Town of Plymouth
Pond and Lake Atlas
Update 2 – 2016 Data Collection
May 2017

Prepared by:

Town of Plymouth
Department of Marine & Environmental Affairs

Laboratory and Data Analysis:

Coastal Systems Program,
School for Marine Science and Technology
University of Massachusetts Dartmouth

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Special Note:
This update has been developed by the Town of Plymouth Department of Marine and Environmental Affairs with Professional Data Analysis and Laboratory Analysis from the Coastal Systems School of Marine Science and Technology as noted in Summary.

Please refer to the Town of Plymouth Pond and Lake Atlas, Final Report, June 2015 for full report and additional water quality information. 2015 data can be found in the Update 1- 2015 document. This document is an addition to the Final Report for water quality sampling collected in the summer of 2016.

The Town of Plymouth Department of Marine and Environmental Affairs funded additional pond sampling in 2016 as part of the ongoing Ponds and Lake Stewardship Program. On the following ponds samples were collected and analyzed by the School of Marine Science and Technology with snapshot data sheets attached hereto:

- Little Herring Pond
- Great Herring Pond
- Kings Pond
- Savery Pond

In 2016, attached herein, is a snapshot for Kings Pond and technical memorandum for Savery Pond. In 2016 Town Staff spent extensive time collecting bi-monthly samples and profiles at Savery as well as installation and maintenance of continuous dissolved oxygen monitoring equipment.

Kings Pond

PALS Pond Number: 253
MassDEP PALIS Number: 95078

Area (acres): 23.9
Bathymetry: none
Maximum Depth (m):
Lake Association:

PALS Sampling	8/30/16		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.2 m		
Total Depth	3.5 m		
Surface pH	5.77	6.5 – 8.3	MassDEP
Deepest DO	-	5.0 mg/L	MassDEP
Shallow temperature	25.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.97 µg/L	1.7 µg/L	CCC
Surface TP	13.0 µg/L	10 µg/L	CCC
Surface TN	0.51 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.5		

OVERVIEW

Kings Pond is located east of Federal Furnace Road and the municipal airport. The shoreline is nearly completely developed with residential development including intense development along the southeastern side where lots tend to be less than a quarter of an acre. There is informal public access via a path through town-owned land at the end of Lancaster Avenue. No bathymetric map was found during the collection and review of historic ponds reports.

Review of available historic reports also suggest that water quality samples collected during the 2016 PALS Snapshot appear to be the first samples collected from the pond. Kings Pond was assigned to the "no uses assessed" category in the latest Massachusetts Integrated List of Waters (MassDEP, 2015).

WATER QUALITY

Data collected during the 2016 PALS Snapshot raised questions about the water quality status of the pond. Observations noted extensive aquatic plant (macrophyte) growth (~80% water lilies across the water surface), but the surface chlorophyll concentration was acceptable. Water column total phosphorus concentrations were moderately elevated, but this also may be due to most of the available phosphorus being utilized by the macrophytes. Total nitrogen concentrations were also somewhat elevated. Comparison of nitrogen and phosphorus concentrations indicated that phosphorus was the key nutrient for managing water quality in Kings Pond. Total depth at the time of the Snapshot showed that the pond is relatively shallow with some loss of clarity and consistent temperatures throughout the water column indicated it was well mixed. The dissolved oxygen probe did not function correctly during the sampling run, so this data was unavailable. Review of historic aerial maps seems to show extensive macrophyte growth throughout the pond has existed since at least 2003.

The available water quality data for Kings Pond suggest that is moderately impaired, but the review of aerial maps suggest that uses of the water are likely impaired by extensive macrophyte growth. Review of macrophyte management techniques should include consideration of the water quality impacts of the techniques, so macrophyte removal does not create conditions that make phosphorus in the pond available for phytoplankton growth with accompanying loss of clarity and potential algal blooms. Additional water quality monitoring and characterization of the macrophytes would be required to develop potential management options, including the identification and evaluation of the nutrient sources contributing to the pond.

Technical Memorandum

To: Kim Tower, Town of Plymouth, Environmental Technician

From: Eduard Eichner, TMDL Solutions, Water Scientist

RE: Savery Pond 2016 Water Quality Monitoring

Date: December 9, 2016

Savery Pond is a 29.4 acre Great Pond located west of Old Sandwich Road and south of Lake Road (PPALS Pond #37, MassDEP PALIS #94136). The pond was sampled as part of the initial 2014 Plymouth Pond and Lake Stewardship (PPALS) snapshot and has been sampled a number of other times including Town-funded snapshot samplings in 2015 and 2016. As part of the 2016 sampling strategy, the Town also deployed a continuous recording device (*i.e.*, sonde) along with three temperature dataloggers over a deep location in the pond. The sonde was programmed to record a number of factors, including temperature, dissolved oxygen, chlorophyll, and depth. This technical memorandum summarizes the results of the samplings and sonde deployment and compares these results to regulatory and ecological standards.

