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APPENDIX A

Methods for Daily Climate Index Development & Additional 2015 Water Quality Data

Daily Climate Index Development & Relationship with Schmidt Stability

To determine the conditions that dictate the duration of stratification in Kentuck Lake each year, a Daily Climate Index (DCI) using daily average air temperature, daily average wind speed, and daily average wind direction was developed and compared against the lake's thermal stability. Thermal stability is a measure of how much work is needed to mix the entire water column of water and is measured in g/cm. A stability value of 0 indicates the entire water column is of uniform temperature and no work is needed to mix it. A higher stability value indicates that a strong temperature/density gradient exists between surface and bottom waters and that more work or energy is needed to mix them together. The goal of this analysis is to determine the conditions that lead to the onset of stratification, the conditions that maintain stratification, and conditions that result in mid-summer mixing events.

Kentuck Lake's maximum fetch length is oriented from southwest to northeast meaning that southwest and northeast winds will impart the highest energy across the lake and most likely to result in mixing events. In the DCI, if daily wind direction was equal to or between 202.5° and 247.5° (west-southwest to south-southwest) or 22.5° and 67.5° (north-northeast to east-northeast) wind speed was multiplied by a factor of 1.75. The DCI and Schmidt Stability Index were calculated using the following equations:

Daily Climate Index (DCI):

$$DCI = \frac{T_z}{\sqrt{W_z * W_d}}$$

Where
T_z = Daily average air temperature (°C)
W_z = Daily average wind speed (kph)
W_d = Wind direction factor. W_d = 1.75 if 22.5°≤ daily wind direction ≤ 67.5° or 202.5° ≤ daily wind direction ≤ 247.5°; otherwise W_d = 1

Schmidt Stability Index:

$$S = \frac{1}{A_0} \sum_{z=0}^{z=m} (p_z - p^*)(z - z_p)(A_z)(\Delta z)$$

Where
A_0 = the area of the water body (cm^2)
A_z = lake area at depth z (cm)
p_z = density as calculated from temperature (g/cm^2)
p^* = lake's mean density (g/cm^2)
z_p = depth at which mean density is found (cm)
m = maximum depth of the lake (cm)
Δz = depth interval of measurements (cm)

To explore both short and longer-term effects of weather on Kentuck Lake's thermal stability, the mean DCI value was calculated over 1, 2, 3, 5, 7, 10, and 15 days prior to the collection of lake temperature data. A Pearson pairwise correlation using the 2014 and 2015 DCI and stability data collected from spring turnover through the first mid-summer complete mixing event was used to determine which mean DCI period was the best predictor of thermal stability. The results of the Pearson pairwise correlation indicated that the 7-day mean DCI value was the strongest predictor of thermal stability in Kentuck Lake with an r value of 0.927 (Table 1).

Table 1. Pearson pairwise correlation tables of established mean 2014 and 2015 Daily Climate Index periods and Schmidt stability from spring turnover to the first summer mixing event (left) and post-summer mixing event (right). Values represent the correlation r values.

Spring Turnover to Summer Mixing Event

DCI Time Period	Schmidt Stability (g/cm)
1-day Mean DCI Value	0.747
2-day Mean DCI Value	0.825
3-day Mean DCI Value	0.878
5-day Mean DCI Value	0.910
7-day Mean DCI Value	0.927
10-day Mean DCI Value	0.893
12-day Mean DCI Value	0.839
15-day Mean DCI Value	0.789

Post-Summer Mixing Event

DCI Time Period	Schmidt Stability (g/cm)
1-day Mean DCI Value	0.610
2-day Mean DCI Value	0.732
3-day Mean DCI Value	0.745
5-day Mean DCI Value	0.748
7-day Mean DCI Value	0.748
10-day Mean DCI Value	0.802
12-day Mean DCI Value	0.744
15-day Mean DCI Value	0.639

Linear regression of the 2014 and 2015 7-day mean DCI and thermal stability data from spring turnover through the first mid-summer mixing event illustrates a good relationship with an R^2 of 0.822 (Figure 1). Another Pearson pairwise correlation of 2015 dissolved oxygen recorded at two-foot intervals from site 1 and epilimnetic total phosphorus concentrations indicated that dissolved oxygen at 30 feet was the best predictor of epilimnetic phosphorus concentration (r value -0.742). Plotting 2014 and 2015 dissolved oxygen at 30 feet against thermal stability revealed an exponential relationship ($R^2 = 0.858$), with 30 feet developing anoxia (dissolved oxygen < 2.0 mg/L) when thermal stability is approximately 64 g/cm. A thermal stability of 64 g/cm develops when the 7-day mean DCI is approximately 5.3 (Figure 1).

