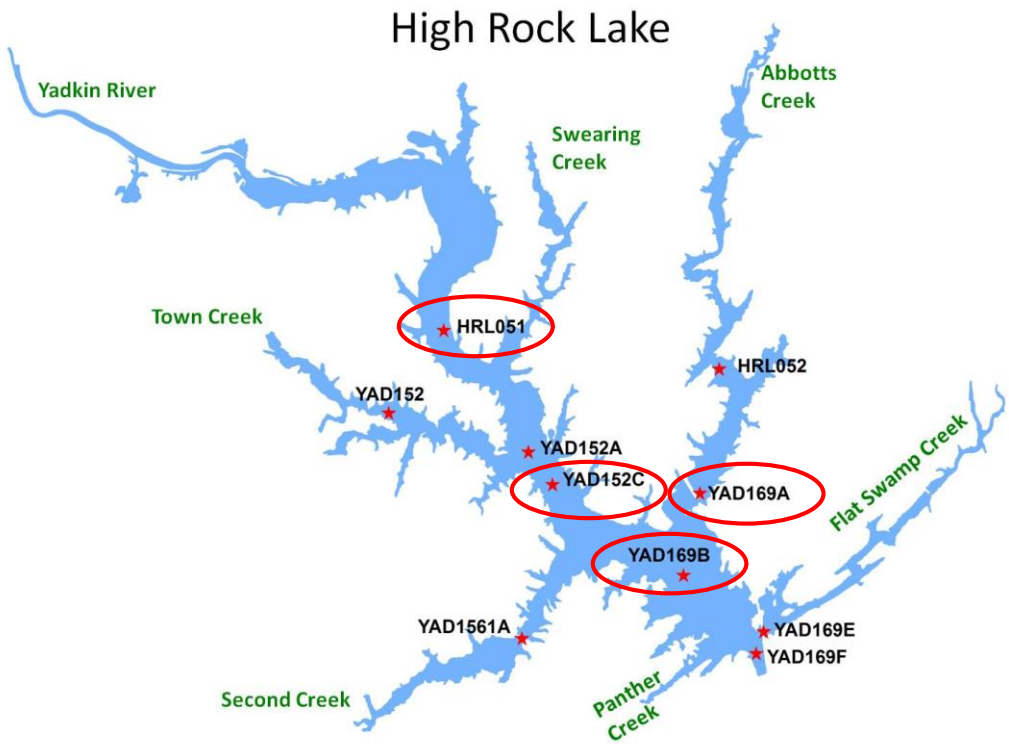
MEMORANDUM

Subject: High Rock Lake Summer 2016 Continuous Data Summary
To: Pam Behm, Modeling and Data Assessment Branch (MAB), Division of Water Resources(DWR)
From: Jing Lin and Bonghi Hong, MAB, DWR
Date: March 9, 2017

A continuous monitoring study on High Rock Lake was conducted from July to September 2016 by the Intensive Survey Branch of Division of Water Resources. Data were provided to the Nutrient Criteria Development Scientific Advisory Council (SAC), together with a memo describing the methods used in the study. This summary provides basic statistics and brief analysis regarding the data obtained from the study.

Data were collected from one continuous station (YAD152C) and three roaming stations (YAD169A, YAD169B, and HRL051). These stations are shown in the map below. For station YAD152C, surface mooring/continuous data were normally collected from water depths of 0.5 to 0.6m below water surface and sub-surface mooring/continuous data were normally collected from water depths of around 4m below water surface, below the thermocline. For the roaming stations, surface mooring/continuous data were normally collected from water depths of 0.7 to 0.8m (0.1m for HRL051) below water surface and sub-surface mooring/continuous data were normally collected from water depths of around 4m below water surface, except for HRL051 which was too shallow for a sub-surface deployment.

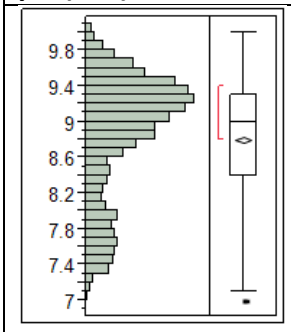
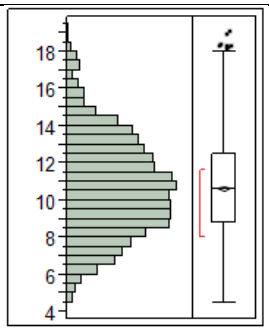
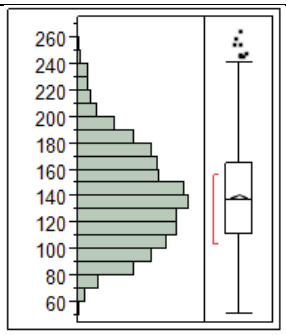
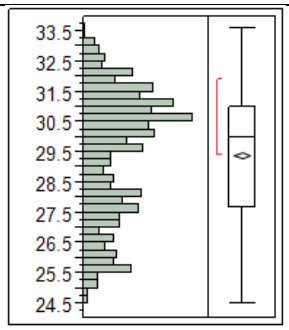


1. **Basic Statistics** (JMP was used for this analysis, histograms and outlier box plots* are also provided)

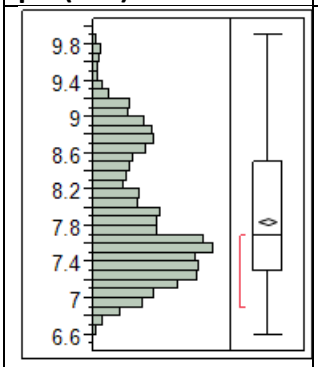
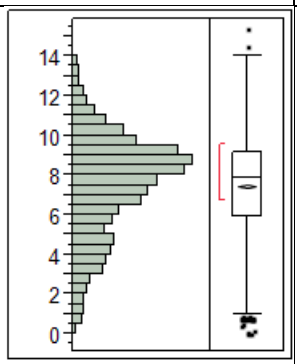
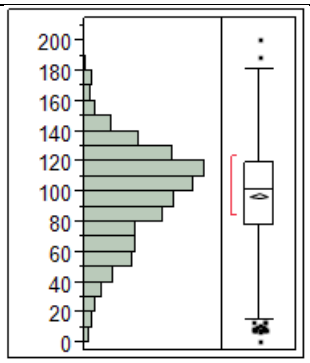
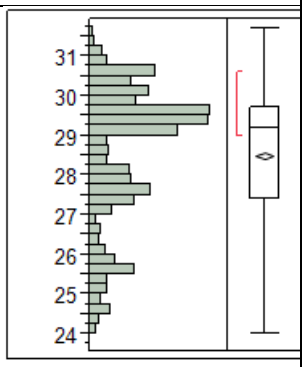
   Distribution of observed pH, DO and temperature exhibited substantial variation across stations and depths. Vertically, for the locations where both the surface and sub-surface observations are available, pH was generally higher at the surface (median pH ranging from 8.5 to 9) than in the sub-surface (7.2-7.7). Extremely high concentrations of DO were frequently observed at the surface, with percent saturation reaching up to 265% at YAD152C. Sub-surface DO concentrations were lower than the surface concentrations, with median concentrations ranging between 3.9 mg/L and 7.9 mg/L. It should be noted though that all the sub-surface measurements were performed around 4m below the surface rather than near the bottom, where the DO concentrations were close to 0 according to the ambient monitoring data. Temperature generally varied to a lesser degree than other variables, with fewer outliers plotted, and showed relatively small differences across stations and depths (although surface temperatures were higher than the sub-surface temperatures).

   Across stations, the deploying periods for the four stations are all different, the numbers of observations (N) included in the statistics are hence different as well. Direct and statistical comparisons of the parameters between all the stations were not conducted. In general, highest values of pH and DO concentrations were observed at station YAD152C. The high pH and DO values at station YAD152C corresponds to high chlorophyll a values we have normally observed there with the Ambient Monitoring Program.

YAD152C surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100.0%	max	10	100.0%	max	19.2	100.0%	max	265	100.0%	max	33.6
99.5%		9.99	99.5%		17.9	99.5%		240	99.5%		33.1
97.5%		9.8	97.5%		16.4	97.5%		220.1	97.5%		32.7
90.0%		9.5	90.0%		14.1	90.0%		188.3	90.0%		31.9
75.0%	Q3	9.3	75.0%	Q3	12.5	75.0%	Q3	164.6	75.0%	Q3	31
50.0%	median	9	50.0%	median	10.6	50.0%	median	137.4	50.0%	median	30
25.0%	Q1	8.4	25.0%	Q1	8.8	25.0%	Q1	111.4	25.0%	Q1	27.7
10.0%		7.6	10.0%		7.3	10.0%		92.14	10.0%		26.1
2.5%		7.3	2.5%		6.1	2.5%		79.1	2.5%		25.4
0.5%		7.1	0.5%		5.0	0.5%		64.6	0.5%		24.9
0.0%	min	7	0.0%	min	4.5	0.0%	min	51.9	0.0%	min	24.5
	Mean	8.80		Mean	10.69		Mean	139.52		Mean	29.41
	Std Dev	0.69		Std Dev	2.63		Std Dev	36.98		Std Dev	2.11
	Std Err Mean	0.02		Std Err Mean	0.06		Std Err Mean	0.82		Std Err Mean	0.05
	Upper 95% Mean	8.83		Upper 95% Mean	10.80		Upper 95% Mean	141.14		Upper 95% Mean	29.50
	Lower 95% Mean	8.77		Lower 95% Mean	10.57		Lower 95% Mean	137.91		Lower 95% Mean	29.32
	N	2013		N	2013		N	2013		N	2013

YAD152C sub-surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100%	max	9.9	100%	max	15.4	100%	max	201.4	100%	max	31.7
99.5%		9.7	99.5%		13.6	99.5%		175.5	99.5%		31.3
97.5%		9.2	97.5%		12	97.5%		154.4	97.5%		30.9
90.0%		8.9	90.0%		10.4	90.0%		134.5	90.0%		30.5
75.0%	Q3	8.5	75.0%	Q3	9.2	75.0%	Q3	119.4	75.0%	Q3	29.7
50.0%	median	7.7	50.0%	median	7.9	50.0%	median	101.7	50.0%	median	29.2
25.0%	Q1	7.3	25.0%	Q1	5.9	25.0%	Q1	77.6	25.0%	Q1	27.4
10.0%		7.1	10.0%		3.7	10.0%		53.4	10.0%		25.6
2.5%		6.8	2.5%		1.8	2.5%		27.0	2.5%		24.6
0.5%		6.7	0.5%		0.7	0.5%		9.5	0.5%		24.2
0.0%	min	6.6	0.0%	min	0	0.0%	min	1.2	0.0%	min	24
	Mean	7.85		Mean	7.47		Mean	97.38		Mean	28.49
	Std Dev	0.70		Std Dev	2.59		Std Dev	32.17		Std Dev	1.77
	Std Err Mean	0.02		Std Err Mean	0.06		Std Err Mean	0.72		Std Err Mean	0.04
	Upper 95% Mean	7.89		Upper 95% Mean	7.58		Upper 95% Mean	98.79		Upper 95% Mean	28.57
	Lower 95% Mean	7.82		Lower 95% Mean	7.35		Lower 95% Mean	95.97		Lower 95% Mean	28.41
	N	2003		N	2003		N	2003		N	2003

***Note:** outlier box plots contain:

• The confidence diamond contains the mean and the upper and lower 95% of the mean.

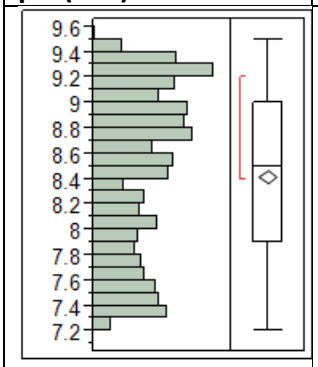
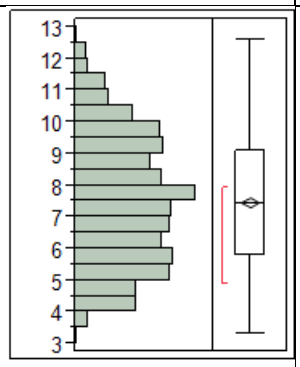
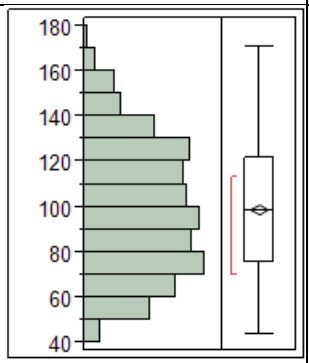
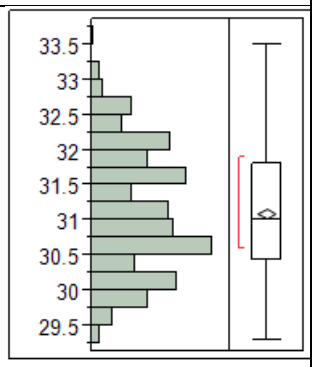
• The ends of the box represent the 25th and 75th quantiles, also expressed as the 1st (Q1) and 3rd quartile (Q3), respectively.

• The difference between the 1st and 3rd quartiles is called the *interquartile range*.