2016 Continuous Recording

In late May 2016, Town staff installed an YSI 6600 V2 sonde and three HOBO temperature recorders over the deepest point in Savery Pond. The sonde was cleaned, calibrated and setup by staff from the Coastal System Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST). The sonde had probes installed to measure temperature, specific conductivity, pressure, depth, chlorophyll, dissolved oxygen, salinity and total dissolved solids. Readings were initially programmed to be recorded every 15 minutes, but was reprogrammed for every 30 minutes following a battery failure in mid-June. Three HOBO temperature recorders were installed at the same location at shallower depths on June 13 and were programmed to record every 15 minutes after calibration. All recording devices were deployed using standard techniques (Figure 1) and were removed in early October.

The total depth at the initial deployment was 3.8 m and it was thought that the sonde probes were at a depth of 3 m. Review of depth recordings indicates that the average depth of the sonde probe was 2.42 m (Figure 2). Given the observations and the secure separation among the recording devices when they were installed, the sonde depth data suggest all recordings occurred at depths approximately 0.5 m shallower than initially designed: HOBOs at 0.5 m, 1.5 m and 2 m; YSI sonde probes at 2.4 m.

Temperature readings showed changeable patterns throughout the recording period. In June to mid-August, there was persistent thermal separation or layering within the pond interrupted by occasional water column mixing that tended to begin at the surface and work toward the deeper

waters (Figure 3). Mixing among the upper 2 m was more frequent with water at 2.4 m often notably colder. After mid-August, this layering mostly disappeared and the whole water column tended to be isothermic. Temperatures increased throughout June, July and the middle of August before beginning a slow general decrease that continued until the recording devices were removed.

During the period of increasing temperatures, temperatures were generally sufficiently different at the top (0.5 m) and bottom (2.4 m) of the water column that there was thermal resistance to mix the water column. One notable exception during this period of thermal layering began on July 9 and persisted for approximately 5 days; the water column during this period largely mixed throughout. On July 8 the Massachusetts Department of Public Health (MassDPH) issued a cyanobacteria (blue green algae) advisory. It is likely that the mixing of the water column during this period allowed deeper waters with higher nutrient levels to feed the phytoplankton population and prompted the algal bloom.

The continuous dissolved oxygen (DO) concentrations show number of days of anoxia just before the cyanobacteria bloom; this anoxia would have tended to support an increase rate of nutrient regeneration from the sediments. Data collected by the sonde at 2.4 m showed that DO concentrations began to decline from a peak in mid-June, became anoxic around July 4, rebounded on July 9 (when the water column mixed), then entered a period between July 19 and August 3 where water at this depth had no measurable DO (Figure 4). DO began to recover after this period, but generally remained below the Massachusetts Department of Environmental Protection minimum concentration of 5 mg/L (310 CMR 4.05). The DO meter stopped recording reliable measurements on August 23. During the reliable recording period, 62% of the readings were below the MassDEP 5 mg/L minimum.

Continuous chlorophyll readings were also generally consistent with temperature and dissolved oxygen data. Chlorophyll readings at 2.4 m were at their lowest levels beginning on July 1 (Figure 5), which would be consistent with most of the nutrients and phytoplankton in the upper portions of the water column. These conditions persisted until July 16 when a significant spike occurred; this would be consistent with dying, post-bloom phytoplankton settling lower in the water column. This is also roughly when thermal layering was reestablished in the water column. The combination of thermal layering and increased oxygen demand by sediment bacteria breaking down settling phytoplankton helps to explain the prolonged period of anoxia after the cyanobacteria bloom. Most of the chlorophyll readings were above the ecoregion guidance concentration (1.7 µg/L); 92% of readings were above this concentration.

2016 Snapshot Water Quality Sampling

In addition to the installation of the continuous dataloggers, water quality samples were collected on 8 dates in 2016 between May and September. These individual snapshot sampling runs followed procedures in the PPALS state-approved Quality Assurance Project Plan (QAPP), which also was the basis for 2014 and 2015 sampling in Savery Pond. Procedures included collection of dissolved oxygen and temperature profiles throughout the water column, measurement of Secchi transparency, and collection of water quality samples at 0.5 m and 1 m above the bottom. Collected samples were analyzed at the SMAST Coastal Systems Analytical

Facility in New Bedford for: 1) pH, 2) alkalinity, 3) chlorophyll a, 4) pheophytin a, 5) total phosphorus (TP), and 6) total nitrogen.