If the 7-day mean DCI is maintained at or above 5.3, thermal stability will increase and anoxic conditions will be maintained that will lead to significant release of nutrients from bottom sediments and an increase in epilimnetic phosphorus concentration. However, if the 7-day mean DCI declines to 5.3 after the lake has already thermally stratified, a complete mixing event will likely occur. In 2014, thermal stability reached 64 g/cm in late-May and stability reached a maximum of 120 g/cm in late-June (Figure 2). The 7-day mean DCI declined to below the 5.3 threshold in early-July and a complete mixing event was observed. In 2015, thermal stability reached 64g/cm in mid-June and continued to increase with the 7-day mean DCI (Figure 2). From early- to mid-July, the 7-day mean DCI began to decline from 7.8 to 5.8 causing a decline in thermal stability and significant deepening of the epilimnion but did not cause a complete mixing event. It was not until late-August when the 7-day mean DCI dropped below 5.3 and reaching a minimum of 3.7 that a complete mixing event occurred.

Climatic conditions are a good predictor of thermal stability and the duration of anoxia in Kentuck Lake from spring turnover through the first summer mixing event; however, this same predictive model does not accurately predict thermal stability based on climatic conditions following a complete summer mixing event. While a thermal stability value of 0 indicates a uniform temperature throughout the entire water column, it does provide any information on the temperature of the water. While thermal stability is 0 during both spring turnover and during summer mixing events, water column temperature is much warmer in summer. With water temperatures throughout the water column now similar to summer air temperatures, a strong thermal gradient can no longer be created and thermal stability remains relatively low. Following the 2014 and 2015 summer mixing events, thermal stability never exceeded 50 g/cm despite higher 7-day mean DCI values.

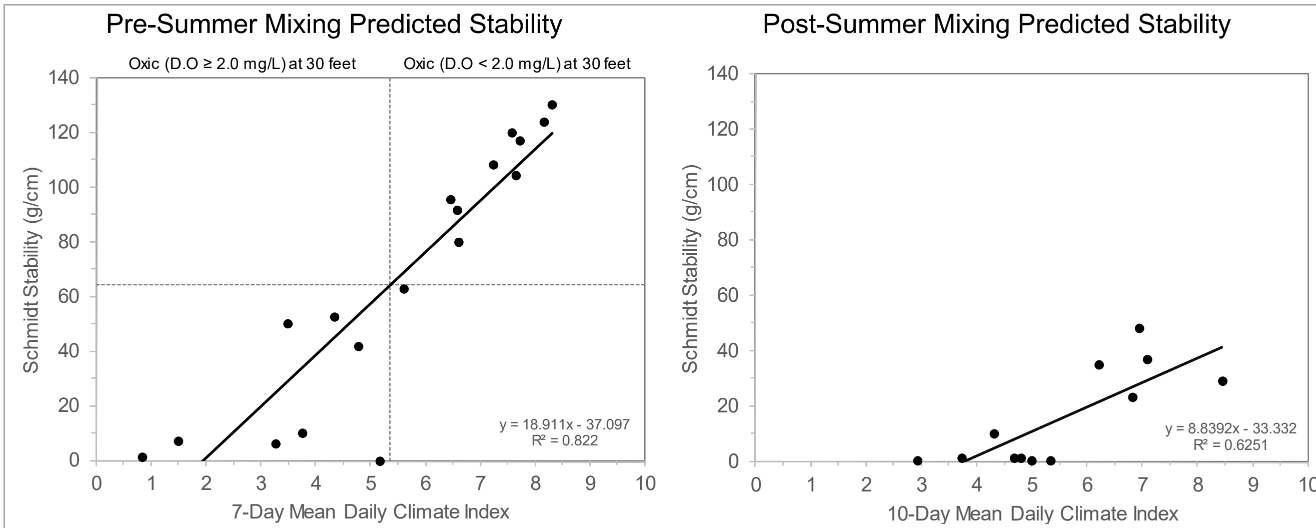

Figure 1. Linear regressions of 2014 and 2015 7-day mean Daily Climate Index and Schmidt stability from spring turnover through the first summer mixing events (left) and 10-day mean Daily Climate Index and Schmidt stability following summer mixing events (right).