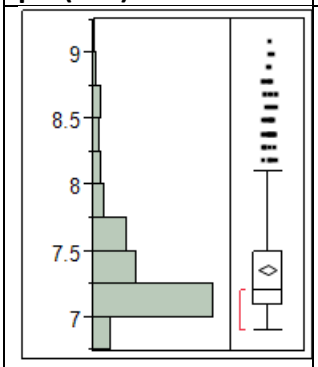
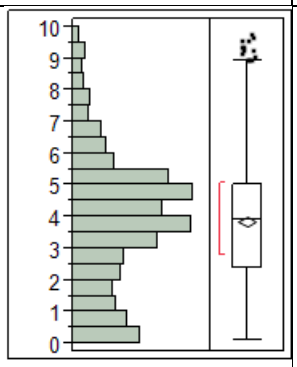
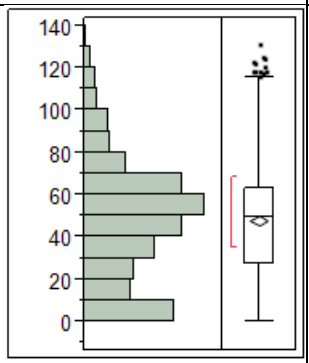
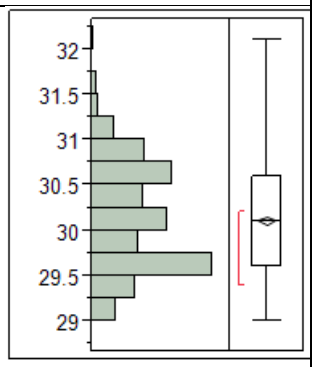
• The box has lines that extend from each end, sometimes called *whiskers*. The whiskers extend from the ends of the box to the outermost data point that falls within the distances computed as follows:
1st quartile - 1.5*(interquartile range) and 3rd quartile + 1.5*(interquartile range)
If the data points do not reach the computed ranges, then the whiskers are determined by the upper and lower data point values (not including outliers).

• The bracket outside of the box identifies the *shortest half*, which is the most dense 50% of the observations.

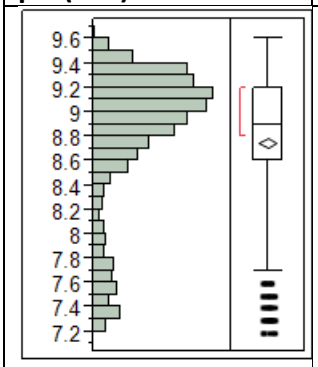
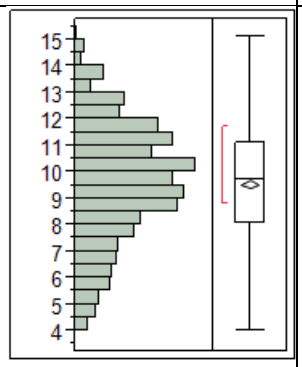
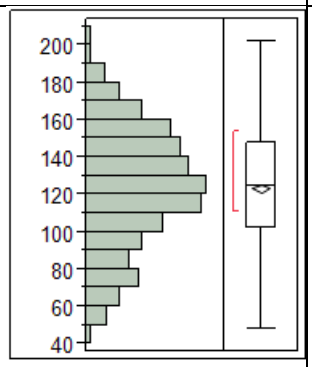
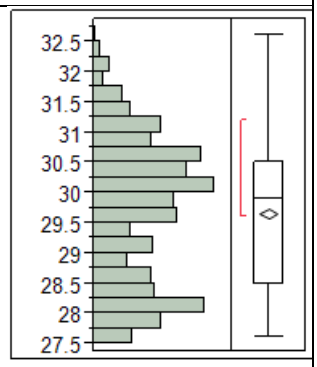
YAD169A surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100%	max	9.5	100%	max	12.6	100%	max	170.8	100%	max	33.5
99.5%		9.4	99.5%		12.3	99.5%		168.7	99.5%		33.1
97.5%		9.3	97.5%		11.4	97.5%		155.7	97.5%		32.7
90.0%		9.2	90.0%		10.1	90.0%		137.2	90.0%		32.3
75.0%	Q3	9	75.0%	Q3	9.1	75.0%	Q3	122.1	75.0%	Q3	31.8
50.0%	median	8.5	50.0%	median	7.4	50.0%	median	98.1	50.0%	median	31
25.0%	Q1	7.9	25.0%	Q1	5.8	25.0%	Q1	75.4	25.0%	Q1	30.5
10.0%		7.4	10.0%		4.9	10.0%		61.3	10.0%		30
2.5%		7.3	2.5%		4.1	2.5%		51.6	2.5%		29.7
0.5%		7.2	0.5%		3.7	0.5%		46.3	0.5%		29.4
0.0%	min	7.2	0.0%	min	3.3	0.0%	min	44	0.0%	min	29.3
	Mean	8.42		Mean	7.47		Mean	99.07		Mean	31.10
	Std Dev	0.65		Std Dev	2.02		Std Dev	28.69		Std Dev	0.87
	Std Err Mean	0.03		Std Err Mean	0.08		Std Err Mean	1.11		Std Err Mean	0.03
	Upper 95% Mean	8.47		Upper 95% Mean	7.63		Upper 95% Mean	101.24		Upper 95% Mean	31.17
	Lower 95% Mean	8.37		Lower 95% Mean	7.32		Lower 95% Mean	96.89		Lower 95% Mean	31.04
	N	669		N	669		N	669		N	669

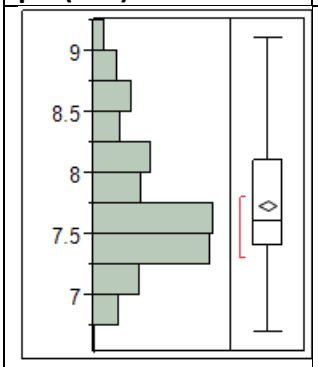
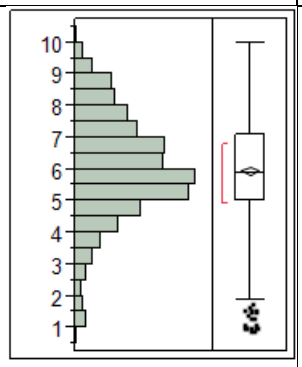
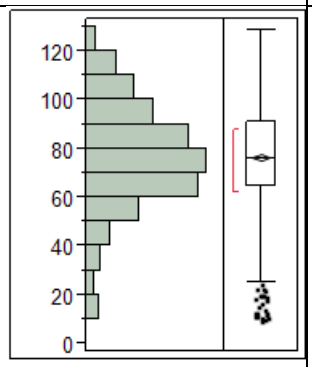
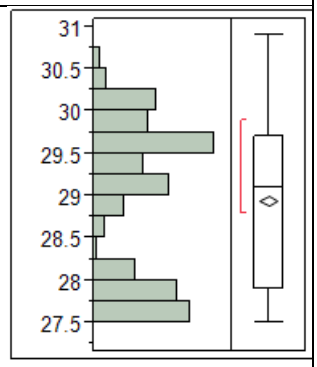
YAD169A sub-surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100%	max	9.1	100%	max	9.8	100%	max	131.3	100%	max	32.1
99.5%		9.0	99.5%		9.6	99.5%		123.9	99.5%		31.7
97.5%		8.7	97.5%		8.7	97.5%		112.0	97.5%		31.2
90.0%		8	90.0%		6.6	90.0%		84.04	90.0%		30.9
75.0%	Q3	7.5	75.0%	Q3	5	75.0%	Q3	62.8	75.0%	Q3	30.6
50.0%	median	7.2	50.0%	median	3.9	50.0%	median	49.1	50.0%	median	30.1
25.0%	Q1	7.1	25.0%	Q1	2.4	25.0%	Q1	27.6	25.0%	Q1	29.6
10.0%		7	10.0%		0.7	10.0%		6.84	10.0%		29.4
2.5%		6.9	2.5%		0.2	2.5%		0.86	2.5%		29.2
0.5%		6.9	0.5%		0.1	0.5%		0.4	0.5%		29.1
0.0%	min	6.9	0.0%	min	0.1	0.0%	min	0.4	0.0%	min	29
	Mean	7.36		Mean	3.85		Mean	47.79		Mean	30.12
	Std Dev	0.45		Std Dev	2.11		Std Dev	28.05		Std Dev	0.59
	Std Err Mean	0.02		Std Err Mean	0.08		Std Err Mean	1.09		Std Err Mean	0.02
	Upper 95% Mean	7.40		Upper 95% Mean	4.01		Upper 95% Mean	49.93		Upper 95% Mean	30.16
	Lower 95% Mean	7.33		Lower 95% Mean	3.69		Lower 95% Mean	45.66		Lower 95% Mean	30.07
	N	663		N	663		N	663		N	663

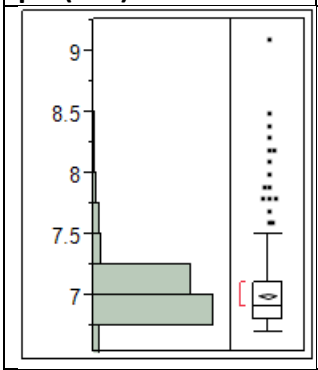
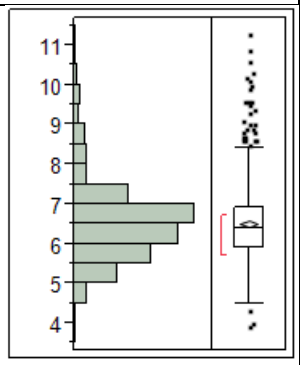
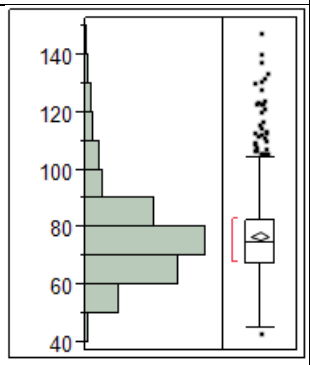
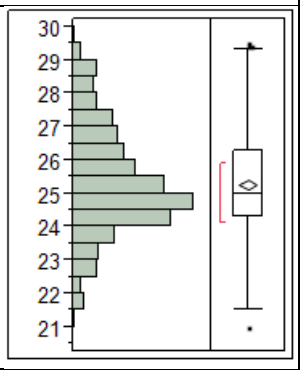
YAD169B surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100%	max	9.6	100%	max	15.1	100%	max	202.1	100%	max	32.6
99.5%		9.5	99.5%		14.7	99.5%		199.1	99.5%		32.4
97.5%		9.4	97.5%		13.6	97.5%		181.8	97.5%		31.8
90.0%		9.3	90.0%		12.4	90.0%		163.8	90.0%		31.2
75.0%	Q3	9.2	75.0%	Q3	11.1	75.0%	Q3	147.6	75.0%	Q3	30.5
50.0%	median	8.9	50.0%	median	9.7	50.0%	median	124.9	50.0%	median	29.9
25.0%	Q1	8.6	25.0%	Q1	8.1	25.0%	Q1	102.4	25.0%	Q1	28.5
10.0%		7.6	10.0%		6.3	10.0%		76.36	10.0%		28
2.5%		7.3	2.5%		4.8	2.5%		58.1	2.5%		27.7
0.5%		7.2	0.5%		4.2	0.5%		49.8	0.5%		27.6
0.0%	min	7.2	0.0%	min	4	0.0%	min	47.7	0.0%	min	27.6
	Mean	8.75		Mean	9.54		Mean	123.34		Mean	29.67
	Std Dev	0.59		Std Dev	2.26		Std Dev	32.16		Std Dev	1.19
	Std Err Mean	0.02		Std Err Mean	0.08		Std Err Mean	1.09		Std Err Mean	0.04
	Upper 95% Mean	8.79		Upper 95% Mean	9.69		Upper 95% Mean	125.49		Upper 95% Mean	29.75
	Lower 95% Mean	8.71		Lower 95% Mean	9.39		Lower 95% Mean	121.20		Lower 95% Mean	29.59
	N	863		N	863		N	863		N	863