Profile data generally mirrored characteristics measured by the continuous dataloggers, although the more limited number of snapshot readings would have suggested less impaired conditions if these were the only data available. Eight (8) of the 29 deeper DO readings (28%) were below the MassDEP minimum concentration. Comparison of all data since the 2014 PPALS Snapshot showed the regularity of low DO conditions (Figure 6), but also showed supersaturated conditions (*i.e.*, above concentrations in equilibrium with atmospheric concentrations). Snapshot temperature readings showed some sense of the thermal layering found in the continuous data, but again did not capture its variability or persistence as well as the continuous data. Comparison of all data since the 2014 PPALS Snapshot showed more pronounced layering in 2015 than in 2016 (Figure 7).

Secchi clarity readings during 2016 showed late May clarity at 66% of the water column (2.5 m), then a drop to the lowest clarity by late July (27%; 1.05 m) and a gradual increase in clarity to 61% (2.2 m) in early October. Comparison of 2016 to 2015 generally shows a similar pattern, although it is notable that clarity was all the way to the bottom in early October 2015 (Figure 8).

The water quality data from the collected snapshot samples generally reinforce the impaired conditions in the pond. Shallow TP concentration averaged 39 µg/L, which is nearly four times the ecoregion guidance level of 10 µg/L.[1] Deep TP averaged 62 µg/L, but this concentration is not statistically different than the shallow average due to the variability in both sets of readings. This variability is likely related to the variability in the thermal layering in the pond. Shallow and deep TN average concentrations were more similar (1.6 mg/L and 1.9 mg/L), but this should be expected given the differences in TP and TN sediment regeneration chemistry and the greater phosphorus sensitivity of the system. Chlorophyll a concentrations averaged 7.9 µg/L, which is 4.6 times the ecoregion guidance level of 1.7 µg/L.[2] This high average concentration was consistent with the continuous datalogger readings. The average chlorophyll a concentration was slightly higher during August/September, which was consistent with slightly higher TP concentrations. N to P ratios showed that phosphorus was the limiting nutrient and, as such, control of its availability will determine water quality conditions in the pond. All 2016 data is listed in Appendix A.

Conclusions/Recommendations

Savery Pond is an impaired ecosystem with excessive nutrients and dissolved oxygen concentrations that were regularly lower than regulatory thresholds. Water quality data collected during 2016 amplified and strengthened the understanding of the characteristics of this impairment. In particular, installation of a continuous datalogger for dissolved oxygen, temperature, chlorophyll and depth with supplementary temperature dataloggers at various depths showed how the pond regularly had temperature layering that prevents mixing of the

[1] Eichner, E.M., B.L. Howes, and S. Horvet. 2015. Town of Plymouth Pond and Lake Atlas. Town of Plymouth, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 138 pp.

[2] *Ibid*.

whole water column. This layering contributed to low dissolved oxygen levels and high phosphorus concentrations, especially in waters close to the bottom of pond.

The next step recommended for this system is the preparation of a water quality management plan. This management plan should address some of the known data gaps, including measurement of sediment nutrient regeneration rates under hypoxic and anoxic conditions, nutrient loads from the pond watershed, and quantification of stream water and nutrient outflows. The plan should also detail options to remediate and restore the system, their potential costs, and regulatory issues that will need to be addressed. The Town is currently evaluating options to proceed with a management plan.

