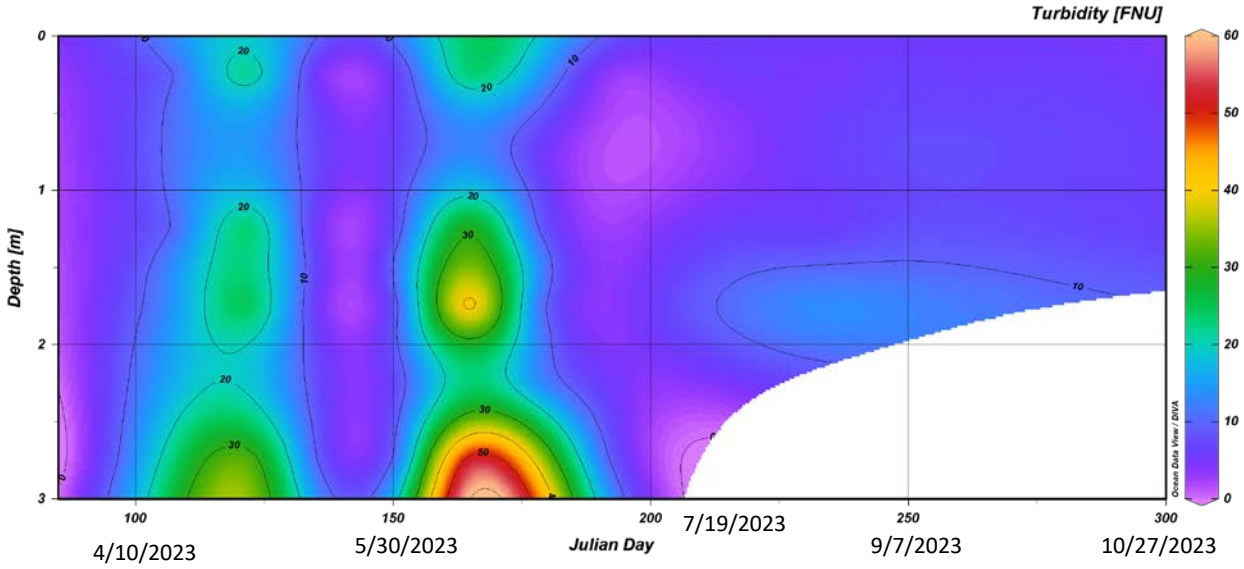
9/7/2023
10/27/2023
Ocean Data View / DIVA


Turbidity [FNU]
Depth [m]
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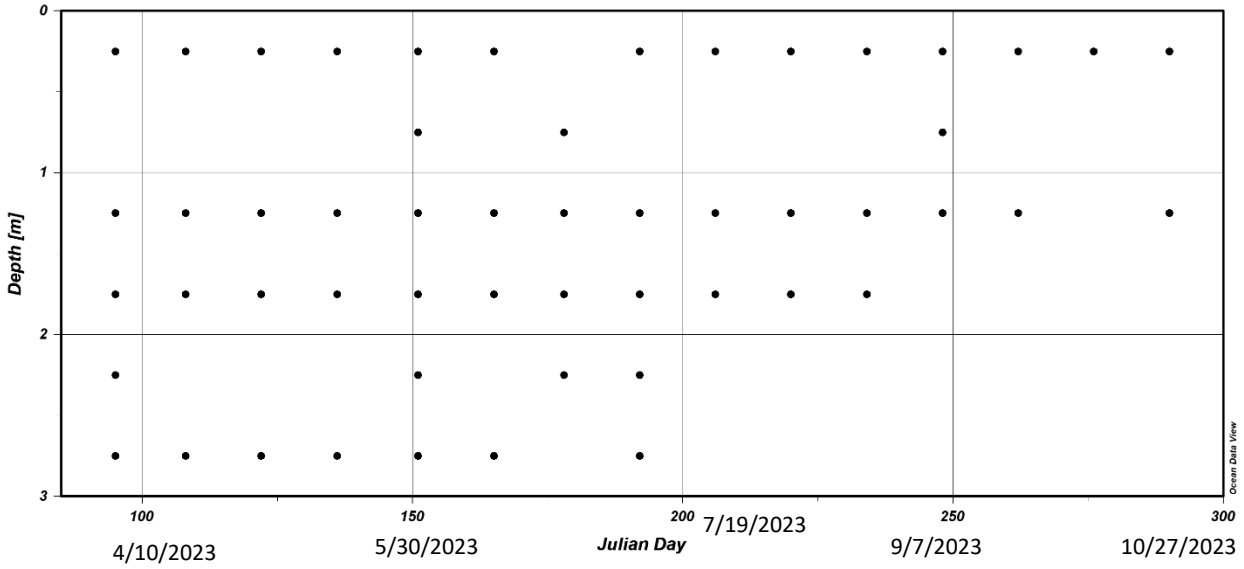
Ocean Data View / DIVA


Depth [m]
Julian Day
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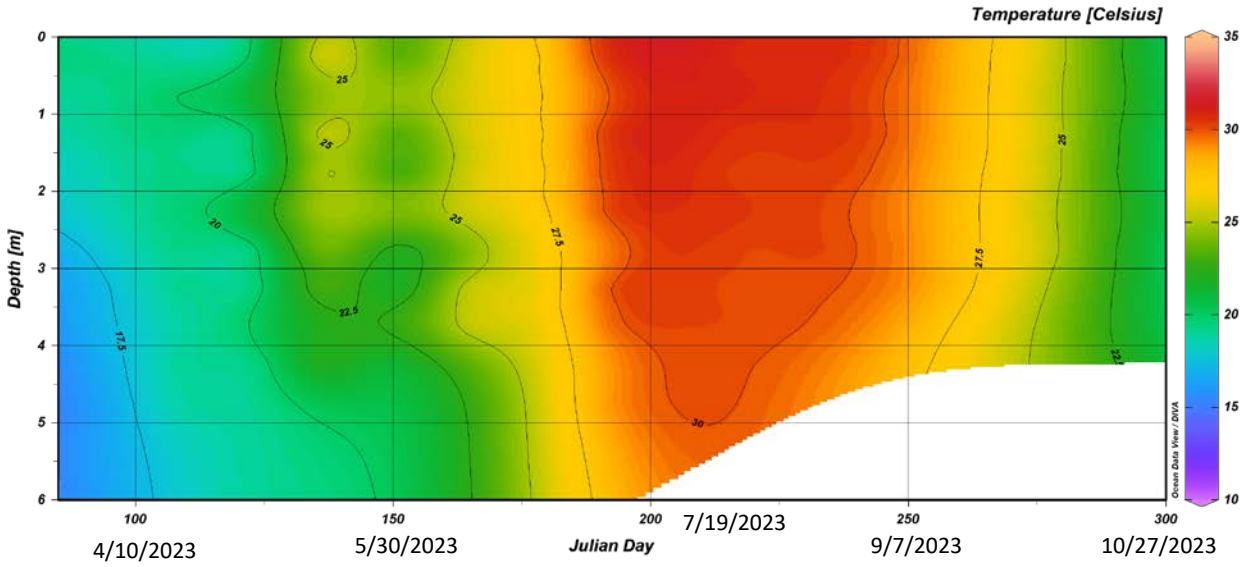