YAD169B sub-surface data

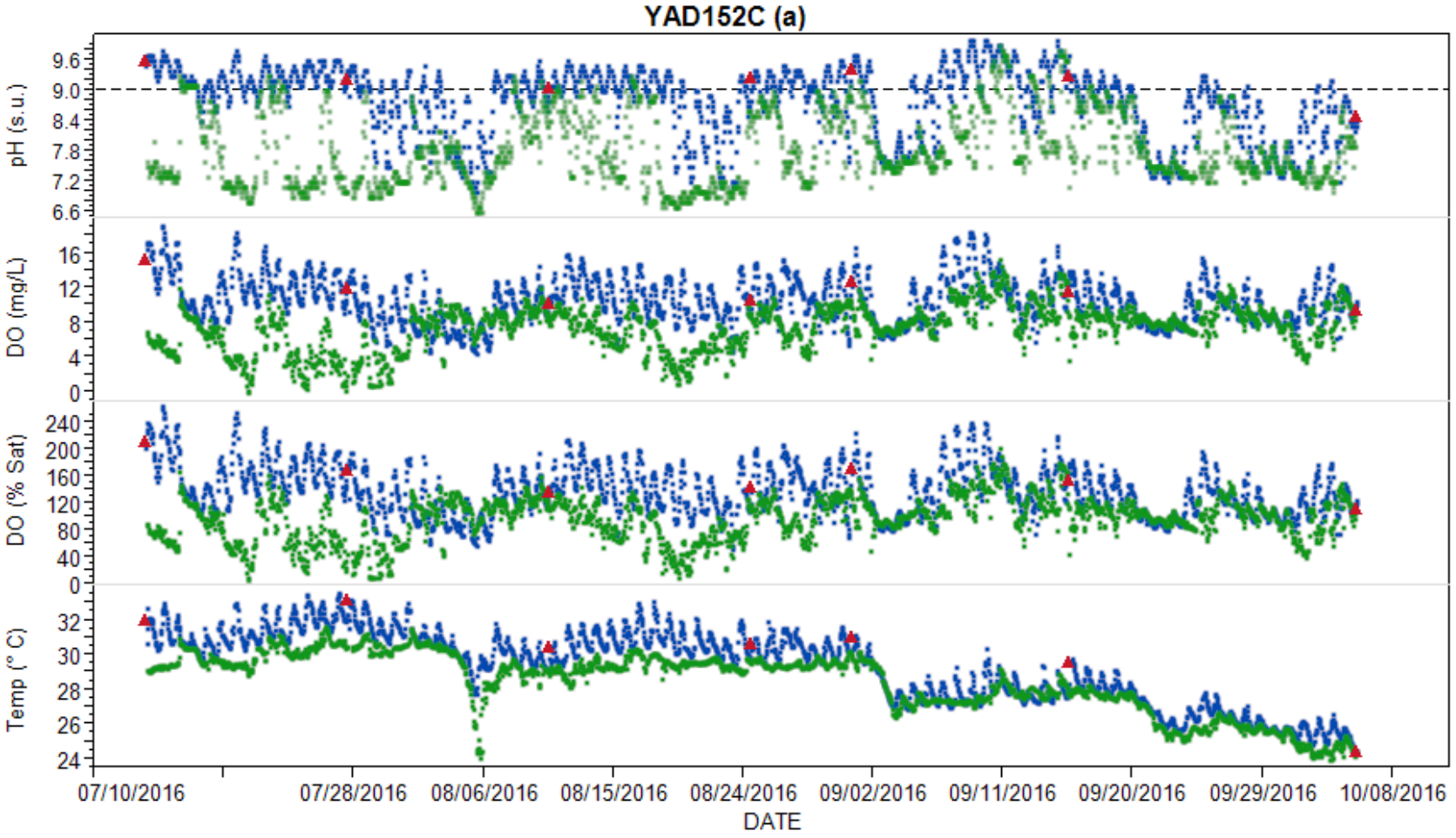
pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100.0%	max	9.1	100.0%	max	10	100.0%	max	128.8	100.0%	max	30.9
99.5%		9.1	99.5%		9.6	99.5%		124.9	99.5%		30.6
97.5%		8.9	97.5%		9.1	97.5%		117.0	97.5%		30.3
90.0%		8.6	90.0%		8.2	90.0%		106.7	90.0%		30
75.0%	Q3	8.1	75.0%	Q3	7.1	75.0%	Q3	90.9	75.0%	Q3	29.7
50.0%	median	7.6	50.0%	median	5.9	50.0%	median	75.8	50.0%	median	29.1
25.0%	Q1	7.4	25.0%	Q1	5	25.0%	Q1	64.5	25.0%	Q1	27.9
10.0%		7.1	10.0%		4	10.0%		50.1	10.0%		27.7
2.5%		6.9	2.5%		1.8	2.5%		22.1	2.5%		27.6
0.5%		6.7	0.5%		1	0.5%		10.9	0.5%		27.6
0.0%	min	6.7	0.0%	min	0.9	0.0%	min	9.5	0.0%	min	27.5
	Mean	7.73		Mean	5.96		Mean	76.49		Mean	28.94
	Std Dev	0.55		Std Dev	1.69		Std Dev	22.18		Std Dev	0.90
	Std Err Mean	0.02		Std Err Mean	0.06		Std Err Mean	0.76		Std Err Mean	0.03
	Upper 95% Mean	7.77		Upper 95% Mean	6.07		Upper 95% Mean	77.98		Upper 95% Mean	29.00
	Lower 95% Mean	7.70		Lower 95% Mean	5.84		Lower 95% Mean	75.01		Lower 95% Mean	28.88
	N	862		N	862		N	862		N	862

HRL051 surface data

pH (s.u.)			DO (mg/L)			DO (% Sat)			Temp (°C)		
											
100%	max	9.1	100%	max	11.3	100%	max	147.7	100%	max	29.5
99.5%		8.5	99.5%		10.8	99.5%		139.4	99.5%		29.4
97.5%		7.8	97.5%		9.595	97.5%		123.2	97.5%		28.9
90.0%		7.2	90.0%		7.8	90.0%		97.9	90.0%		27.5
75.0%	Q3	7.1	75.0%	Q3	6.9	75.0%	Q3	82.6	75.0%	Q3	26.3
50.0%	median	6.9	50.0%	median	6.4	50.0%	median	74.4	50.0%	median	25
25.0%	Q1	6.8	25.0%	Q1	5.9	25.0%	Q1	67.3	25.0%	Q1	24.3
10.0%		6.8	10.0%		5.4	10.0%		60.1	10.0%		23.3
2.5%		6.7	2.5%		4.8	2.5%		53.0	2.5%		22.3
0.5%		6.7	0.5%		4.1	0.5%		46.1	0.5%		21.5
0.0%	min	6.7	0.0%	min	3.9	0.0%	min	43.2	0.0%	min	21
	Mean	6.99		Mean	6.51		Mean	76.98		Mean	25.29
	Std Dev	0.27		Std Dev	1.07		Std Dev	15.94		Std Dev	1.62
	Std Err Mean	0.01		Std Err Mean	0.05		Std Err Mean	0.73		Std Err Mean	0.07
	Upper 95% Mean	7.02		Upper 95% Mean	6.60		Upper 95% Mean	78.41		Upper 95% Mean	25.43
	Lower 95% Mean	6.97		Lower 95% Mean	6.41		Lower 95% Mean	75.56		Lower 95% Mean	25.14
	N	481		N	481		N	481		N	481

2. Time Series Plots

Temporal distributions of hourly data are presented here for the entire study period to show diurnal as well as longer-term data variations. The variation of diurnal ranges of the data can also be seen and are discussed in the next session where daily minimum and daily maximum of the data are presented.



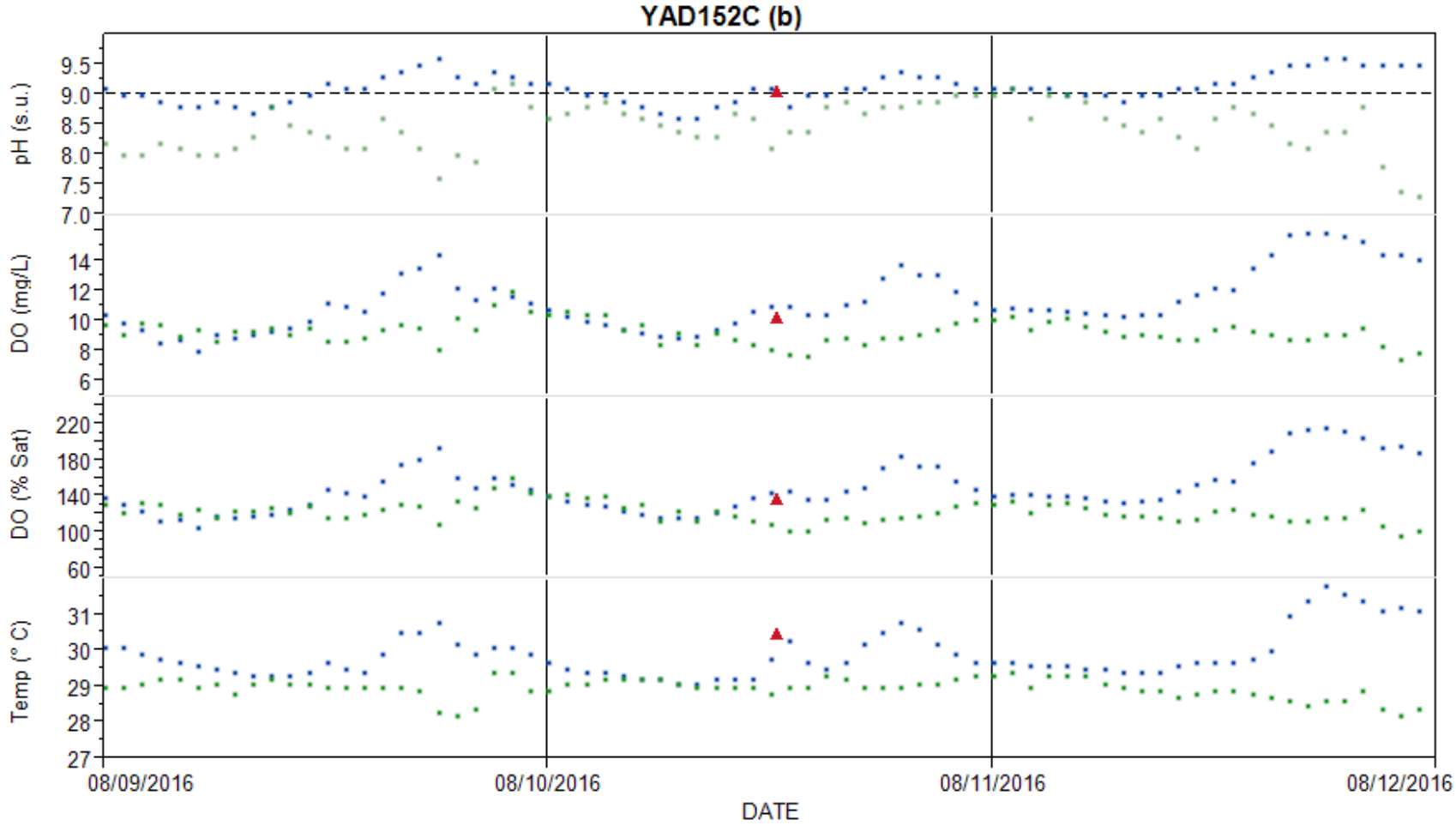


Figure 1. Time series plots of surface (blue dots) and sub-surface (green dots) data from the stationary mooring station YAD152C during the entire mooring period (a) and during 8/9/16 to 8/12/16 as a zoomed-in example for clearer demonstration of daily variations (b). Surface mooring/continuous data were normally collected from water depths of 0.5 to 0.6m below water surface and sub-surface mooring/continuous data were normally collected from water depths of around 4m below water surface. Red triangles are the surface data (about 0.1m below water surface) from the bi-weekly ambient monitoring program.

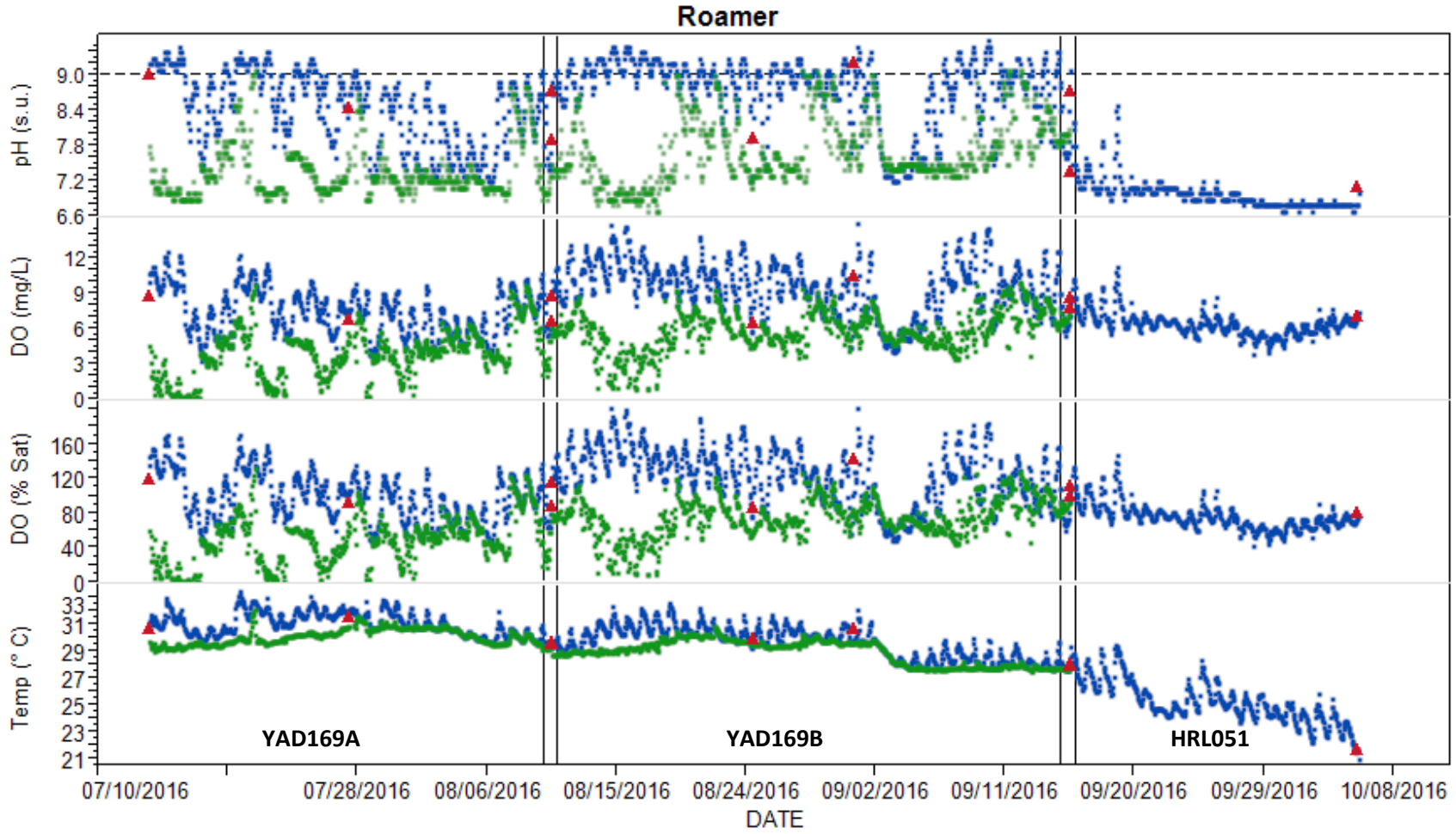


Figure 2. Time series plots of surface (blue dots) and sub-surface (green dots) data from the roaming mooring stations YAD169A/YAD169B/HRL051. Surface mooring/continuous data were normally collected from water depths of 0.7 to 0.8m (0.1m for HRL051) below water surface and subsurface mooring/continuous data were normally collected from water depths of around 4m below water surface. Sub-surface readings from HRL051 are not available due to the shallowness of the water. Red triangles are the surface data (about 0.1m below water surface) from the bi-weekly ambient monitoring program at the corresponding stations.