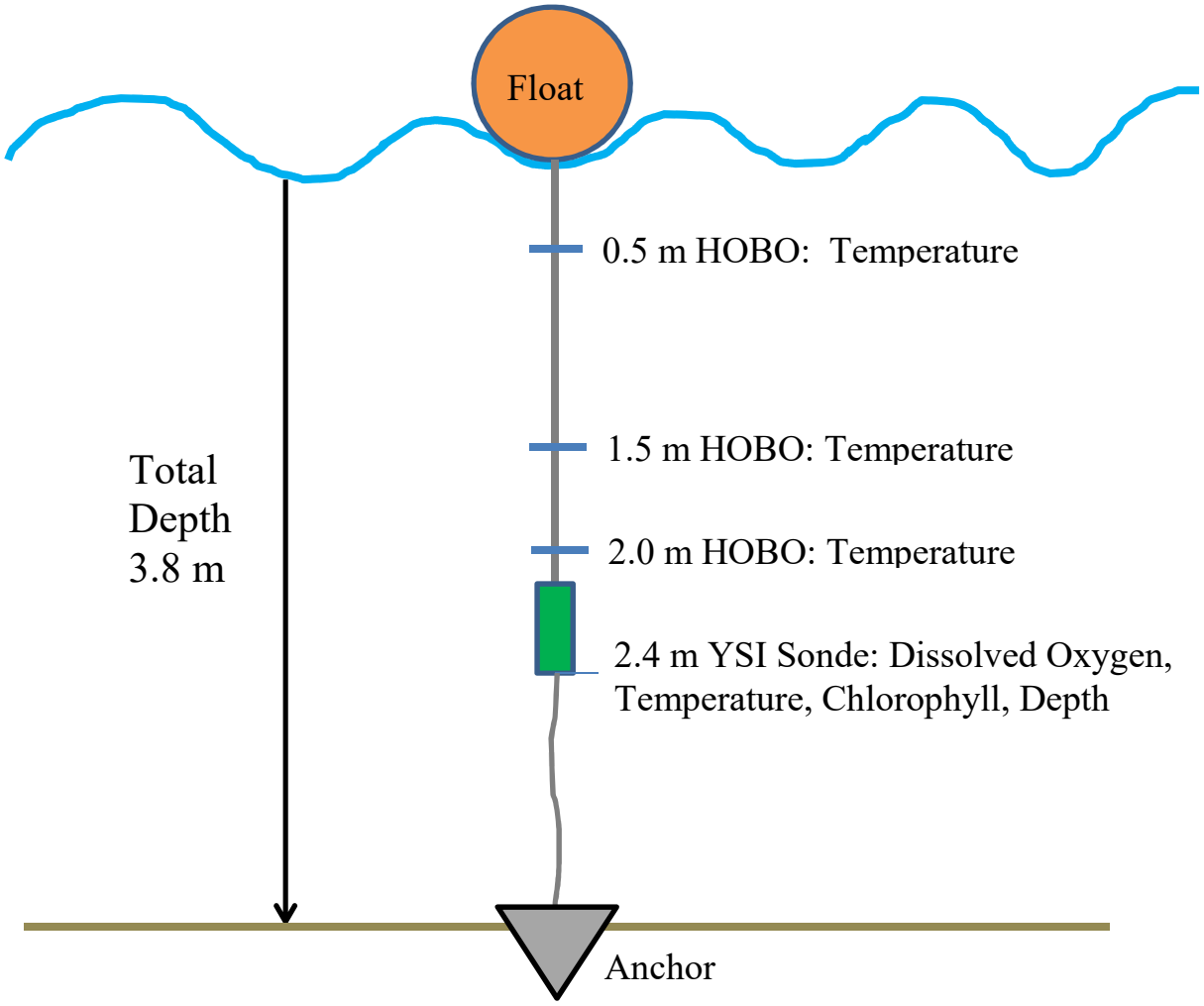

Figure 1. 2016 Continuous Dataloggers Installation in Savery Pond (May 31 to October 4). Data loggers were programmed to record readings every 30 minutes. Diagram is not to scale.