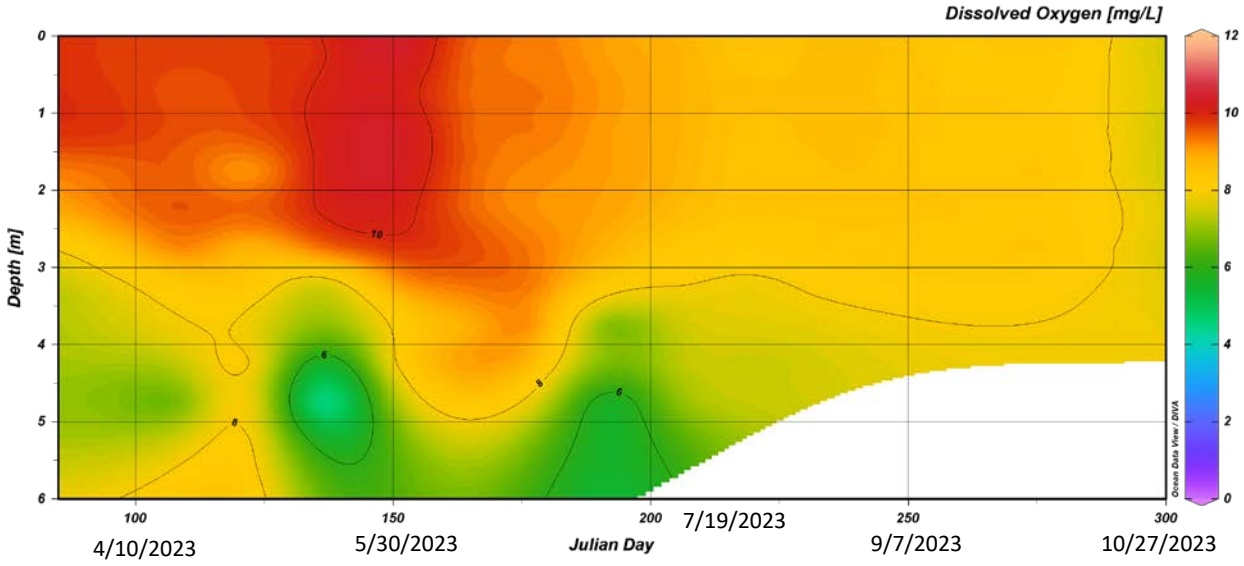
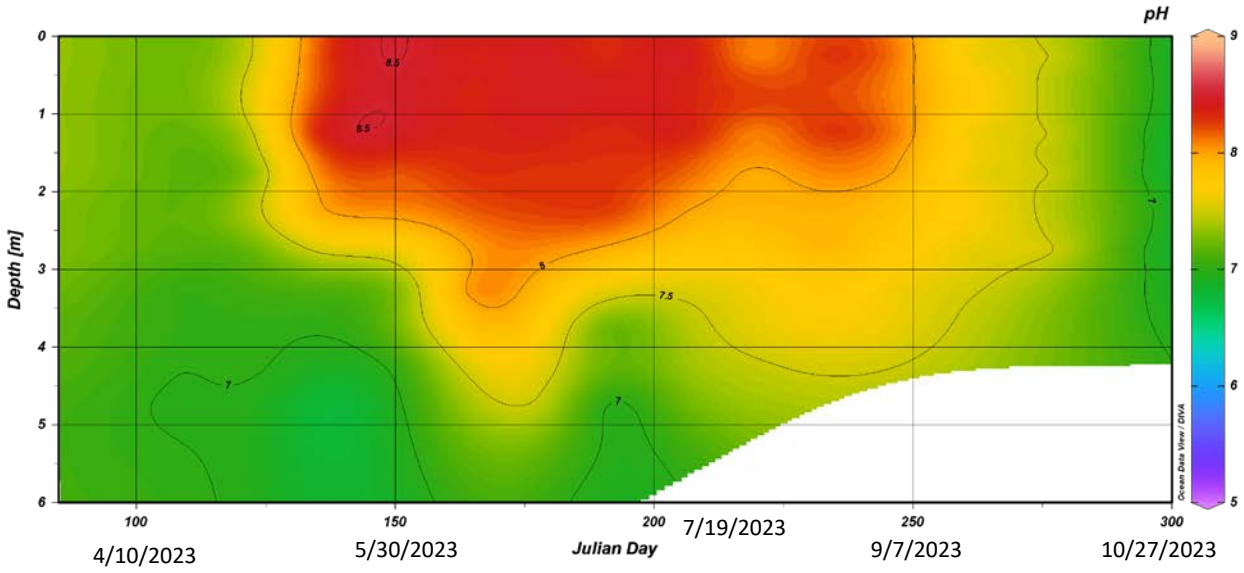
10/27/2023
Ocean Data View

S-839 – average total depth = 4.9 m



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Julian Day
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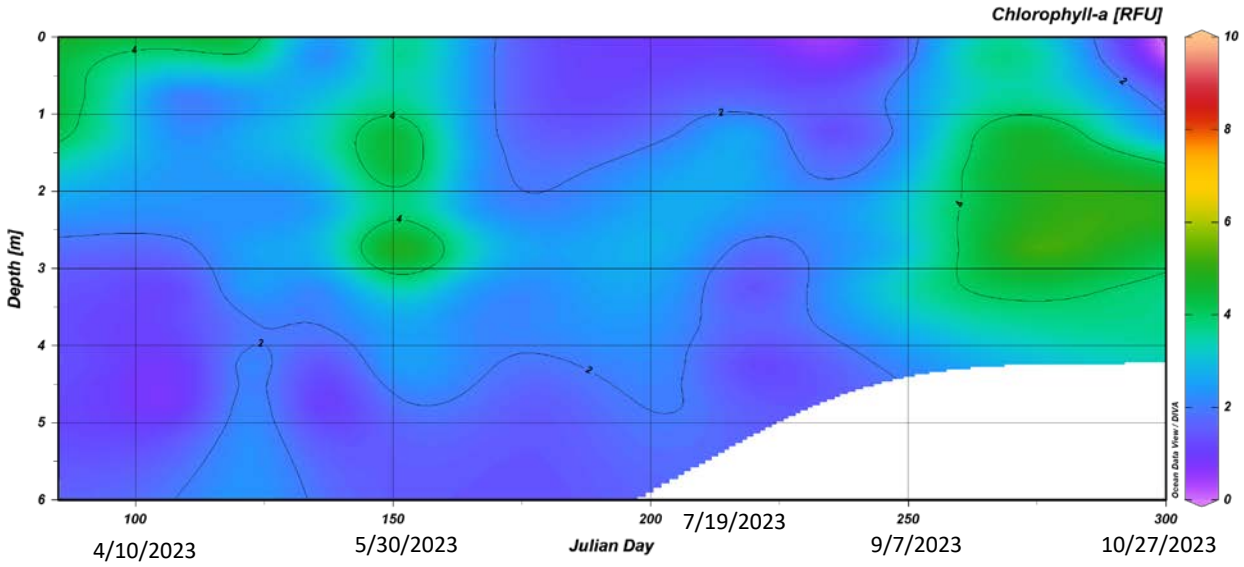