Using 2014 and 2015 post-summer mixing climatic and stability data, another predictive model created to predict stability following a summer mixing event. A Pearson pairwise correlation indicated that the 10-day mean DCI was the best predictor of thermal stability following a mixing event with an r value 0.802 (Table 1). The linear regression of the post-summer mixing 10-day DCI and stability data are displayed in Figure 1, and Figure 2 illustrates that this additional model is a better predictor of stability following a summer mixing event.

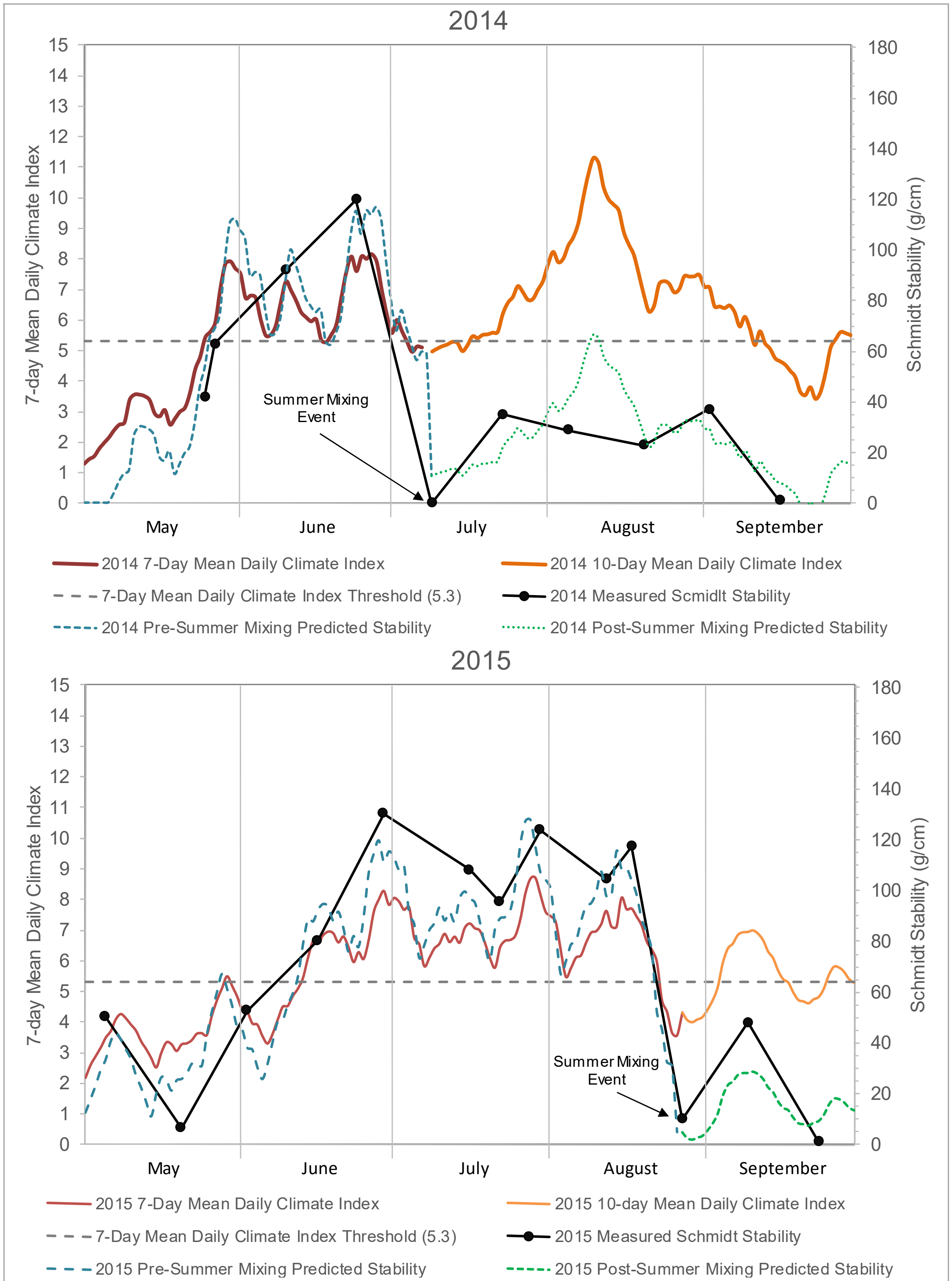