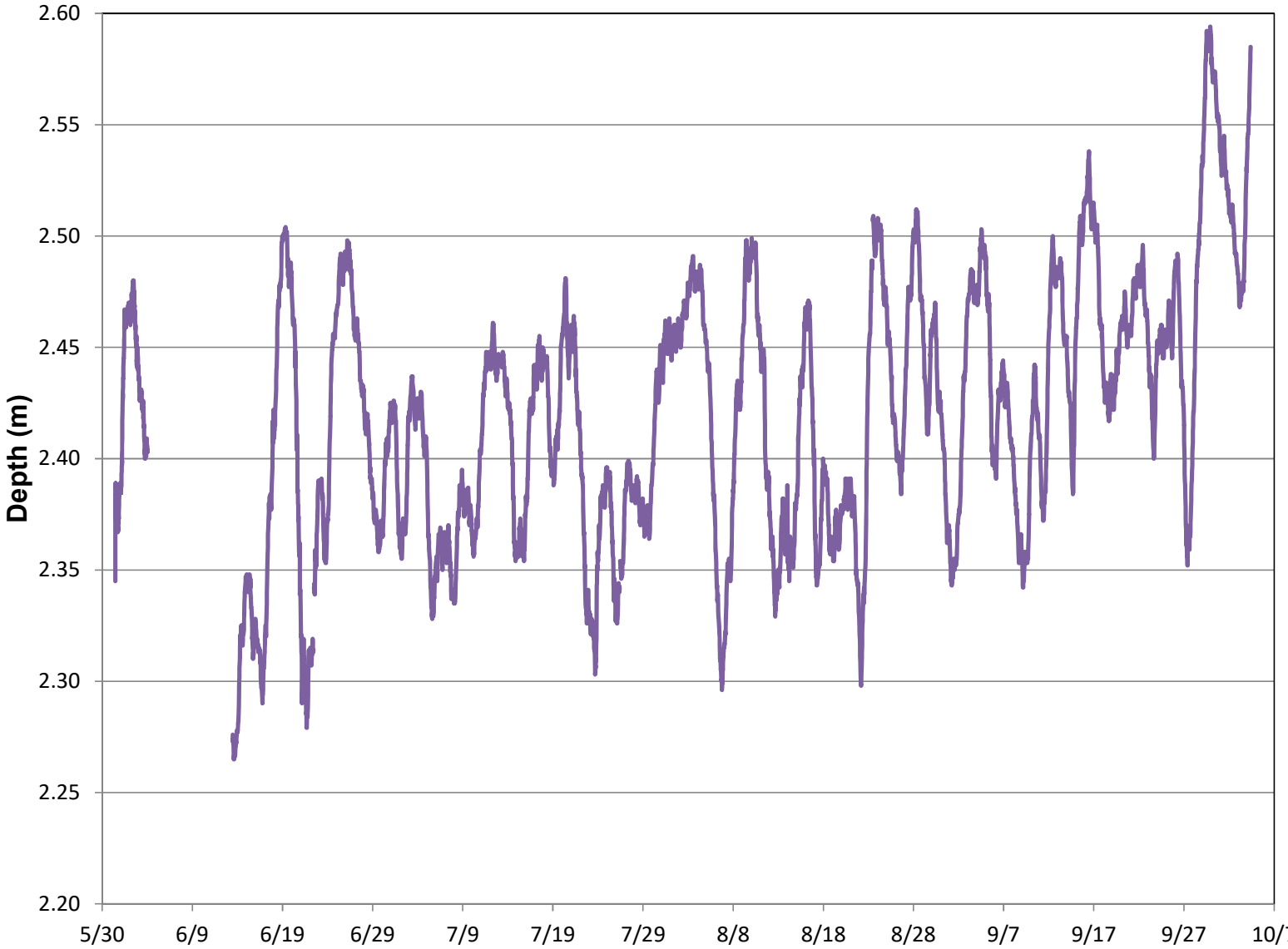

Figure 2. 2016 Continuous Depth Recording in Savery Pond (May 31 to October 4). Data logger was programmed to record readings every 30 minutes. Average depth during deployment was 2.42 m.