3. Diurnal ranges

The temporal variations of the diurnal ranges (difference between daily maximum and daily minimum) of the data are presented here together with daily flow from USGS station 02116500 (Yadkin River at Yadkin College). The pH and DO exhibited relatively large diurnal variability across time and space compared to the temperature. Daily ranges of DO and pH were highest at YAD152C, where the difference between daily maximum and minimum values of DO got as high as 11 mg/L and pH as high as 2.7. Observed daily variability was lowest at the shallow HRL051 station, with the highest daily DO range of 5.8 mg/L and pH of 1.7. Surface DO showed slightly higher ranges than sub-surface DO; for example, at YAD152C the overall mean range at the surface was 5.3 mg/L, while it was 4.2 mg/L in the sub-surface. However, again it should be noted that the ambient data suggests that DO near the bottom might be even less varying, with all values close to zero. For the days when daily DO variation is high, pH variation tended to be also high, whereas temperate showed relatively small deviations from the daily means throughout the monitoring periods.

Daily flow measured during the monitoring periods (7/13 - 10/5) at Yadkin River at Yadkin College is also reported at the top of the plots. This USGS monitoring station covers about 60% of High Rock Lake drainage area. The range of mean flows observed at this station for the last ten years (2007-2016) during the same time frame (7/13 - 10/5) was: 931 cfs - 4403 cfs, with the 10-year average of 1837 cfs. Since the 2016 mean flow during 7/13 - 10/5 was 1829 cfs, the year 2016 appears to represent the average flow condition of the last ten years. It can be seen from the plot that flows were generally uneventful, except for a peak flow (12600 cfs) occurred on 8/4. This flow event was within the range of the peak flows observed at this station for the last ten years (2007-2016) during the same time frame (7/13 - 10/5): 3290 cfs - 23700 cfs, with the average of 10092 cfs. This flow event might have been responsible for the large dips in pH (6.6) and temperature (24 °C) observed at YAD152C on the next day (8/5).

Data from ambient monitoring were generally in good agreement with the daily mean values of the diurnal data, and mostly between the daily maximum and minimum values. (Note, however, that the depths at which the ambient monitoring and diurnal data were taken are not exactly the same.)

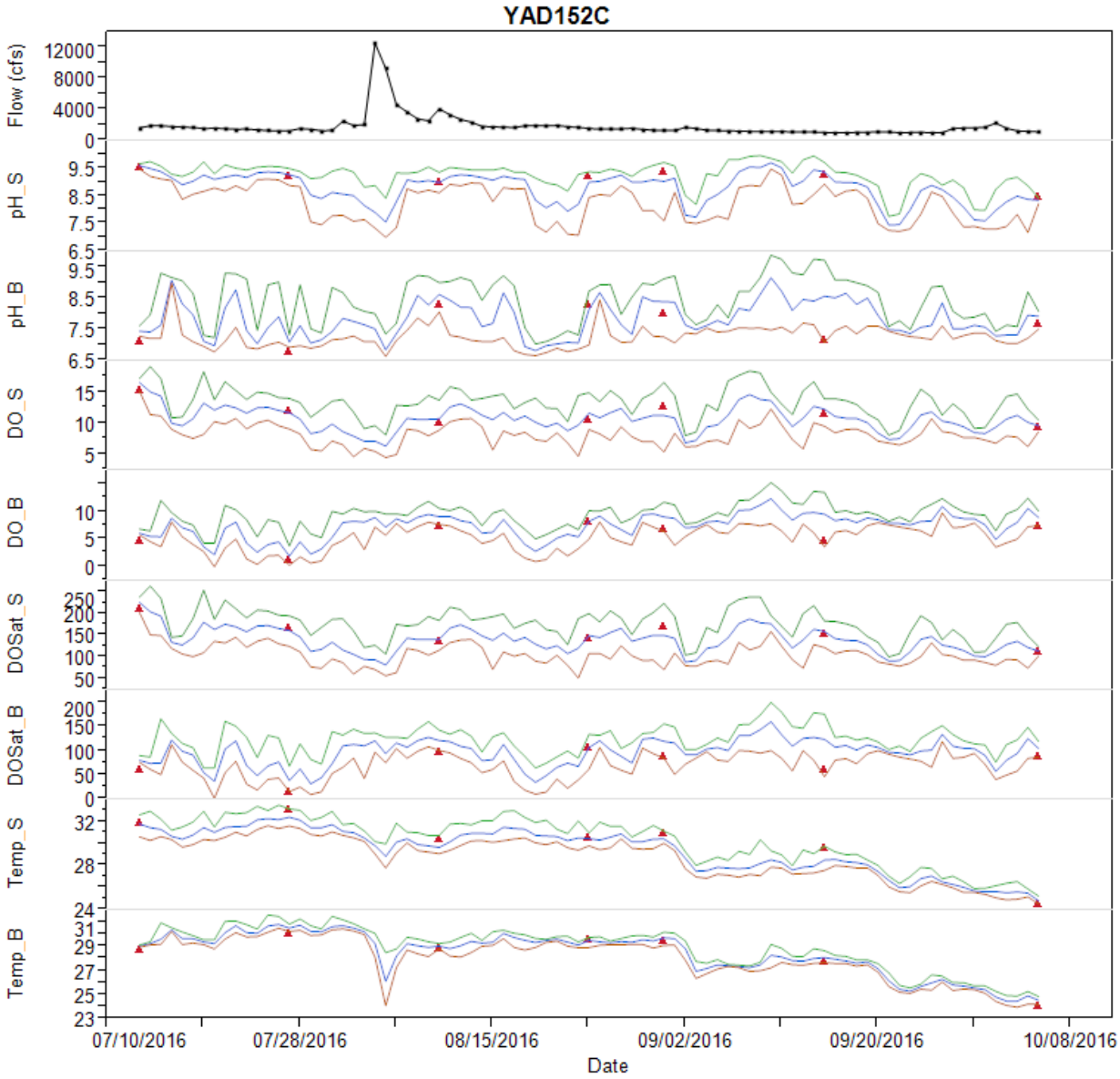


Figure 3. Time series plots of daily average flow (cfs) at USGS station 02116500 (Yadkin River at Yadkin College), daily average (blue lines), daily minimum (orange lines) and daily maximum (green lines) of surface/sub-surface pH (s.u.) (pH_S/pH_B), surface/sub-surface dissolved oxygen (mg/L) (DO_S/DO_B), surface/sub-surface DO (% saturation) DOSat_S/DOSat_B, and surface/sub-surface temperature (Temp_S/Temp_B) at station YAD152C. Red triangles are data from the bi-weekly ambient monitoring program. The top readings (depth around 0.1m) of the vertical profiles from the ambient data are plotted together with the surface continuous data and the ambient data around 4m below the water surface are plotted together with the sub-surface continuous data.