7/19/2023
9/7/2023
10/27/2023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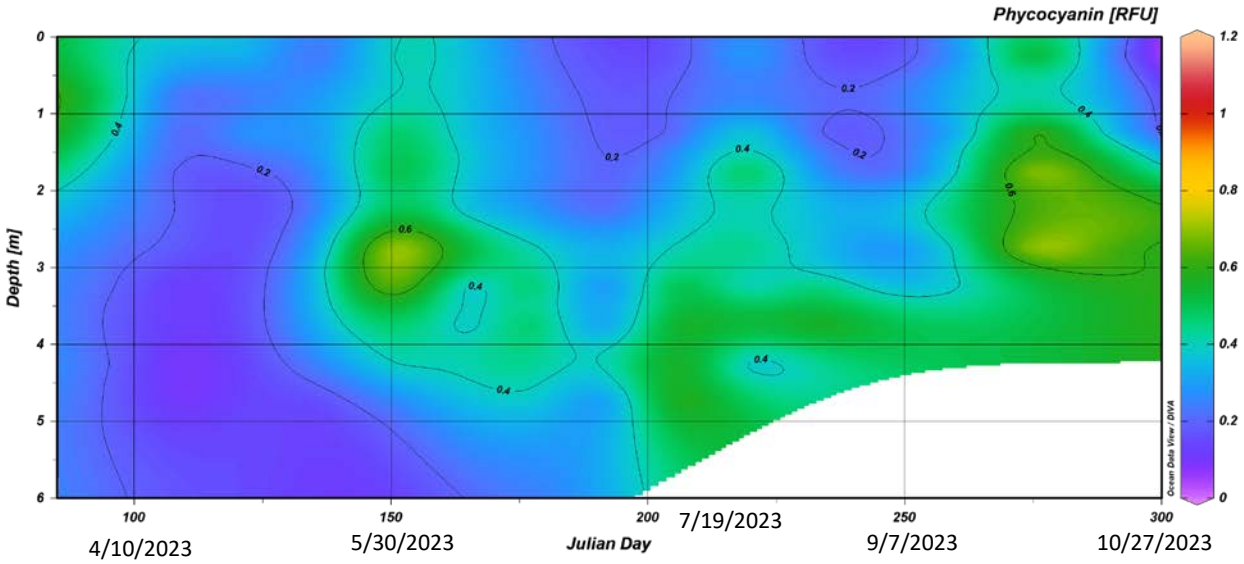
Phycocyanin [RFU]
Depth [m]
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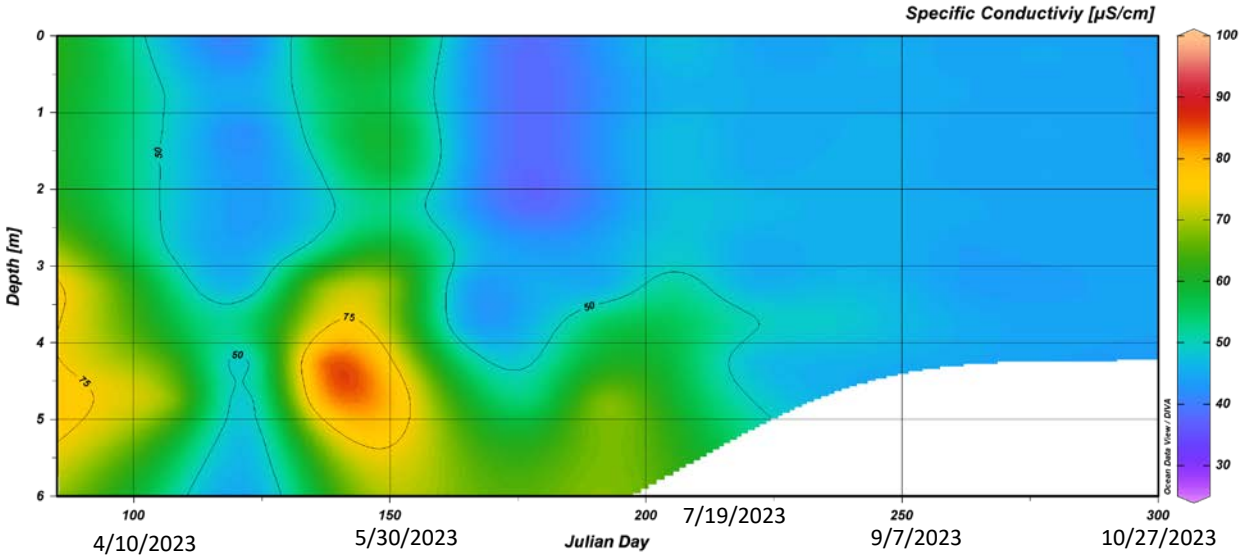
Ocean Data View / DIVA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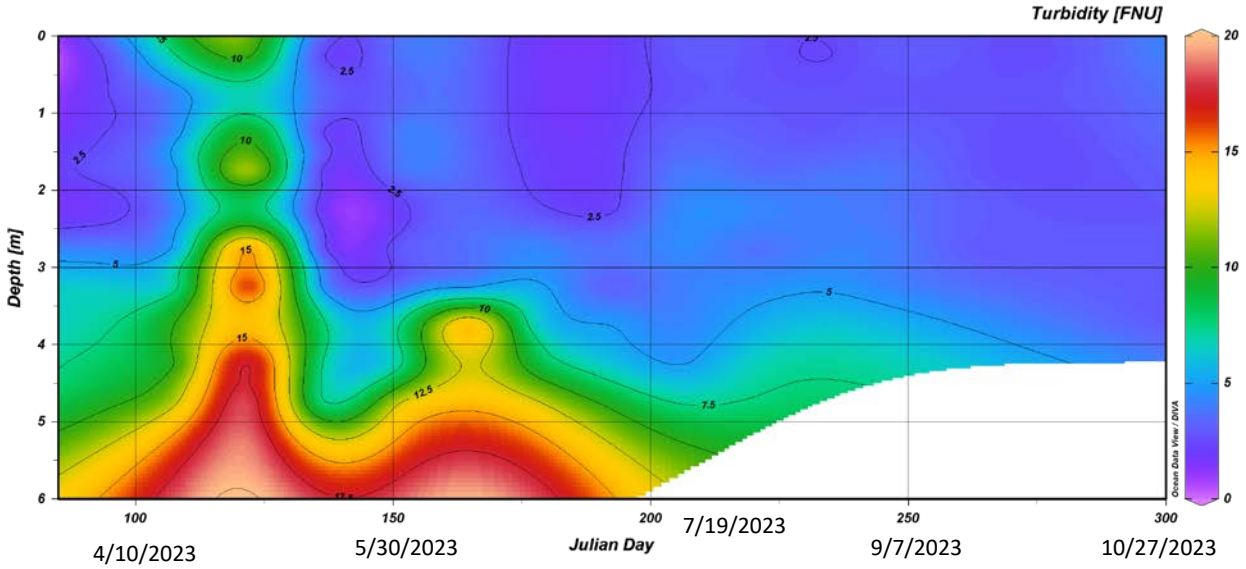