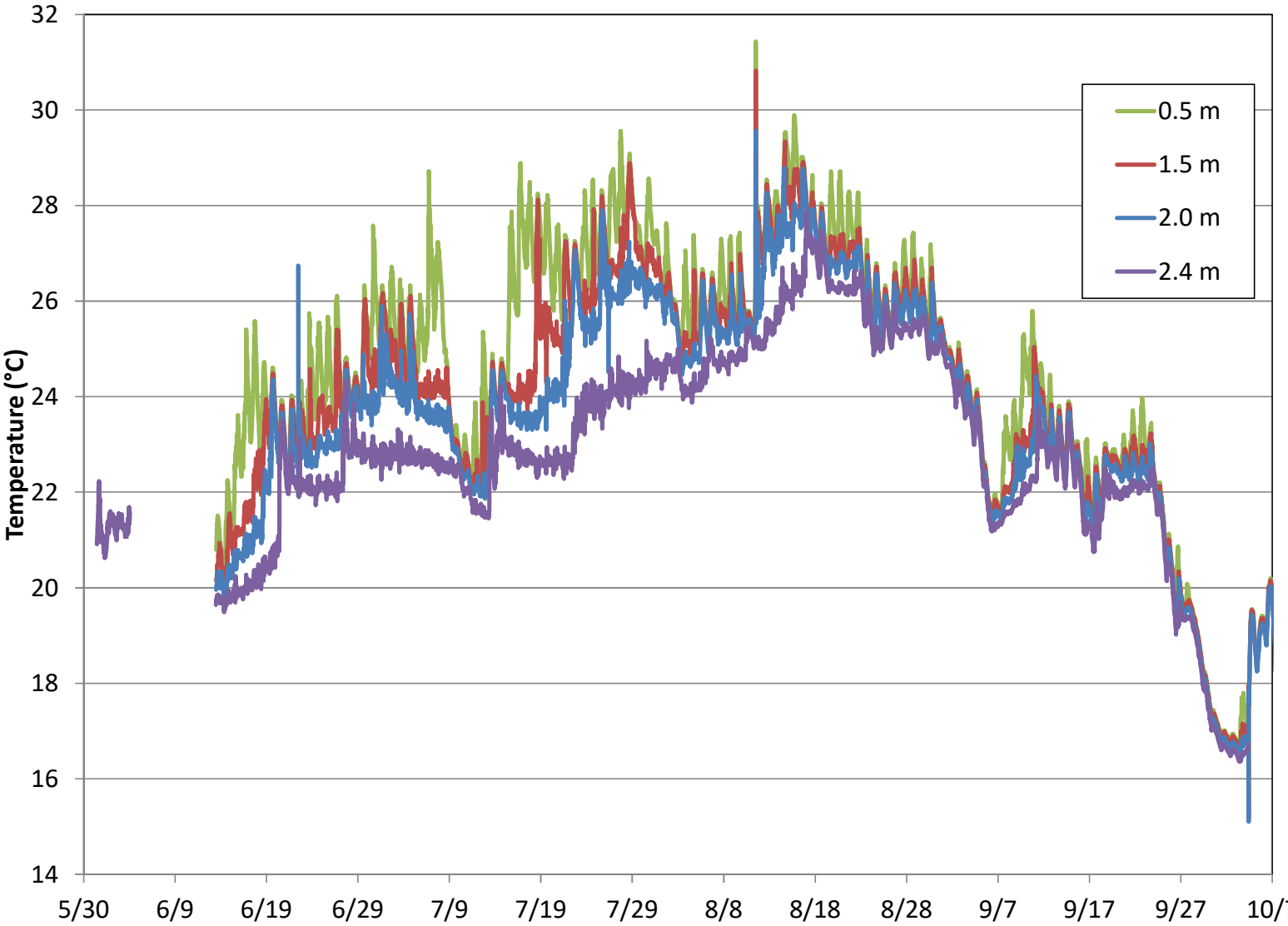

Figure 3. 2016 Continuous Temperature Recording in Savery Pond (May 31 to October 4). Data loggers were programmed to record readings every 30 minutes and installed at the indicated depths. Temperatures prior to mid-August showed thermal layering sufficient to prevent mixing of the whole water column.