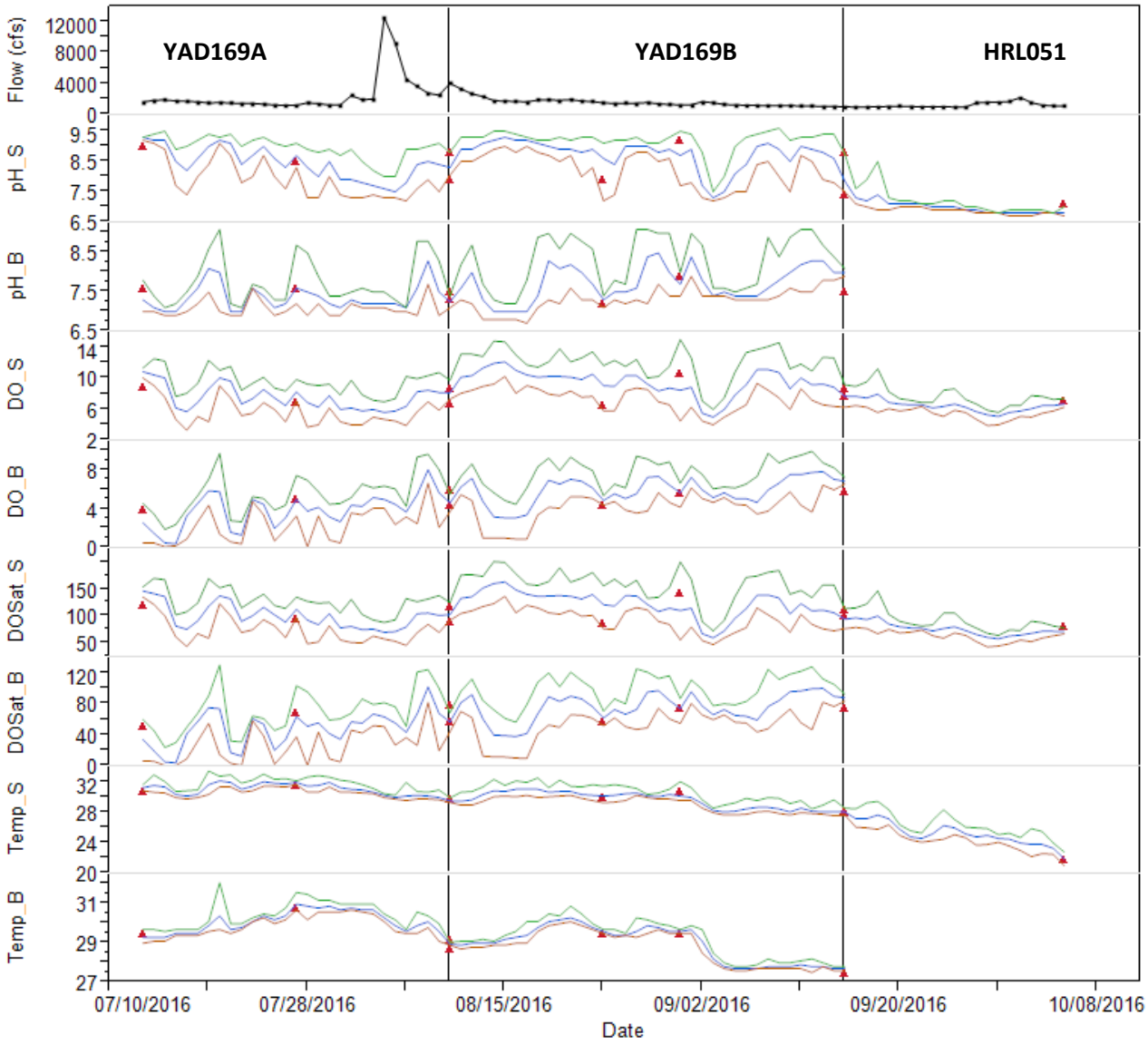


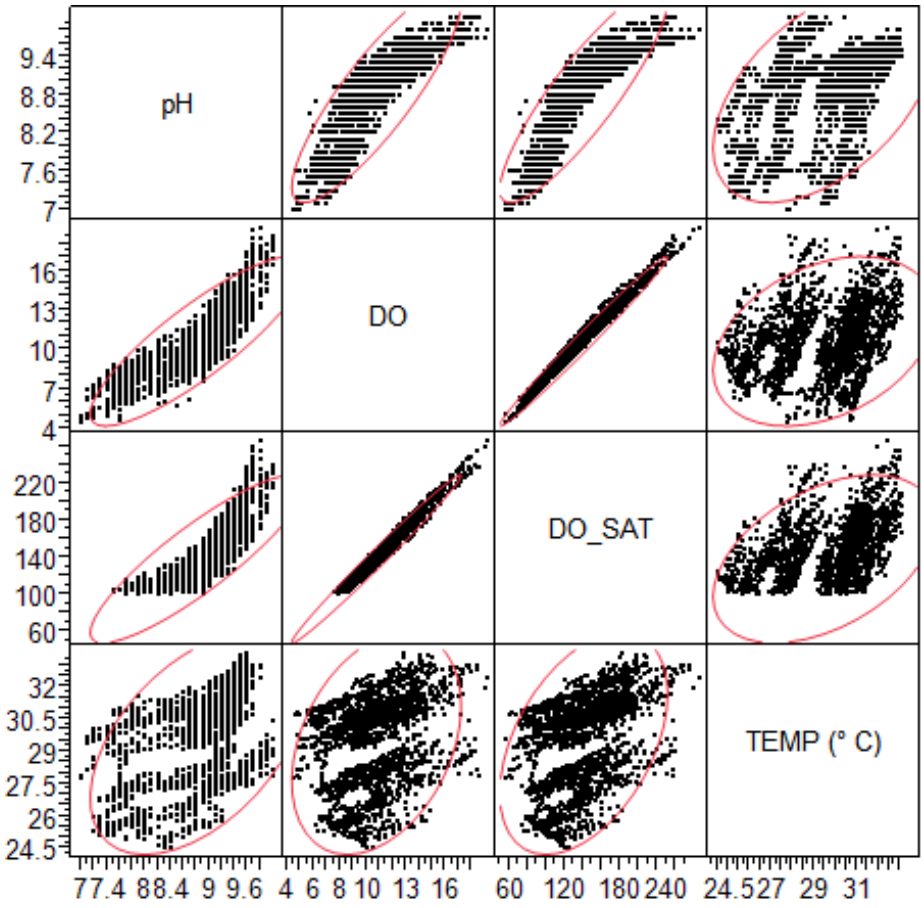
Figure 4. Time series plots of daily average flow (cfs) at USGS station 02116500 (Yadkin River at Yadkin College), daily average (blue lines), daily minimum (orange lines) and daily maximum (green lines) of surface/sub-surface pH (s.u.) (pH_S/pH_B), surface/ sub-surface dissolved oxygen (mg/L) (DO_S/DO_B), surface/ sub-surface DO (% saturation) DOSat_S/DOSat_B, and surface/ sub-surface temperature (Temp_S/Temp_B) at the roaming mooring stations YAD169A/YAD169B/HRL051. Red triangles are data from the bi-weekly ambient monitoring program. The top readings (depth around 0.1m) of the vertical profiles from the ambient data are plotted together with the surface continuous data and the ambient readings around 4m below the water surface are plotted together with the sub-surface continuous data.

4. **Data Correlations** (JMP was used for this analysis. A 95% bivariate normal density ellipse is shown in each scatterplot. In addition, both Pearson product-moment (pairwise) correlations and nonparametric Spearman's ρ correlations are provided)

   A matrix of scatterplots is provided in the following where the labels indicate the y-axis of the corresponding row and the x-axis of the corresponding column. Linear correlations between the variables are also computed and provided in the tables. Nonparametric correlations are provided in addition to the pairwise correlations since some of the variables are likely not normally distributed. Despite the difference in the values of the correlations, both the methods suggest that pH, DO and water temperature have statistically significant positive relationships in surface water. In sub-surface water at several locations, water temperature and DO were not significantly correlated or became negatively correlated.

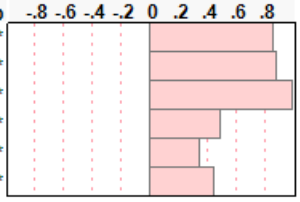
   It should be noted that although linear correlations were calculated and provided here, some of the relationships between the variables appear not strictly linear. For example, it can be seen from the scatterplots that especially when pH is high (above 9) in the surface waters of YAD152C, YAD169A and YAD169B, both DO concentration and DO %Saturation increase dramatically as pH increases. In fact, both polynomial fit (degree=2) and exponential fit between DO (dependent variable) and pH (independent variable) are statistically significant at surface waters of YAD152C. The R-square for the linear fit is 0.74, whereas it is 0.81 and 0.82 for the polynomial and the exponential fits.

YAD152C surface data



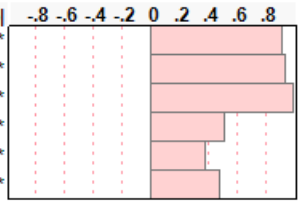
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 99%	Upper 99%	Signif Prob
DO	pH	0.8589	2013	0.8430	0.8732	<.0001*
DO SAT	pH	0.8788	2013	0.8650	0.8912	<.0001*
DO SAT	DO	0.9906	2013	0.9894	0.9916	<.0001*
TEMP (° C)	pH	0.4928	2013	0.4480	0.5350	<.0001*
TEMP (° C)	DO	0.3412	2013	0.2895	0.3910	<.0001*
TEMP (° C)	DO SAT	0.4480	2013	0.4009	0.4927	<.0001*

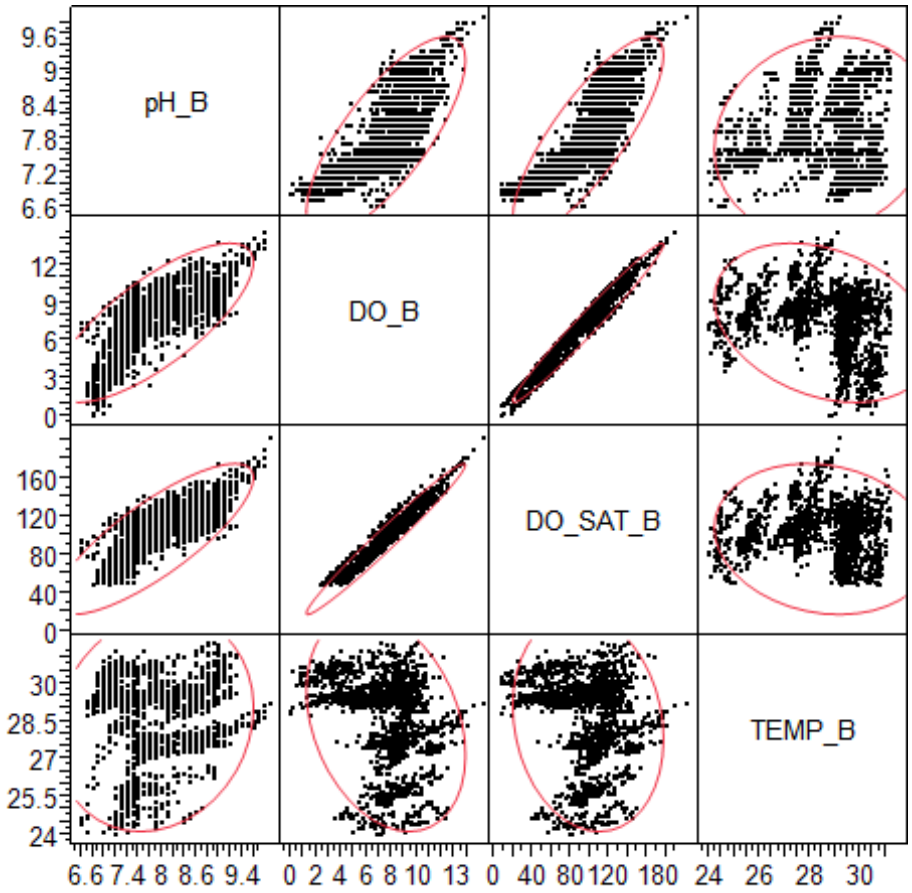


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO	pH	0.9113	<.0001*
DO SAT	pH	0.9395	<.0001*
DO SAT	DO	0.9904	<.0001*
TEMP (° C)	pH	0.5134	<.0001*
TEMP (° C)	DO	0.3848	<.0001*
TEMP (° C)	DO SAT	0.4824	<.0001*

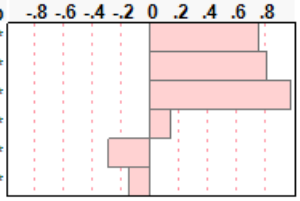


YAD152C sub-surface data



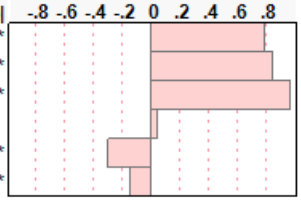
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO_B	pH_B	0.7606	2003	0.7415	0.7784	<.0001*
DO_SAT_B	pH_B	0.8142	2003	0.7989	0.8285	<.0001*
DO_SAT_B	DO_B	0.9825	2003	0.9809	0.9839	<.0001*
TEMP_B	pH_B	0.1399	2003	0.0967	0.1826	<.0001*
TEMP_B	DO_B	-0.2957	2003	-0.3351	-0.2552	<.0001*
TEMP_B	DO_SAT_B	-0.1498	2003	-0.1923	-0.1067	<.0001*

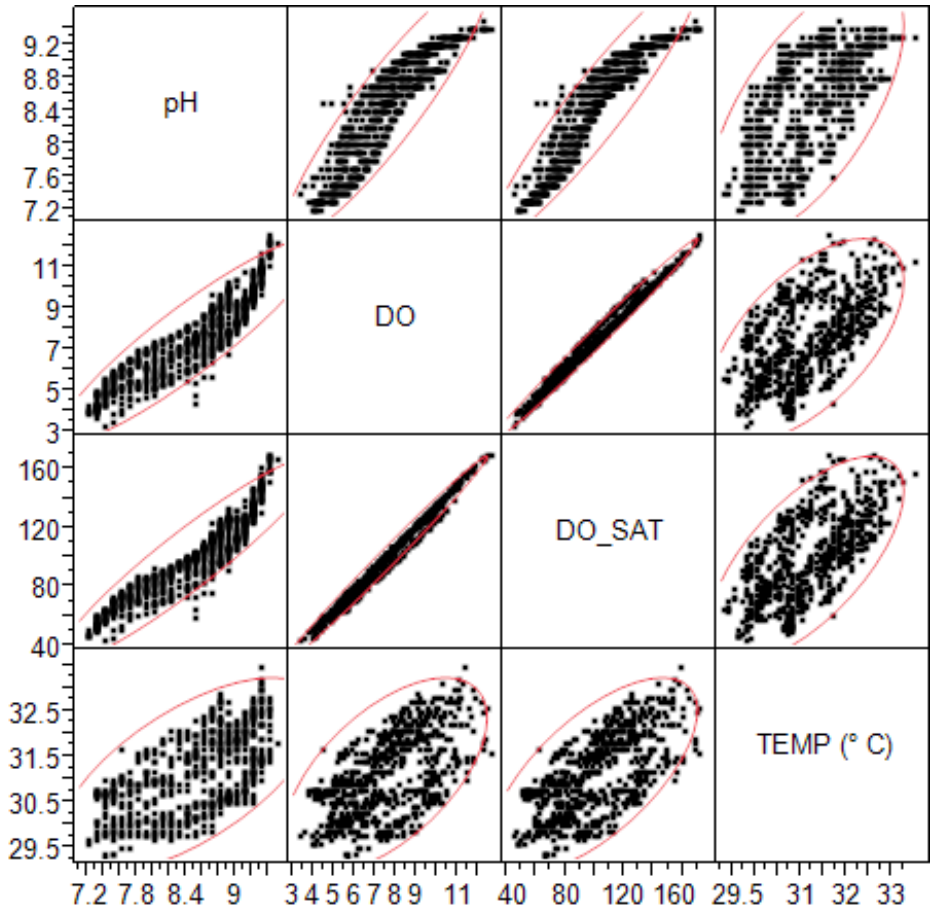


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO_B	pH_B	0.7946	<.0001*
DO_SAT_B	pH_B	0.8487	<.0001*
DO_SAT_B	DO_B	0.9776	<.0001*
TEMP_B	pH_B	0.0436	0.0512
TEMP_B	DO_B	-0.3000	<.0001*
TEMP_B	DO_SAT_B	-0.1473	<.0001*

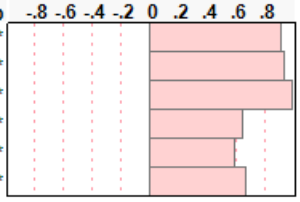


YAD169A surface data



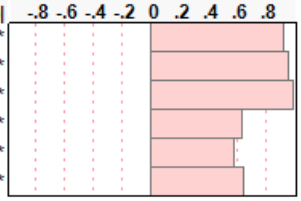
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO	pH	0.9144	669	0.9010	0.9260	<.0001*
DO SAT	pH	0.9381	669	0.9283	0.9466	<.0001*
DO SAT	DO	0.9927	669	0.9915	0.9938	<.0001*
TEMP (° C)	pH	0.6435	669	0.5968	0.6858	<.0001*
TEMP (° C)	DO	0.5906	669	0.5389	0.6379	<.0001*
TEMP (° C)	DO SAT	0.6650	669	0.6205	0.7053	<.0001*