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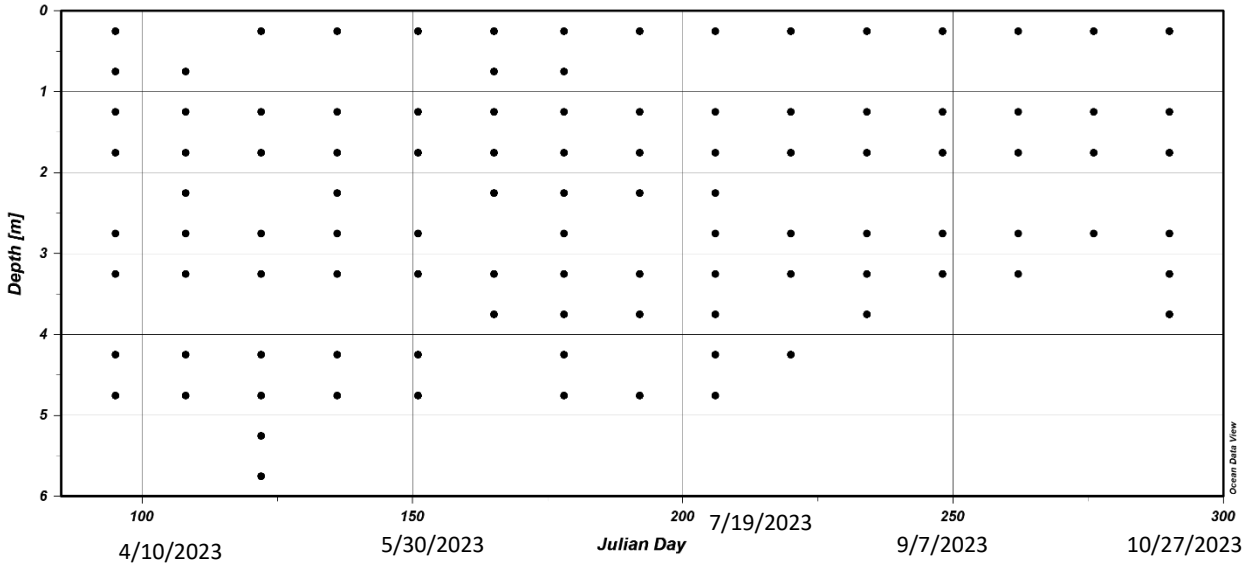
Depth [m]
Julian Day
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7/19/2023
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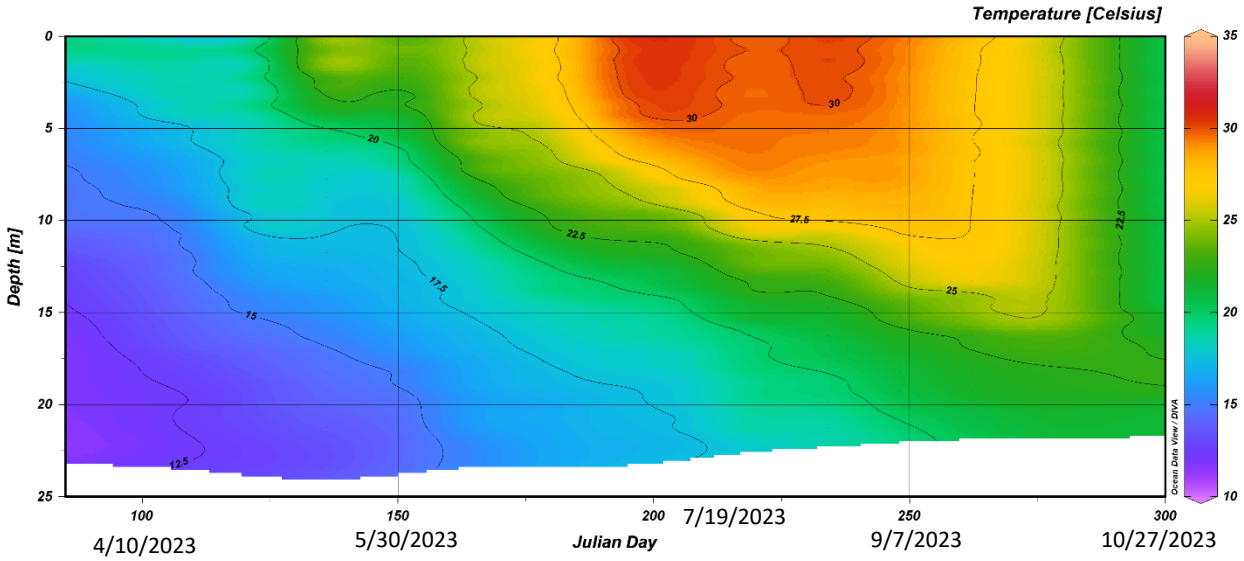