Figure 2. Kentuck Lake 2014 and 2015 growing season measured stability, pre-summer mixing predicted stability based on 7-day mean Daily Climate Index, and post-summer mixing predicted stability based on 10-day mean Daily Climate Index. Anoxic conditions are present at 30 feet and deeper when pre-summer mixing 7-day mean Daily Climate Index values are above 5.3 and stability is above 64 g/cm.

Kentuck Lake 2015 Additional Water Quality Data

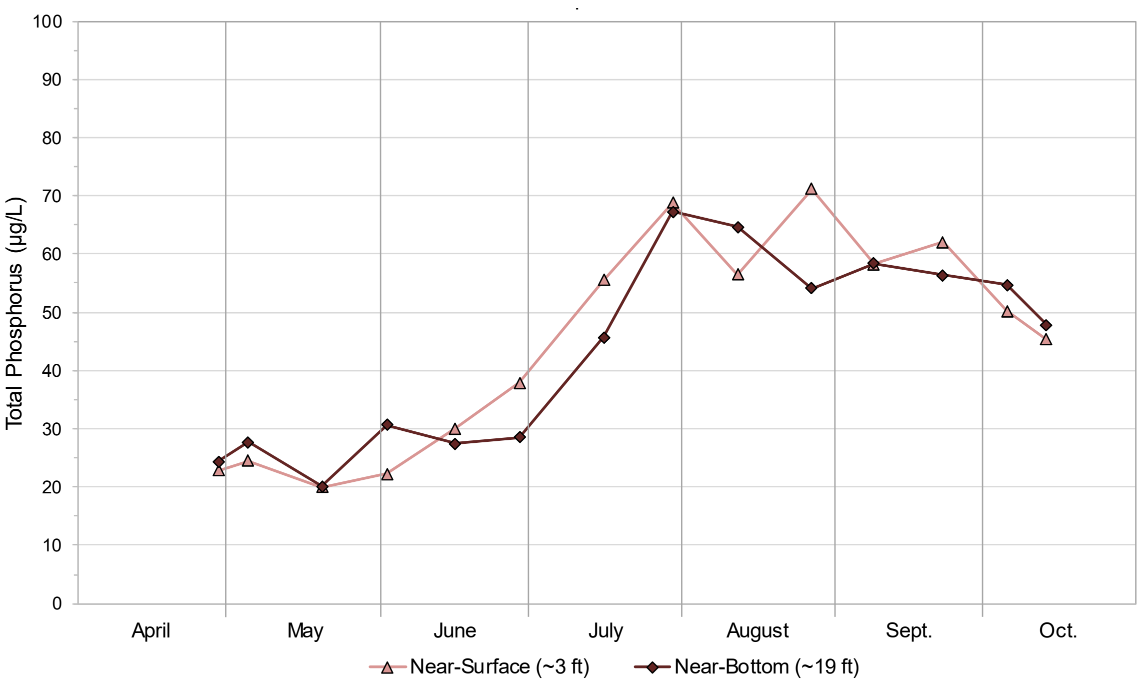

Figure 3. Kentuck Lake 2015 near-surface and near-bottom total phosphorus concentrations from site 2.