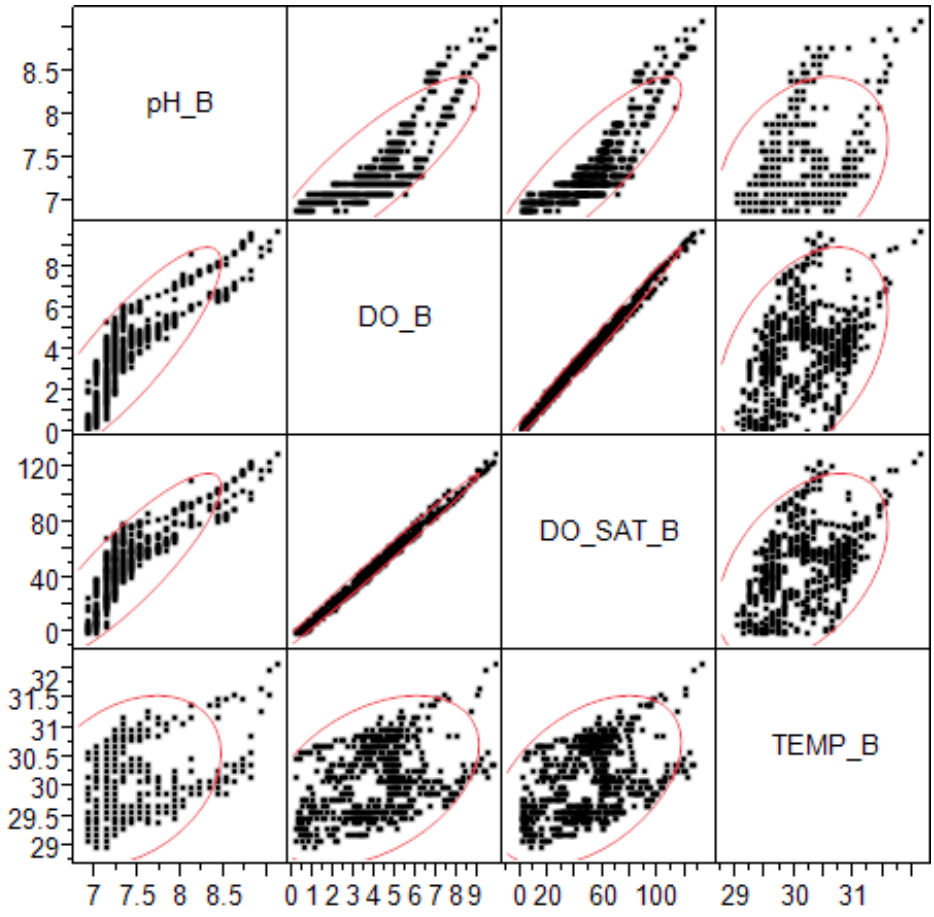


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO	pH	0.9326	<.0001*
DO SAT	pH	0.9583	<.0001*
DO SAT	DO	0.9923	<.0001*
TEMP (° C)	pH	0.6401	<.0001*
TEMP (° C)	DO	0.5776	<.0001*
TEMP (° C)	DO SAT	0.6531	<.0001*

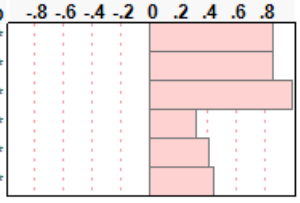


YAD169A sub-surface data



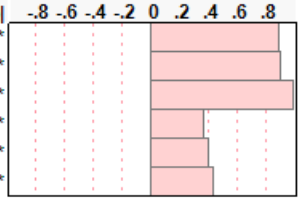
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO_B	pH_B	0.8549	663	0.8330	0.8741	<.0001*
DO_SAT_B	pH_B	0.8655	663	0.8451	0.8834	<.0001*
DO_SAT_B	DO_B	0.9957	663	0.9950	0.9963	<.0001*
TEMP_B	pH_B	0.3222	663	0.2522	0.3888	<.0001*
TEMP_B	DO_B	0.4163	663	0.3513	0.4774	<.0001*
TEMP_B	DO_SAT_B	0.4510	663	0.3881	0.5096	<.0001*

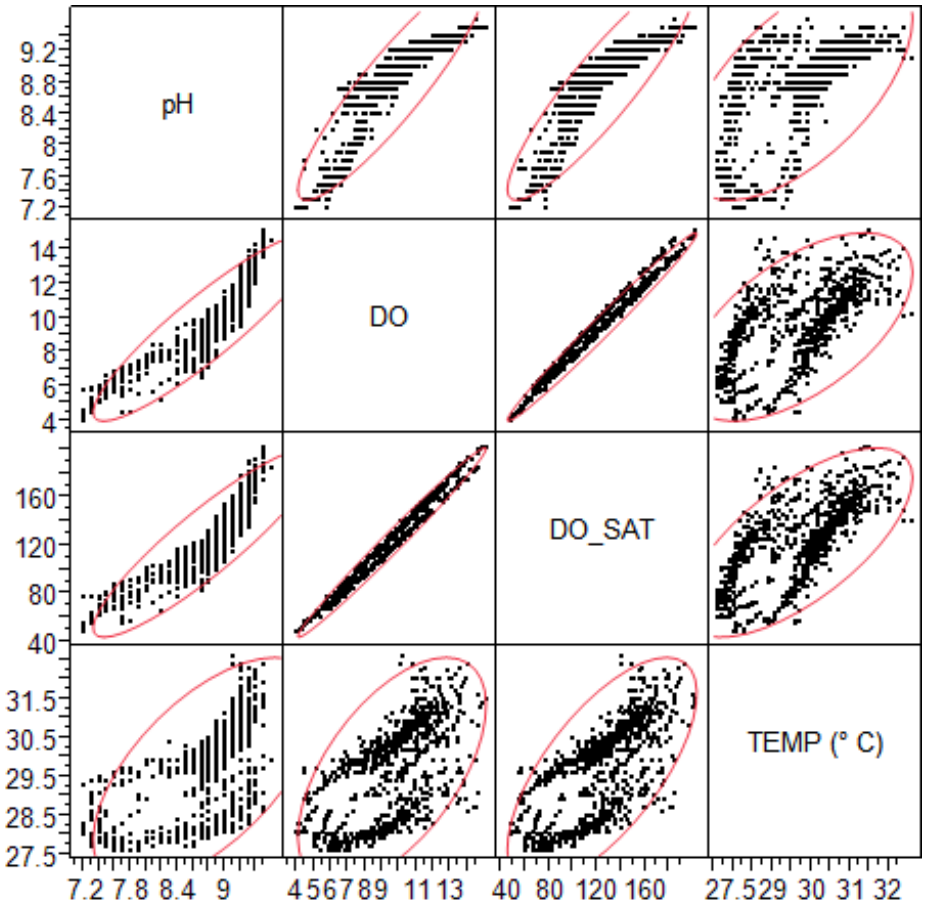


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO_B	pH_B	0.8901	<.0001*
DO_SAT_B	pH_B	0.9001	<.0001*
DO_SAT_B	DO_B	0.9945	<.0001*
TEMP_B	pH_B	0.3647	<.0001*
TEMP_B	DO_B	0.4077	<.0001*
TEMP_B	DO_SAT_B	0.4390	<.0001*

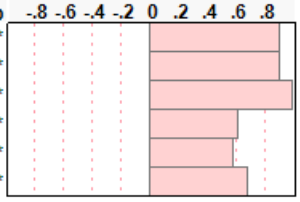


YAD169B surface data



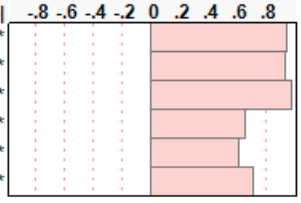
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO	pH	0.9089	863	0.8965	0.9198	<.0001*
DO SAT	pH	0.9052	863	0.8924	0.9166	<.0001*
DO SAT	DO	0.9893	863	0.9878	0.9907	<.0001*
TEMP (° C)	pH	0.6105	863	0.5668	0.6507	<.0001*
TEMP (° C)	DO	0.5783	863	0.5322	0.6211	<.0001*
TEMP (° C)	DO SAT	0.6839	863	0.6467	0.7179	<.0001*

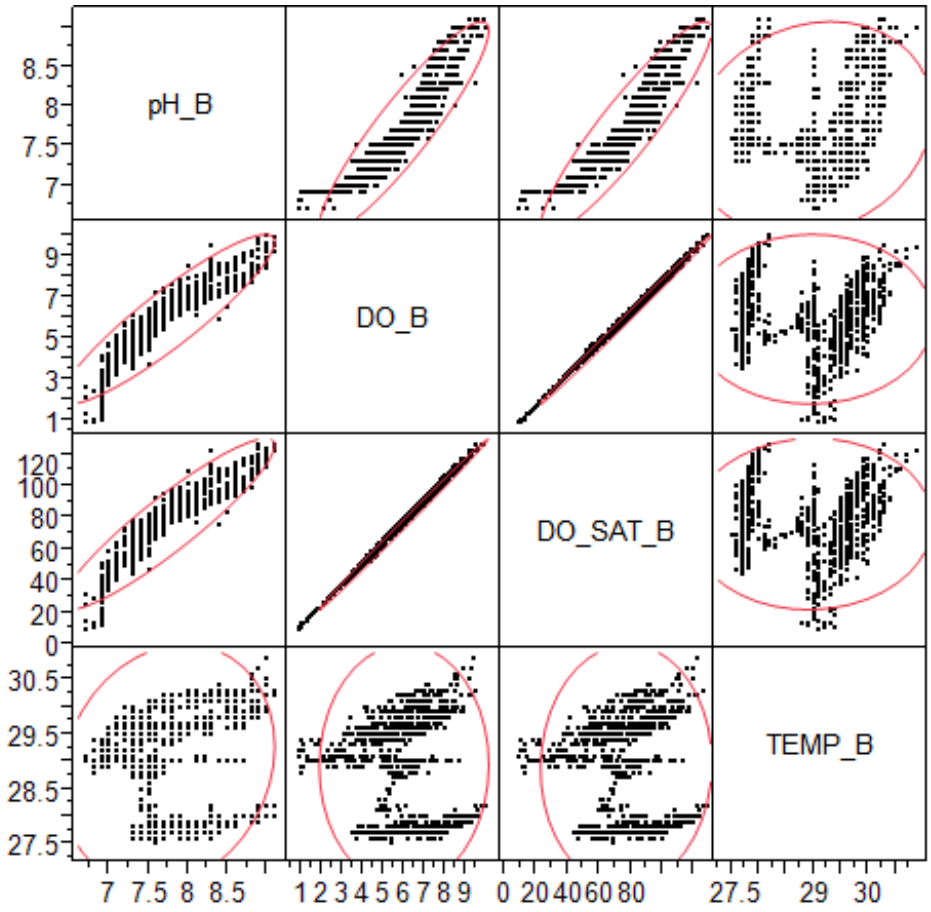


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO	pH	0.9478	<.0001*
DO SAT	pH	0.9422	<.0001*
DO SAT	DO	0.9880	<.0001*
TEMP (° C)	pH	0.6570	<.0001*
TEMP (° C)	DO	0.6161	<.0001*
TEMP (° C)	DO SAT	0.7143	<.0001*

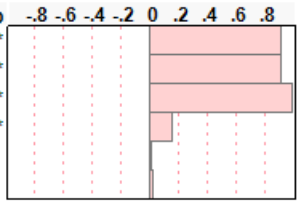


YAD169B sub-surface data



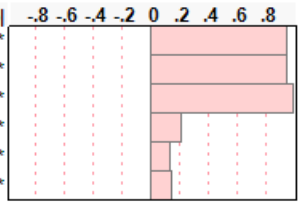
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO_B	pH_B	0.9144	862	0.9028	0.9247	<.0001*
DO_SAT_B	pH_B	0.9189	862	0.9078	0.9287	<.0001*
DO_SAT_B	DO_B	0.9983	862	0.9981	0.9985	<.0001*
TEMP_B	pH_B	0.1608	862	0.0950	0.2252	<.0001*
TEMP_B	DO_B	0.0093	862	-0.0575	0.0761	0.7846
TEMP_B	DO_SAT_B	0.0243	862	-0.0426	0.0909	0.4764