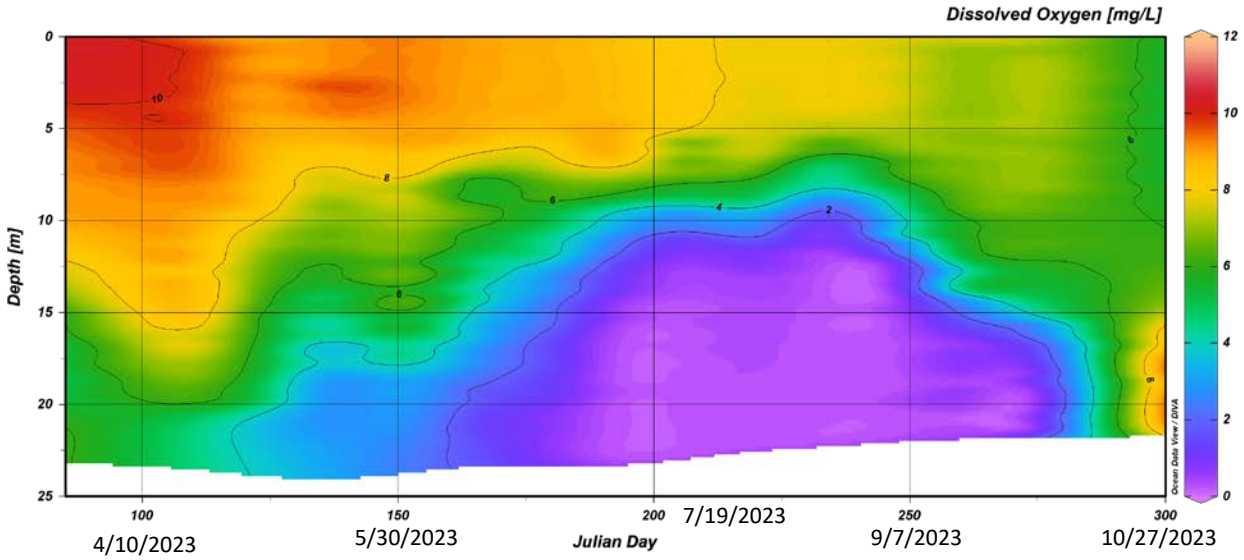
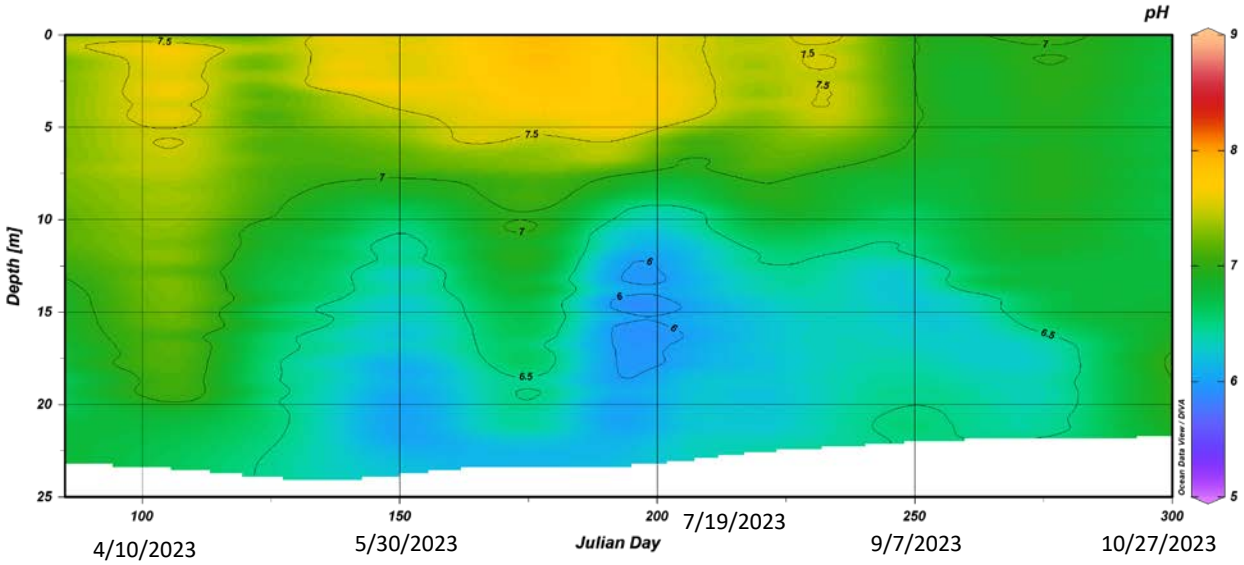
10/27/2023

S-840 – average total depth = 22.2 m



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Julian Day
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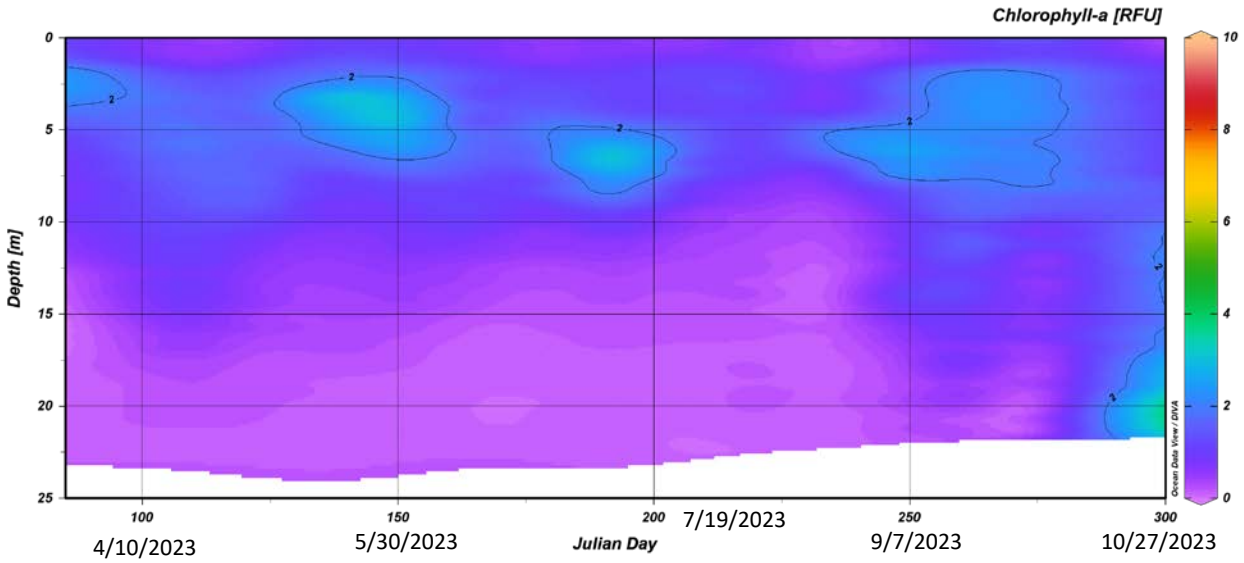
Ocean Data View / DIVA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8