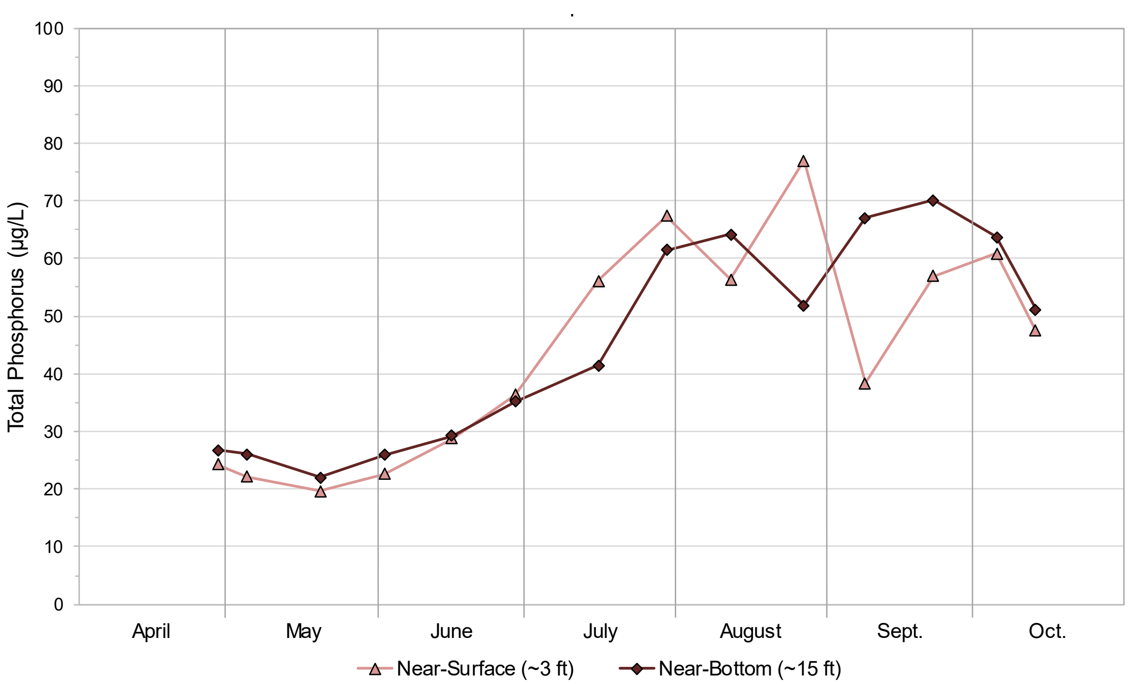

Figure 4. Kentuck Lake 2015 near-surface and near-bottom total phosphorus concentrations from site 3.

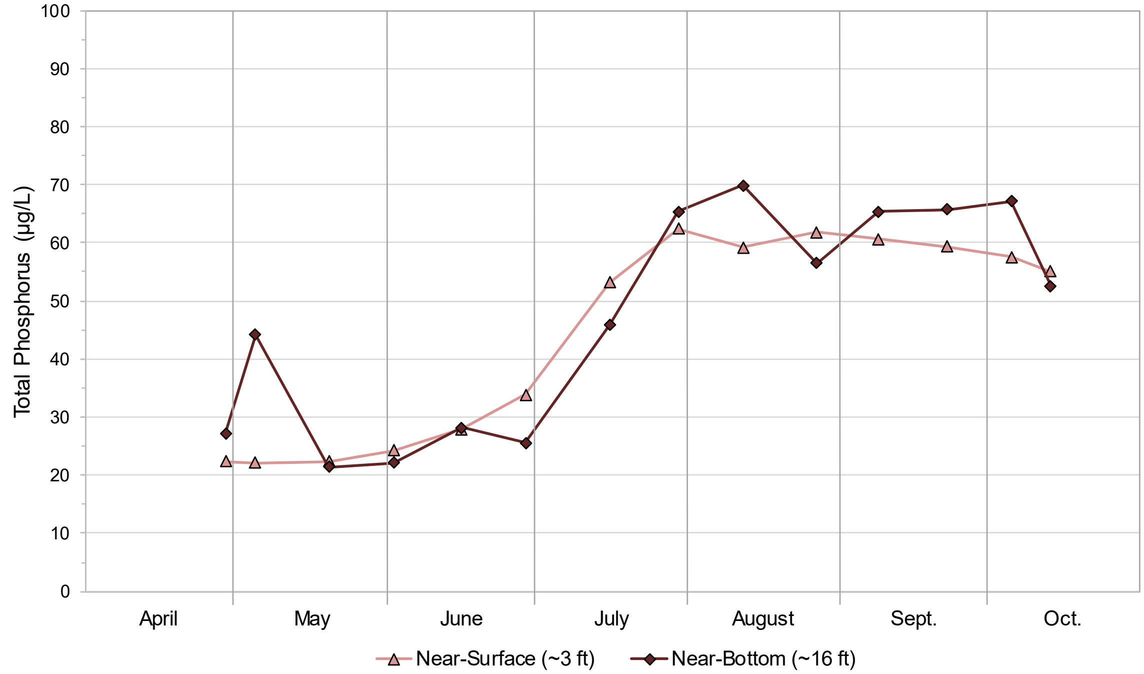

Figure 5. Kentuck Lake 2015 near-surface and near-bottom total phosphorus concentrations from site 4.