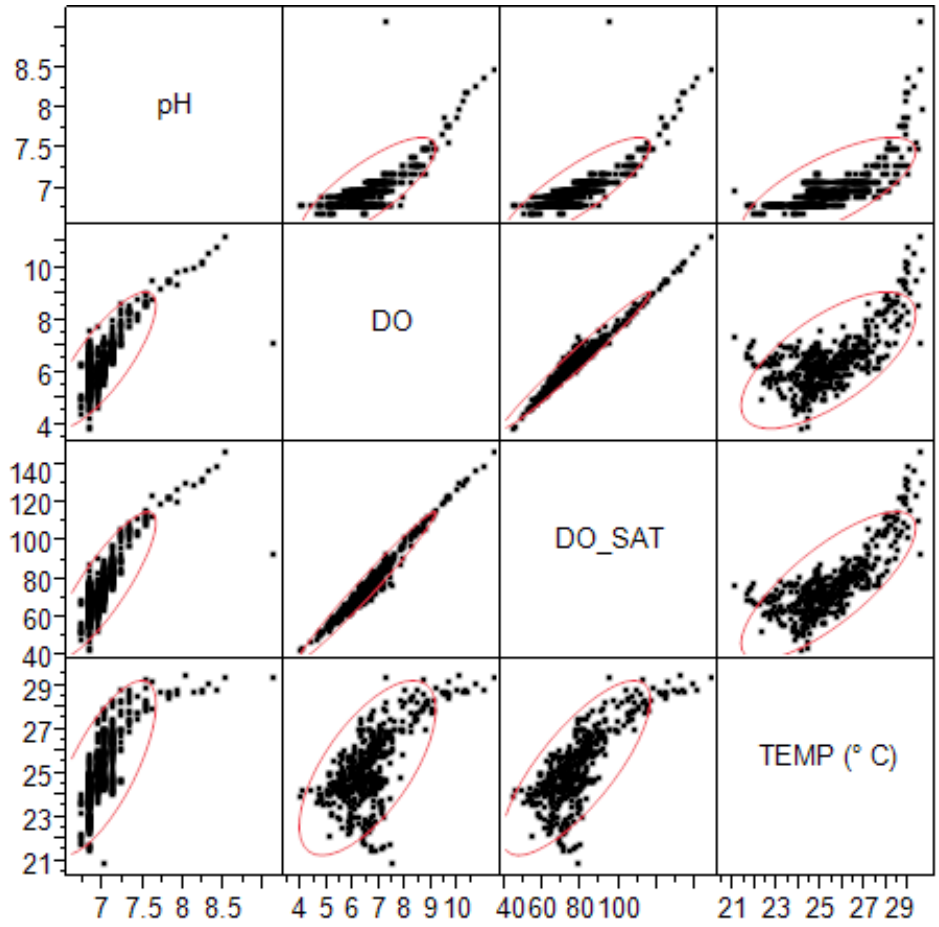


Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO_B	pH_B	0.9473	<.0001*
DO_SAT_B	pH_B	0.9498	<.0001*
DO_SAT_B	DO_B	0.9978	<.0001*
TEMP_B	pH_B	0.2133	<.0001*
TEMP_B	DO_B	0.1361	<.0001*
TEMP_B	DO_SAT_B	0.1448	<.0001*

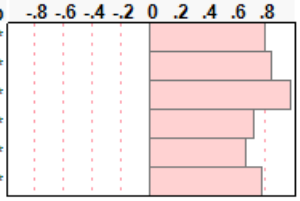


HRL051 surface data



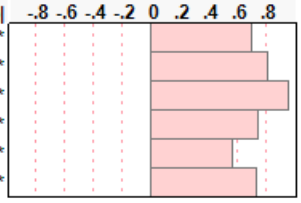
Pairwise Correlations

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob
DO	pH	0.8037	481	0.7696	0.8333	<.0001*
DO SAT	pH	0.8524	481	0.8259	0.8751	<.0001*
DO SAT	DO	0.9842	481	0.9811	0.9868	<.0001*
TEMP (° C)	pH	0.7287	481	0.6838	0.7680	<.0001*
TEMP (° C)	DO	0.6664	481	0.6135	0.7133	<.0001*
TEMP (° C)	DO SAT	0.7799	481	0.7422	0.8126	<.0001*



Nonparametric: Spearman's ρ

Variable	by Variable	Spearman ρ	Prob>|ρ|
DO	pH	0.7051	<.0001*
DO SAT	pH	0.8149	<.0001*
DO SAT	DO	0.9659	<.0001*
TEMP (° C)	pH	0.7495	<.0001*
TEMP (° C)	DO	0.5745	<.0001*
TEMP (° C)	DO SAT	0.7373	<.0001*



DWR Staff Findings: Dissolved oxygen criteria development for High Rock Lake

Dissolved Oxygen

1. North Carolina's dissolved oxygen (DO) criteria presently protects aquatic life uses in High Rock Lake.
2. The following sources provide a site-specific list of species for protection:
    a. Fish: Yadkin Hydroelectric Project Application for License Volume IV(A), Appendix E-4, Table 5-2 (Alcoa) and Assessment of Balanced and Indigenous Populations in the Yadkin River and High Rock Lake near Buck Steam Station, Tables 4-1, 4.2, and Appendices (Duke Energy)
    b. Macroinvertebrates: Assessment of Balanced and Indigenous Populations in the Yadkin River and High Rock Lake near Buck Steam Station, Tables 3-3 to 3-7 (Duke Energy)
3. EPA's Gold Book (pp. 214-224) recommends DO criteria in table form, relating various considerations including monitoring frequency, aquatic life stages, and cold/warm water. The relationship between the criteria recommendation and monitoring protocols are considered.
4. In 1986 EPA also published Ambient Water Quality Criteria for Dissolved Oxygen. This document provides the scientific basis, including literature citations, for the Gold Book's findings.
5. The document entitled "Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries, dated April 2003, dedicates a chapter to exploring dissolved oxygen criteria for the Chesapeake Bay system. While important differences exist between the Chesapeake Bay and High Rock Lake, both water bodies serve as habitat for several of the same oxygen-sensitive species. Striped bass, largemouth bass, black crappie, white bass and channel catfish are among fish species residing in High Rock Lake. Walleye and smallmouth bass were stocked in the 50s and 60s, respectively. This document explored the implications of both fresh and saltwater criteria, as both habitats are found within the Bay watershed. Select passages include:
    a. "The EPA freshwater criteria document, published in 1986, stipulated five limits for dissolved oxygen effects on warm-water species (Table III-4, U.S. EPA 1986). To protect early life stages, the criteria include a 7-day mean of 6 mg liter-1 and an instantaneous minimum of 5 mg liter-1."
    b. "Some of the most sensitive survival and growth responses reported for warm-water species in the freshwater criteria document were for early life stages of channel catfish and largemouth bass…"
    c. "The EPA freshwater early life stage criteria were based on embryonic and larval data for the following eight species: largemouth bass, black crappie, white sucker, white bass, northern pike, channel catfish, walleye and smallmouth bass (U.S. EPA 1986)."
    d. "Some field observations have indicated that juveniles and adults of anadromous species prefer dissolved oxygen concentrations > 6 mg liter-1 (Hawkins 1979; Christie et al. 1981; Rothschild 1990). However, no lethal or sublethal effects other than possible avoidance have been documented for dissolved oxygen concentrations between 5 and 6 mg liter-1."
    e. "This target DO concentration (>5 mg liter-1 at all times) was selected to protect the early life stages of striped bass, white perch, alewife, blueback herring, American shad,

hickory shad and yellow perch. This concentration of DO will allow eggs to hatch normally (Bradford et al. 1968; O'Malley and Boone 1972; Marcy and Jacobson 1976; Harrell and Bayless 1981; Jones et al. 1988), as well as allow survival and growth of larval and juvenile stages of all anadromous target species (Tagatz 1961; Bogdanov et al. 1967; Krouse 1968; Bowker et al. 1969; Chittenden 1969, 1972, 1973; Meldrim et al. 1974; Rogers et al. 1980; Miller et al. 1982; Coutant 1985; ASMFC 1987; Jones et al. 1988).

6. Striped bass (*Morone saxatilis*) are presently the only stocked species on High Rock Lake, others occur naturally. Striped bass do not spawn in High Rock Lake, at least as a general rule. They are stocked as 1-2 inch fingerlings at approximately 2 months old. Adult growth may be limited by a combination of DO and temperature impacts (pers. comm. Lawrence Dorsey, Wildlife Resources Commission, Mar. 2, 2017).
7. EPA's Gold Book (pp. 133-140) also recommends criteria related to total dissolved gases, recommending no more than 110% saturation. It generally describes conditions that can create supersaturation (including algal blooms) and its effects on various aquatic species. While much of the discussion is directed toward salmonid species, effects are also described for *Daphnia magna*, with mortality at 115% total gas saturation. *Daphnia* are often a predominant food source for planktivorous fish in lakes, and thus may serve as a proxy for lower levels of the food web in the context of criteria development.

General Considerations

- Criteria recommendations should include magnitude, duration, frequency, and spatial extent.
- Criteria recommendations should be well supported and be protective of relevant designated uses.
- Criteria recommendations should also include consideration of our present monitoring approach, approaches for monitoring upon development of an anticipated High Rock Nutrient Strategy, and account for potential advances in monitoring technology.
- Criteria recommendations should be considered in light of our present assessment methodologies. Adjustments to assessment methodologies may also be recommended if desirable.

North Carolina Division of Water Resources (DWR)

Surface Water Quality Standards History Document – **Dissolved Oxygen (DO)**

Compiled: February 23, 2017

Overview

North Carolina currently has DO water quality standards for the following surface water classifications:

- Freshwater:
  - Class C
    - These water quality standards apply to all freshwaters in the state.
- Saltwater:
  - Class SC
    - These water quality standards apply to all tidal salt waters in the state.

Details concerning the current water quality standard, its derivation, and historical record follow.

Class C – Fresh surface waters

Designated uses per 15A North Carolina Administrative Code (NCAC) 02B .0211 (1): *"aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, agriculture, and any other usage except for primary recreation or as a source of water supply for drinking, culinary, or food processing purposes;"*

Current standard per 15A NCAC 02B .0211 (6): *"not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters, lake coves, or backwaters, and lake bottom waters may have lower values if caused by natural conditions;"*

Basis for existing standard per available DWR documentation:

North Carolina has had a Class C water quality standard for DO since at least 1953. This combined narrative and numeric standard has changed over time, but has remained consistent since being modified in rule 15A NCAC 02B .0211 in April of 2001. The scientific basis for the original DO standard cannot be definitively determined as descriptive documentation regarding its original adoption cannot be located by DWR staff, though it is probably based on the first edition of "Water Quality Criteria" by Jack Edward McKee and Harold W. Wolf published in 1952. The current DO standard of *not less than 6.0 mg/l for trout waters and not less than a daily average of 5.0 mg/L and minimum instantaneous value of not less than 4.0 mg/L* is consistent with EPA's current Nationally Recommended Water Quality Criteria for the protection of

freshwater aquatic life which is based on the Quality Criteria for Water – 1986, otherwise known as the "Gold Book" (EPA 440/5-86-001).

In march of 1977, North Carolina adopted language for Class C waters, in the .0211 rule, that allowed for the establishment of alternate DO standards for those stream sections where treatment costs would outweigh realistic potential to meet the DO standard in adopted at that time. This language was expanded on and moved to its own rule (15A NCAC 02B .0213), entitled "Revisions to Dissolved Oxygen Standards", in December of 1978. Rule .0213 was later repealed from NC's water quality standards in October of 1989. Historical documentation indicates that this language was repealed due to adoption of rules 15A NCAC 02B .0205 (Natural Characteristics Outside Standards Limits) and .0218 (Exemptions from Surface Water Quality Standards) that would address this issue.

History per available Division of Water Resources documentation:

Modifications to previous standards are underscored.

November 19, 1953:

- Earliest record found for North Carolina DO standard
- Reference item: "Rules and Regulations and Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina"; Adopted by State Stream Sanitation Committee, Dept. of Water Resources, SSSC #2
- Language for Class C waters:
    - DO standard: *"Not less than 5.0 parts per million for trout producing waters; not less than 4.0 parts per million for non-trout waters, except that swamp waters may have a minimum of 3.0 parts per million."*

October 13, 1970:

- Reference item: "Rules, Regulations, Classifications and Water Quality Standards Applicable to the Surface Waters of North Carolina"; Adopted by Board of Water and Air Resources, Dept. of Water and Air Resources
- Language for Class C waters:
    - DO standard: *"not less than 6.0 mg/l for natural trout waters; 5.0 mg/l for put-and-take trout waters; not less than a daily average of 5.0 mg/l with a minimum of less than 4.0 mg/l for non-trout waters, except that swamp waters may have lower values if caused by natural conditions."*

March 1, 1977:

- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective March 1, 1977; Environmental Management Commission.
- Language for Class C waters:
    - DO standard: *"not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters may have lower values if caused by natural conditions. In certain stream*

segments where the cost of meeting the standard with treatment in excess of present waste treatment technology is economically prohibitive when compared with the expected benefits to be obtained, or the natural quality of the water or uncontrollable non-point source pollution prevents the attainment of a daily average dissolved oxygen concentration of 5.0 mg/l, exceptions to the dissolved oxygen standard shall be established on a case-by-case basis in accordance with Section 143-214.1 of the General Statutes of North Carolina. Such exceptions shall be indicated in the schedules of classifications with the revised minimum dissolved oxygen standard, which will be based on field data and/or assimilative capacity calculations and shall be established at the highest dissolved oxygen concentration attainable with the application of present waste treatment technology;"

December 14, 1978:

- Introduction of new rule related to DO. No changes were made to the DO standard in 15A NCAC 02B .0211.
- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective September, 1979; Environmental Management Commission.
- 15A NCAC 02B .0213 Revisions to Dissolved Oxygen Standards
    - Revisions: *"For Class "C" and Class "SC" waters. on its own initiative or pursuant to a request under G.S. 150A-16 by affected dischargers, may grant revisions to the dissolved oxygen standard for certain stream segments, where the commission finds that:*
        1. *Natural background conditions in the stream segment preclude the attainment of a daily average dissolved oxygen concentration of 5.0 mg/l; or*
        2. *Irretrievable and uncontrollable man-induced conditions preclude the attainment of a daily average dissolved oxygen concentration of 5.0 mg/l; or*
        3. *Application of effluent limitations for existing sources in the stream segment more stringent than present waste treatment technology in order to attain and maintain a daily average dissolved oxygen concentration of 5.0 mg/l would result in substantial adverse economic and social impact;*
    - *Any such revisions shall be established in accordance with G.S 143-214.1 and shall be indicated in schedules of classifications. The revised dissolved oxygen standard shall be established at the highest level economically attainable but shall be no lower than the level attainable with the application of present waste stream technology by dischargers to the stream segment. Dischargers to such waters shall provide treatment at least as stringent as present waste treatment technology."*

September 1, 1979:

- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective September, 1979; Environmental Management Commission.
- Language for Class C waters:

- DO standard: *"not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters may have lower values if caused by natural conditions."*

October 1, 1989:

- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective October 1, 1989; Environmental Management Commission.
- Language for Class C waters:
  - DO standard: *"not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters may have lower values if caused by natural conditions."*
- 15A NCAC 02B .0213 Revisions to Dissolved Oxygen Standards
  - Rule repealed.