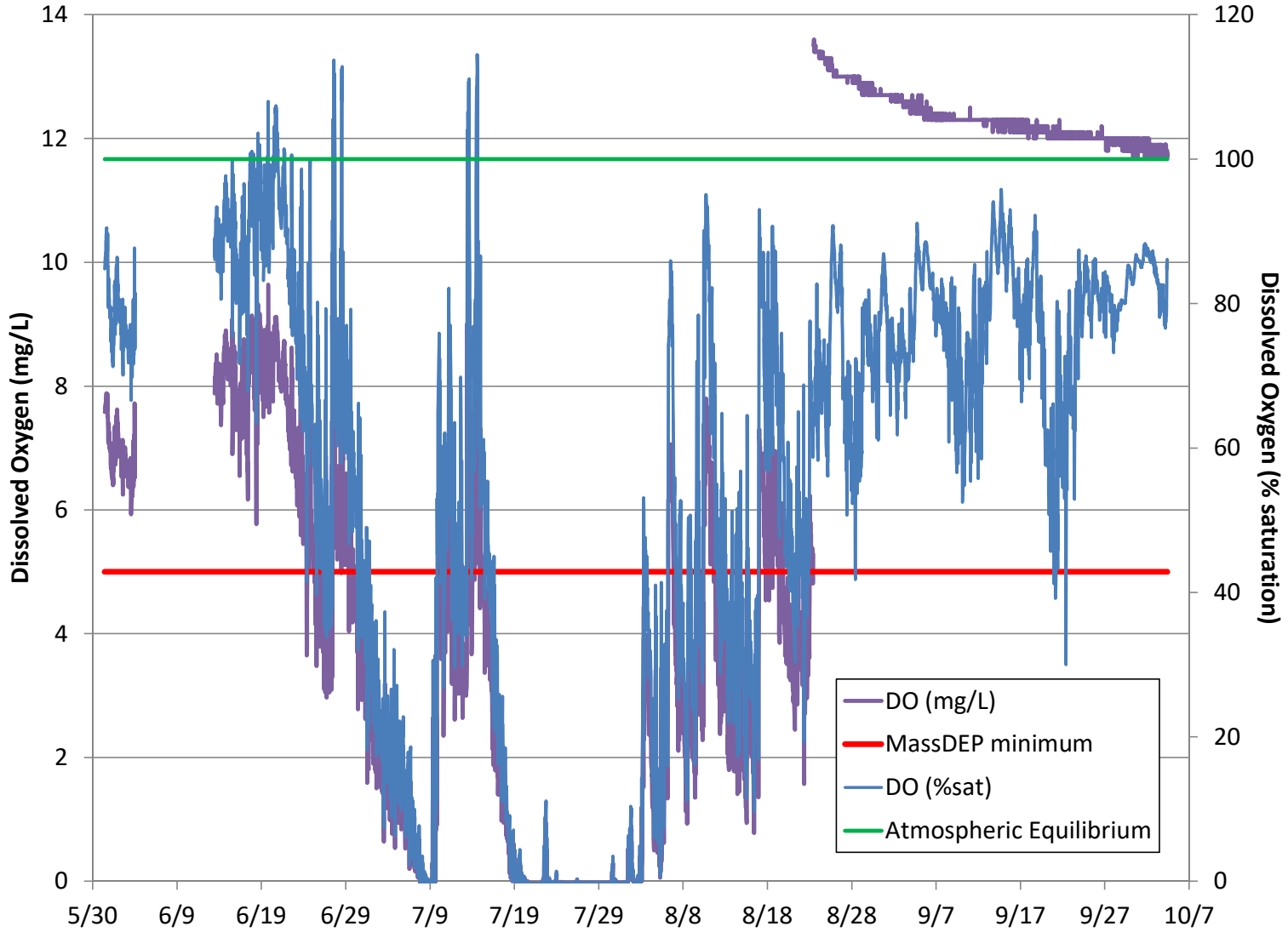

Figure 4. 2016 Continuous Dissolved Oxygen Recording in Savery Pond (May 31 to October 4). Data logger was programmed to record readings every 30 minutes and installed at a depth of approximately 2.4 m. The DO meter stopped recording reliable measurements August 23 (indicated by the purple line above 12 mg/L). During the reliable recording period, 62% of the readings were below the MassDEP 5 mg/L minimum (310 CMR 4.05).

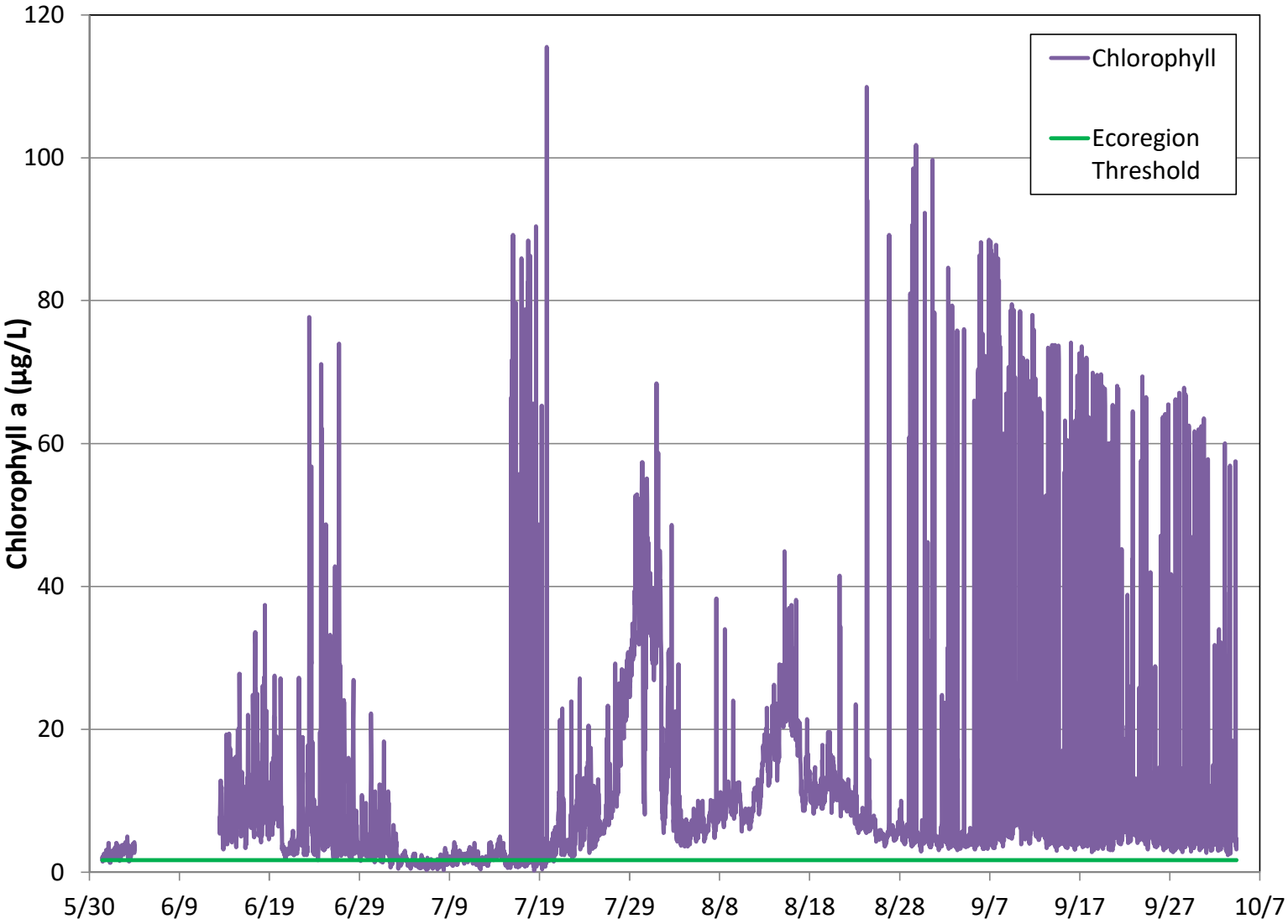

Figure 5. 2016 Continuous Chlorophyll *a* Recording in Savery Pond (May 31 to October 4). Data logger was programmed to record readings every 30 minutes and installed at a depth of approximately 2.4 m. 92% of readings were above the ecoregion guidance concentration (1.7 µg/L).