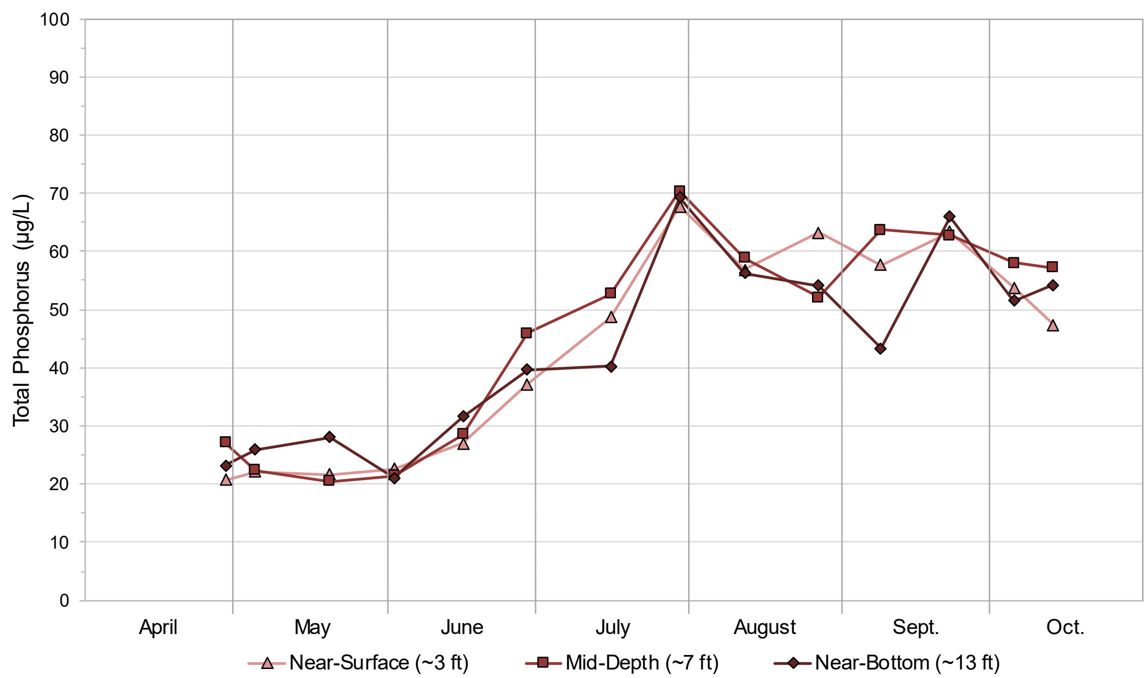

Figure 6. Kentuck Lake 2015 near-surface, mid-depth, and near-bottom total phosphorus concentrations from site 5.