April 1, 2001:

- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective April 1, 2001; Environmental Management Commission.
- Language for Class C waters:
  - DO standard: *"not less than 6.0 mg/l for trout waters; for non-trout waters, not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l; swamp waters, lake coves, or backwaters, and lake bottom waters may have lower values if caused by natural conditions;"*

Class SC – Tidal salt waters

Designated uses per 15A NCAC 02B .0220 (1): *"any usage except primary recreation or shellfish for market purposes; usages include aquatic life propagation and maintenance of biological integrity (including fishing, fish and functioning Primary Nursery Areas (PNAs)), wildlife, and secondary recreation;"*

Current standard per 15A NCAC 02B .0220 (5): *"not less than 5.0 mg/l, except that swamp waters, poorly flushed tidally influenced streams or embayments, or estuarine bottom waters may have lower values if caused by natural conditions;"*

Basis for existing standard per available Division of Water Resources documentation:

North Carolina has had a Class SC water quality standard for DO since at least 1953. This combined narrative and numeric standard has changed over time, but has remained consistent since being modified in rule 15A NCAC 02B .0211 in October of 1989. The scientific basis for the original DO standard cannot be definitively determined as descriptive documentation regarding its original adoption cannot be located by DWR staff, though it is probably based on the first edition of "Water Quality Criteria" by Jack Edward McKee and Harold W. Wolf published in 1952. The current DO standard of *not less than 5.0 mg/l* matches well with EPA's current Nationally Recommended Water Quality Criteria for the protection of freshwater aquatic life for juvenile and adult survival and growth effects, based on the Ambient Aquatic Life Criteria

for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras (November 2000; EPA-822-R-00-012), though it does not specifically address protections for larval recruitment effects or hypoxic conditions.

In march of 1977, North Carolina adopted language for Class C waters, in the .0211 rule, that allowed for the establishment of alternate DO standards for those stream sections where treatment costs would outweigh realistic potential to meet the DO standard in adopted at that time. Though this language did not appear in the Class SC .0212 rule specifically, it was expanded on and moved to its own rule (15A NCAC 02B .0213), entitled "Revisions to Dissolved Oxygen Standards", in December of 1978 where it did include Class SC waters. Rule .0213 was later repealed from NC's water quality standards in October of 1989. Historical documentation indicates that this language was repealed due to adoption of rules 15A NCAC 02B .0205 (Natural Characteristics Outside Standards Limits) and .0218 (Exemptions from Surface Water Quality Standards) that would address this issue.

History per available Division of Water Resources documentation:

Modifications to previous standards are underscored.

November 1, 1953:

- Earliest record found for North Carolina DO standard
- Reference item: "Rules and Regulations and Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina"; Adopted by State Stream Sanitation Committee, Dept. of Water Resources, SSSC #2
- Language for Class SC waters:
    - DO standard: *"Not less than 4.0 parts per million, except that swamp waters may have a minimum of 3.0 parts per million."*

October 13, 1970:

- Reference item: "Rules, Regulations, Classifications and Water Quality Standards Applicable to the Surface Waters of North Carolina"; Adopted by Board of Water and Air Resources, Dept. of Water and Air Resources
- Language for Class SC waters:
    - DO standard: *Not less than 5.0 mg/l, except that swamp waters may have a minimum of 4.0 mg/l."*

December 14, 1978:

- Introduction of new rule related to DO. No changes were made to the DO standard in 15A NCAC 02B .0211.
- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective September, 1979; Environmental Management Commission.
- 15A NCAC 02B .0213 Revisions to Dissolved Oxygen Standards
    - Revisions: *"For Class "C" and Class "SC" waters. on its own initiative or pursuant to a request under G.S. 150A-16 by affected dischargers, may grant revisions to the dissolved oxygen standard for certain stream segments, where the commission finds that:*

1. *Natural background conditions in the stream segment preclude the attainment of a daily average dissolved oxygen concentration of 5.0 mg/l; or*
2. *Irretrievable and uncontrollable man-induced conditions preclude the attainment of a daily average dissolved oxygen concentration of 5.0 mg/l; or*
3. *Application of effluent limitations for existing sources in the stream segment more stringent than present waste treatment technology in order to attain and maintain a daily average dissolved oxygen concentration of 5.0 mg/l would result in substantial adverse economic and social impact;*

- *Any such revisions shall be established in accordance with G.S 143-214.1 and shall be indicated in schedules of classifications. The revised dissolved oxygen standard shall be established at the highest level economically attainable but shall be no lower than the level attainable with the application of present waste stream technology by dischargers to the stream segment. Dischargers to such waters shall provide treatment at least as stringent as present waste treatment technology."*

September 1, 1979:

- Reference item: North Carolina Administrative Code 15A NCAC 02B .0100, 15A NCAC 02B .0200; Effective April 1, 2001; Environmental Management Commission
- Language for Class SC waters:
  - DO standard: *"Not less than 5.0 mg/l, except that swamp waters may have <u>lower values if caused by natural conditions</u>"*

October 1, 1989:

- Reference item: 15 NCAC 02B .0100, 15A NCAC 02B .0200; Effective October 1, 1989; Environmental Management Commission.
- Language for Class SC waters:
  - DO standard: *"not less than 5.0 mg/l, except that swamp waters, poorly flushed tidally influenced streams or embayments, or estuarine bottom waters may have lower values if caused by natural conditions;"*
- 15A NCAC 02B .0213 Revisions to Dissolved Oxygen Standards
  - <u>Rule repealed</u>.

Reference Items

- EPA Ambient Aquatic Life Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras (November 2000; EPA-822-R-00-012)
- EPA Quality Criteria for Water – 1986 "Gold Book" (EPA 440/5-86-001)
- North Carolina Administrative Code Title 15A Chapter 02B

North Carolina Division of Water Resources (DWR)

Surface Water Quality Standards History Document - **pH**

February 16, 2017

Overview

North Carolina currently has pH water quality standards for the following surface water classifications:

- Freshwater:
  - Class C
    - These water quality standards apply to all freshwaters in the state.
- Saltwater:
  - Class SC
    - These water quality standards apply to all tidal salt waters in the state.

Details concerning the current water quality standard, its derivation, and historical record follow.

Class C – Fresh surface waters

Designated uses per 15A North Carolina Administrative Code (NCAC) 02B .0211 (1): *"aquatic life propagation and maintenance of biological integrity (including fishing and fish), wildlife, secondary recreation, agriculture, and any other usage except for primary recreation or as a source of water supply for drinking, culinary, or food processing purposes;"*

Current standard per 15A NCAC 02B .0211 (14): *"shall be normal for the waters in the area, which range between 6.0 and 9.0 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;"*

Basis for existing standard per available DWR documentation:

North Carolina has had a Class C water quality standard for pH since at least 1953. This combined narrative and numeric standard has changed over time, but has remained consistent since being modified in rule 15A NCAC 02B .0211 in October of 1989. The scientific basis for the original pH standard cannot be definitively determined as descriptive documentation regarding its original adoption cannot be located by DWR staff, though it is probably based on the first edition of "Water Quality Criteria" by Jack Edward McKee and Harold W. Wolf in 1952. The current pH standard of 6.0-9.0 S.U. is consistent with EPA's current Nationally Recommended Water Quality Criteria for the protection of freshwater aquatic life which is based on the Quality Criteria for Water – 1986, otherwise known as the "Gold Book" (EPA 440/5-86-001). North Carolina adopted the pH exception of 4.3 S.U. for swamp waters at least as far back as 1963. The scientific basis of this exception in unknown, however it does appear in the "Water Quality

Criteria 1972" federal guidance report from the Committee of Water Quality Criteria Environmental Studies Board (requested & funded by EPA). The language in rule regarding this exception has changed slightly over the years, but has remained consistent since being modified in 15A NCAC 02B .0211 in October of 1989.

History per available Division of Water Resources documentation:

Modifications to previous standards are underscored.

November 19, 1953:

- Earliest record found for North Carolina pH standard
- Reference item: "Rules and Regulations and Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina"; Adopted by State Stream Sanitation Committee, Dept. of Water Resources, SSSC #2
- Language for Class C waters:
    - pH standard: *"shall be normal for the waters in the area, which generally shall range between 6.0 and 8.5 except that swamp waters may have a low of 4.3."*

February 1, 1986:

- Reference item: 15A NCAC 02B .0100, 15A NCAC 02B .0200; Effective February 1, 1986; Environmental Management Commission.
- Language for Class C waters:
    - pH standard: *"shall be normal for the waters in the area, which generally shall range between 6.0 and 9.0 except that swamp waters may have a low of 4.3."*

October 1, 1989:

- Reference item: 15A NCAC 02B .0100, 15A NCAC 02B .0200; Effective October 1, 1989; Environmental Management Commission.
- Language for Class C waters:
    - pH standard: *"shall be normal for the waters in the area, which range between 6.0 and 9.0 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;"*

Class SC – Tidal salt waters

Designated uses per 15A NCAC 02B .0220 (1): *"any usage except primary recreation or shellfish for market purposes; usages include aquatic life propagation and maintenance of biological integrity (including fishing, fish and functioning Primary Nursery Areas (PNAs)), wildlife, and secondary recreation;"*

Current standard per 15A NCAC 02B .0220 (12): *"shall be normal for the waters in the area, which range between 6.0 and 8.5 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;"*

Basis for existing standard per available Division of Water Resources documentation:

North Carolina has had a Class SC water quality standard for pH since at least 1953. This combined narrative and numeric standard has remained consistent over time save for a slight modification to the language regarding swamp waters adopted in rule 15A NCAC 02B .0212 in October of 1989. The scientific basis for the original pH standard cannot be definitively determined as descriptive documentation regarding its original adoption cannot be located by DWR staff though it is probably based on the first edition of "Water Quality Criteria" by Jack Edward McKee and Harold W. Wolf in 1952. The current pH standard of 6.0-8.5 S.U. is consistent with EPA's current Nationally Recommended Water Quality Criteria for the protection of saltwater aquatic life which is based on the Quality Criteria for Water – 1986, otherwise known as the "Gold Book" (EPA 440/5-86-001). North Carolina adopted the pH exception of 4.3 S.U. for swamp waters at least as far back as 1953. The scientific basis of this exception in unknown, however it does appear in the "Water Quality Criteria 1972" federal guidance report from the Committee of Water Quality Criteria Environmental Studies Board (requested & funded by EPA). The language in rule regarding this exception has changed slightly over the years, but has remained consistent since being modified in 15A NCAC 02B .0220 in October of 1989.

History per available Division of Water Resources documentation:

Modifications to previous standards are underscored.

November 1, 1953:

- Earliest record found for North Carolina pH standard
- Reference item: "Classifications and Water Quality Standards Applicable to Surface waters of North Carolina"; Adopted by State Stream Sanitation Committee, Dept. of Water Resources, SSSC #2
- Language for Class SC waters:
    - pH standard: *"shall be normal for the waters in the area, which generally shall range between 6.0 and 8.5 except that swamp waters may have a low of 4.3."*

October 1, 1989:

- Reference item: 15A NCAC 02B .0100, 15A NCAC 02B .0200; Effective October 1, 1989; Environmental Management Commission
- Language for Class SC waters:
    - pH standard: *"shall be normal for the waters in the area, which range between 6.0 and 8.5 except that swamp waters may have a pH as low as 4.3 <u>if it is the result of natural conditions</u>;"*

April 1, 2001:

- Reference item: 15A NCAC 02B .0100, 15A NCAC 02B .0200; Effective April 1, 2001; Environmental Management Commission
- Language for Class SC waters:
    - pH standard: *"shall be normal for the waters in the area, which range between 6.0 and 8.5 except that swamp waters may have a pH as low as 4.3 if it is the result of natural conditions;"*

- Rule identity for Class SC changed from 15A NCAC 02B .0212 to 15A NCAC 02B .0220

Reference Items

- EPA Quality Criteria for Water – 1986 “Gold Book” (EPA 440/5-86-001)
- North Carolina Administrative Code Title 15A Chapter 02B
- Water Quality Criteria 1972 Committee of Water Quality Criteria Environmental Studies Board (requested & funded by EPA)