6
4
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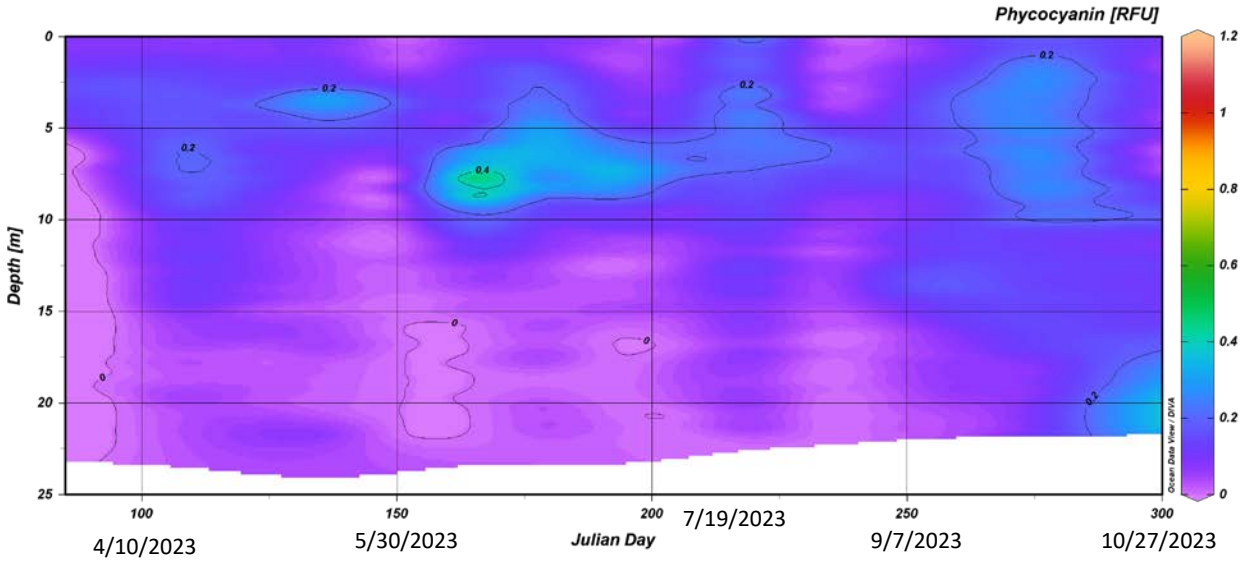
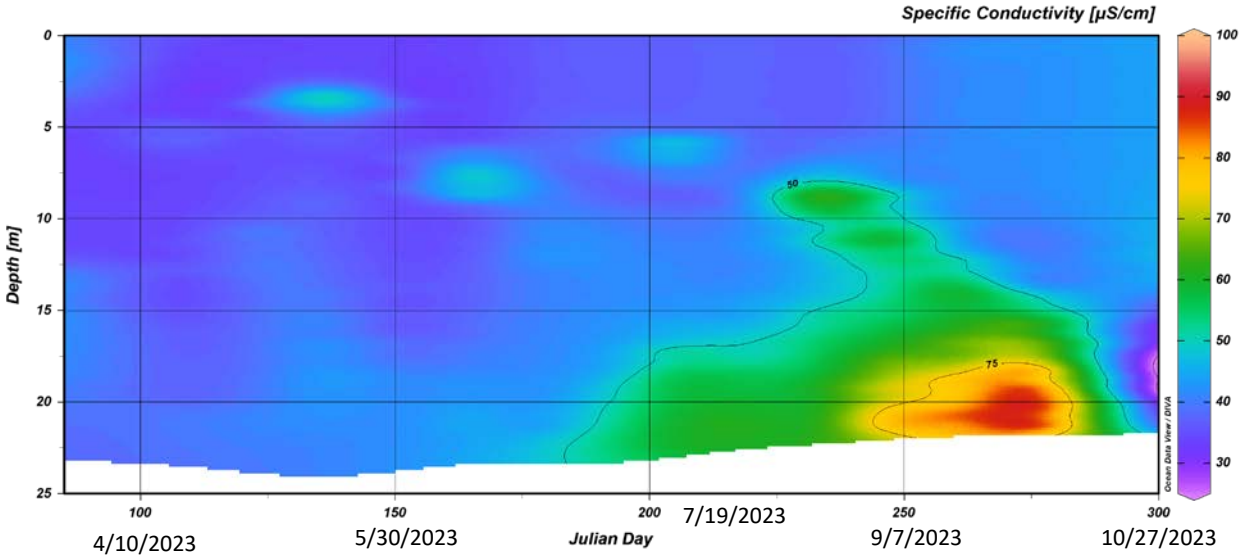
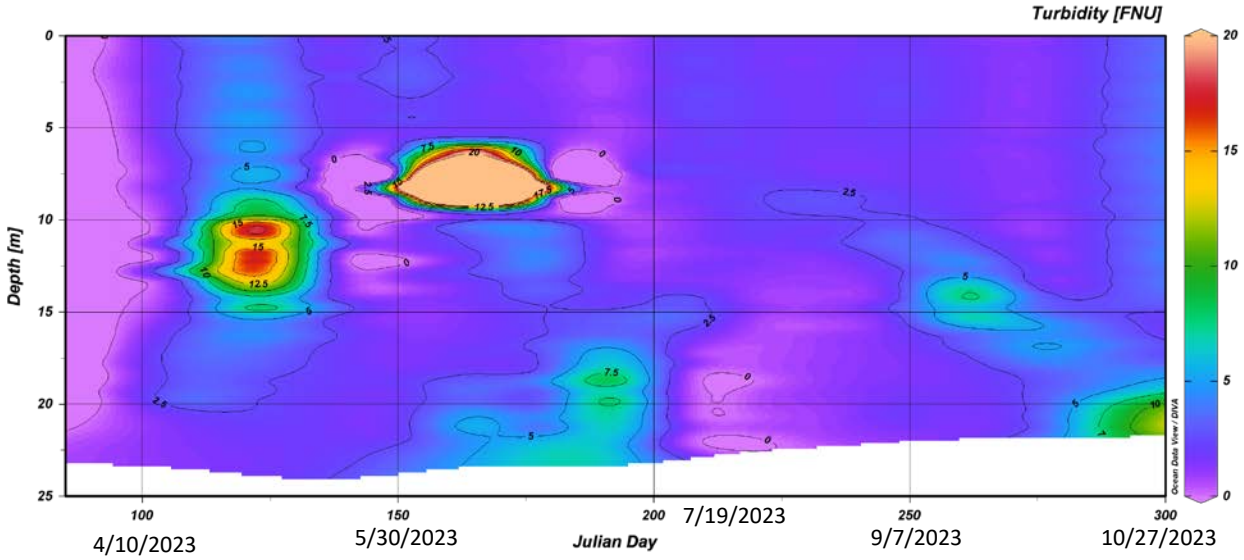
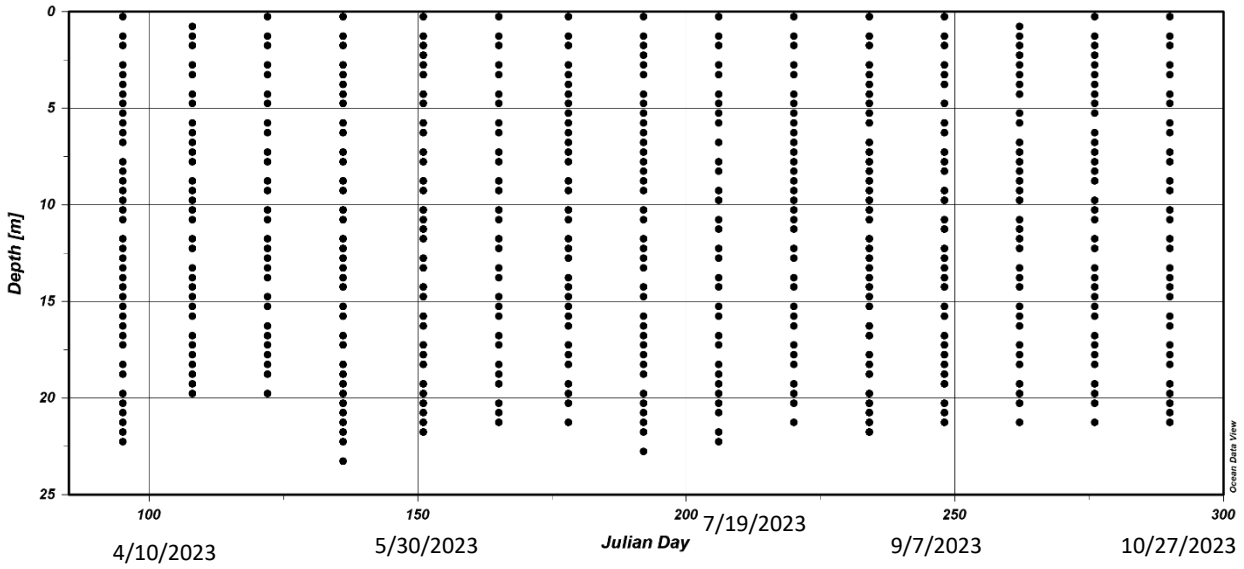
0
Ocean Data View / DIVA


Phycocyanin [RFU]
Depth [m]
Julian Day
4/10/2023