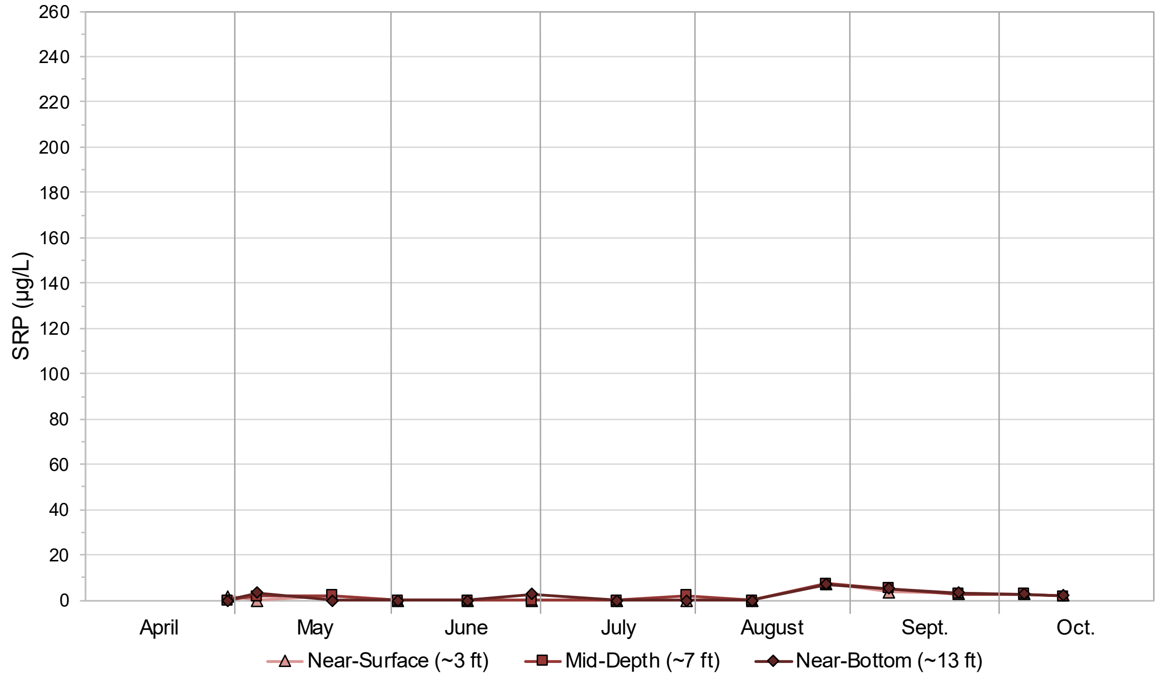

Figure 7. Kentuck Lake 2015 near-surface and near-bottom soluble reactive phosphorus concentrations from site 5.

Table 2. Kentuck Lake 2015 dominant phytoplankton taxa. Analysis completed by Jim Kreitlow (WDNR).

Date	Depth (ft)	Temp. (°C)	D.O. (mg/L)	Dominant Taxa	Type
4/29/2015	3.0*	8.7	11.7	*Asterionella formosa* *Gymnodinium* sp.	Diatom Dinoflagellate
	20.0*	8.7	11.5	No Dominant Taxa	
	38.0*	7.2	8.6	*Asterionella formosa* *Cryptomonas* sp. *Fragilaria crotonensis*	Diatom Cryptomonad Diatom
5/5/2015	3.0	14.0	10.8	No Dominant Taxa	
	20.0*	12.2	10.2	No Dominant Taxa	
	37.0*	7.7	4.6	*Trachelomonas* sp.	Euglenid
5/20/2015	3.0*	13.9	10.0	*Asterionella formosa* *Dinobyron* sp. *Fragilaria crotonensis* *Synedra ulna*	Diatom Golden Brown Diatom Diatom
	25.0*	13.2	10.0	*Asterionella formosa*	Diatom

				Dictyopsphaerium sp.	Green
				Dinobyron sp.	Golden Brown
	37.0*	13.1	9.7	*Asterionella formosa*	Diatom
				Dinobyron sp.	Golden Brown
				Mallamonas sp.	Golden Brown
				Synedra ulna	Diatom
6/2/2015	3.0*	17.4	9.7	*Asterionella formosa*	Diatom
				Dinobyron sp.	Golden Brown
	20.0*	17.0	9.6	*Asterionella formosa*	Diatom
				Dinobyron sp.	Golden Brown
				Fragilaria crotonensis	Diatom
	37.0*	13.1	9.0	*Asterionella formosa*	Diatom
				Melosira sp.	Diatom
				Trachelomonas sp.	Euglenid
6/16/2015	3.0	19.3	10.0	*Anabaena* spp.	Blue-green
				Cryptomonas sp.	Cryptomonad
				Gloeotrichia echinulata	Blue-green
	28.0*	17.2	1.7	*Asterionella formosa*	Diatom
				Fragilaria crotonensis	Diatom
				Melosira sp.	Diatom
	37.0*	12.6	0.0	*Asterionella formosa*	Diatom
				Fragilaria crotonensis	Diatom
6/29/2015	3.0	23.6	11.7	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
	26.0*	18.3	1.0	*Dictyosphaerium* sp.	Green
	37.0*	12.9	0.0	No Dominant Taxa	
7/16/2015	3.0	23.1	10.5	*Anabaena* spp.	Blue-green
				Gloeotrichia echinulata	Blue-green
	21.0*	19.9	1.2	No Dominant Taxa	
	37.0*	14.0	0.0	*Melosira* sp.	Diatom
				Stephanodiscus sp.	Diatom
7/30/2015	3.0	23.0	7.9	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green

				Ceratium hirundinella	Dinoflagellate
	30.0	16.8	0.2	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Ceratium hirundinella	Dinoflagellate
				Gloeotrichia echinulata	Blue-green
	35.0	13.0	0.0	*Anabaena* spp.	Blue-green
8/12/2015	3.0	21.5	8.4	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
	31.0	14.6	0.1	*Anabaena* spp.	Blue-green
				Stephanodiscus sp.	Diatom
	36.0	13.3	0.4	*Anabaena* spp.	Blue-green
				Stephanodiscus sp.	Diatom
8/27/2015	3.0	17.9	11.0	*Anabaena* spp.	Blue-green
				Dictyosphaerium sp.	Green
				Fragilaria crotonensis	Diatom
				Mallamonas sp.	Golden Brown
				Stephanodiscus sp.	Diatom
				Synedra sp.	Diatom
	20.0	17.5	8.3	*Anabaena* spp.	Blue-green
				Fragilaria crotonensis	Diatom
				Gomphosphaeria sp.	Blue-green
				Melosira sp.	Diatom
				Stephanodiscus sp.	Diatom
				Synedra sp.	Diatom
	36.0	17.1	7.5	*Dictyosphaerium* sp.	Green
				Euastrum sp.	Green
				Fragilaria crotonensis	Diatom
				Gomphosphaeria sp.	Blue-green
				Pediastrum boryanum	Green
				Stephanodiscus sp.	Diatom
				Synedra sp.	Diatom
9/9/2015	3.0	21.4	9.7	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Dictyosphaerium sp.	Green
				Fragilaria crotonensis	Diatom
				Stephanodiscus sp.	Diatom
	19.0	18.9	0.6	*Anabaena* spp.	Blue-green

				Aphanizomenon flos-aquae	Blue-green
				Fragilaria crotonensis	Diatom
				Synedra sp.	Diatom
	37.0*	17.8	0.0	*Fragilaria crotonensis*	Diatom
				Synedra sp.	Diatom
9/23/2015	3.0	17.8	10.6	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Cryptomonas sp.	Cryptomonad
				Gomphosphaeria sp.	Blue-green
				Stephanodiscus sp.	Diatom
	20.0	17.8	10.2	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Gomphosphaeria sp.	Blue-green
				Stephanodiscus sp.	Diatom
	37.0	17.6	6.4	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Gomphosphaeria sp.	Blue-green
				Stephanodiscus sp.	Diatom
10/6/2015	3.0	13.9	10.2	*Anabaena* spp.	Blue-green
				Aphanizomenon flos-aquae	Blue-green
				Coelosphaerium sp.	Blue-green
				Fragilaria crotonensis	Diatom
	20.0	13.8	10.0	*Dictyosphaerium* sp.	Green
				Fragilaria crotonensis	Diatom
				Gomphosphaeria sp.	Blue-green
				Melosira sp.	Diatom
				Stephanodiscus sp.	Diatom
	37.0	13.8	10.2	*Dictyosphaerium* sp.	Green
				Fragilaria crotonensis	Diatom
				Gomphosphaeria sp.	Blue-green
				Melosira sp.	Diatom
				Stephanodiscus sp.	Diatom
10/14/2015	3.0	12.2	11.6	*Dictyosphaerium* sp.	Green
				Fragilaria crotonensis	Diatom
				Gomphosphaeria sp.	Blue-green
				Melosira sp.	Diatom
				Stephanodiscus sp.	Diatom

20.0	12.2	11.4	*Aphanizomenon flos-aquae*	Blue-green
			Fragilaria crotonensis	Diatom
			Gomphosphaeria sp.	Blue-green
			Melosira sp.	Diatom
			Stephanodiscus sp.	Diatom
37.0	12.1	11.6	*Dictyosphaerium* sp.	Green
			Fragilaria crotonensis	Diatom
			Gomphosphaeria sp.	Blue-green
			Melosira sp.	Diatom
			Stephanodiscus sp.	Diatom

**Blue-green algae present but not dominant*