5/30/2023
7/19/2023
9/7/2023
10/27/2023


Specific Conductivity [µS/cm]
Depth [m]
Julian Day
4/10/2023
5/30/2023
7/19/2023
9/7/2023
10/27/2023

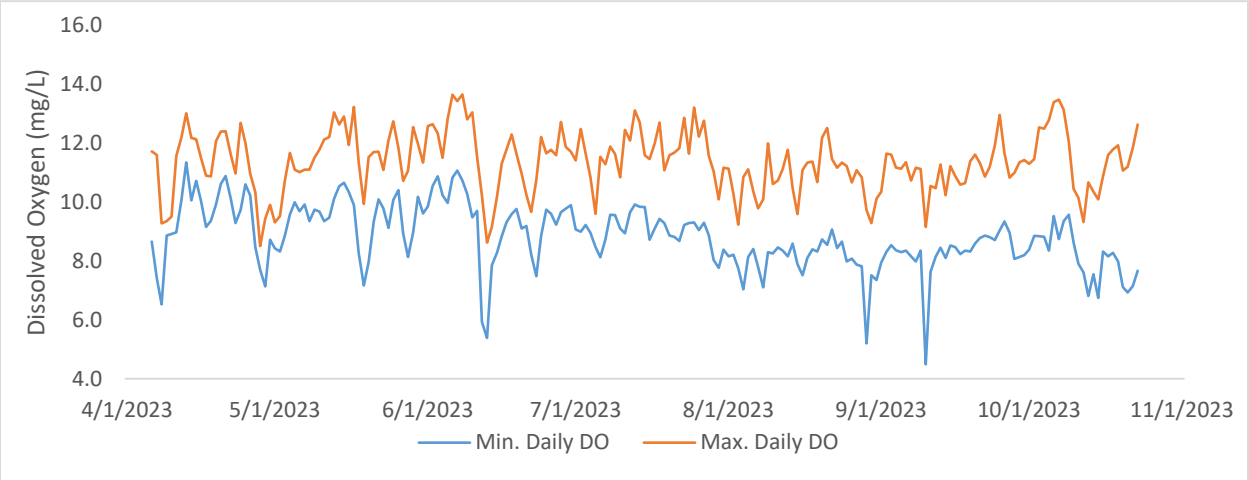


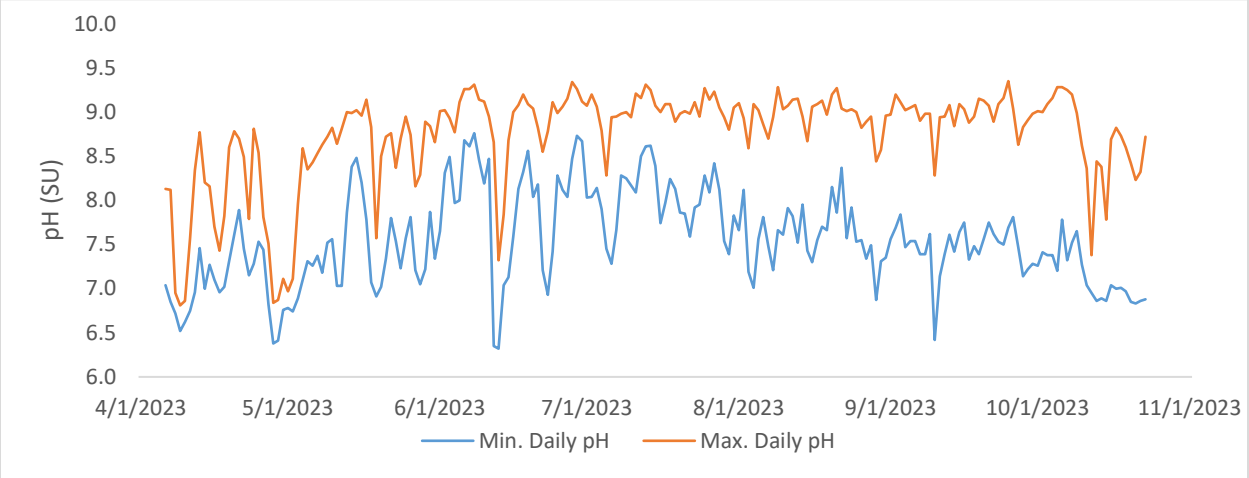
Off-scale turbidity spike on 6/14/2023 (depth ~6-9 m). Maximum values in this band were ~115 FNU.



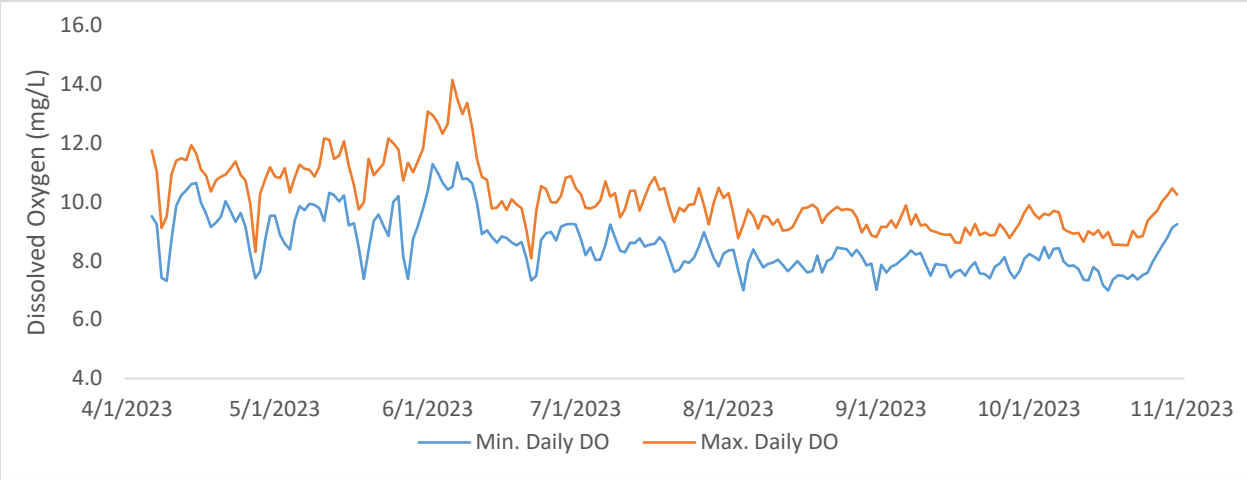
Appendix B – Surface Continuous Monitoring Time-series Plots

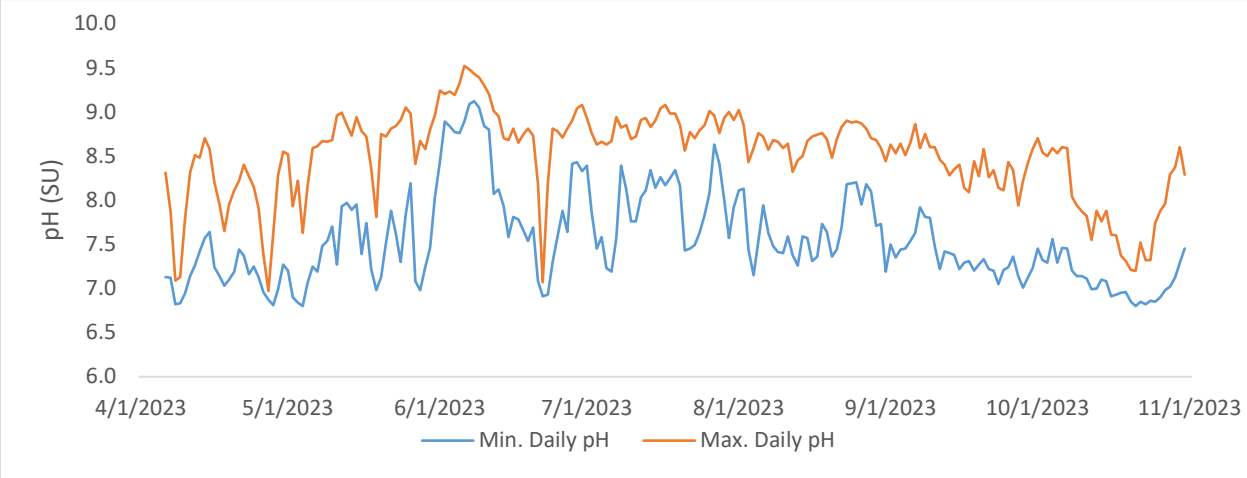
SV-838 – additional continuous monitoring plots





SV-839 – additional continuous monitoring plots





SV-838 and SV-839 Combined – additional continuous monitoring plots