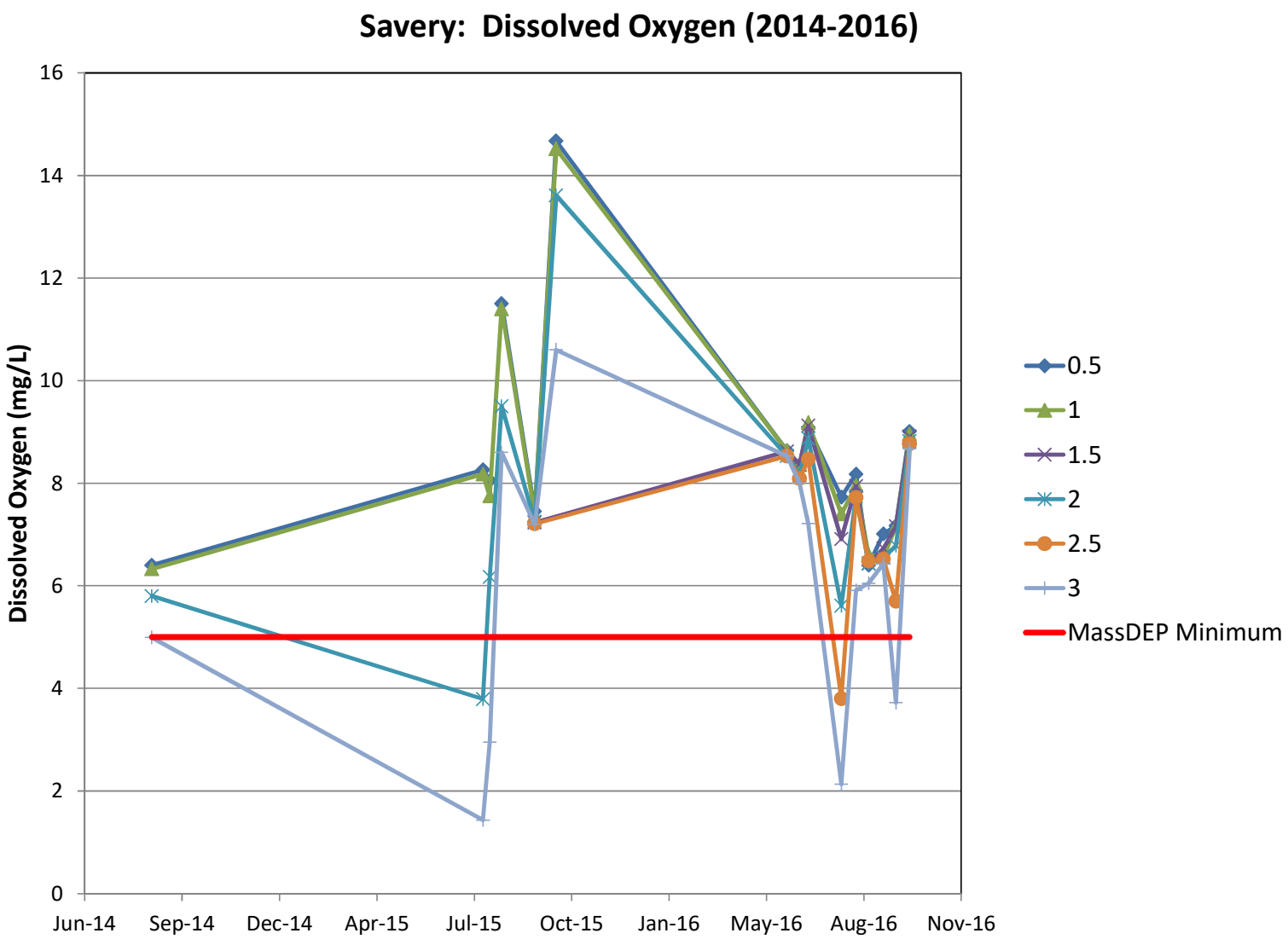

Figure 6. Snapshot Dissolved Oxygen Recordings in Savery Pond (2014-2016). Data includes 2014 PPALS Snapshot, four snapshots in 2015, and nine snapshots in 2016. Readings show variability of conditions, including both concentrations above atmospheric equilibrium and those below the MassDEP regulatory minimum.

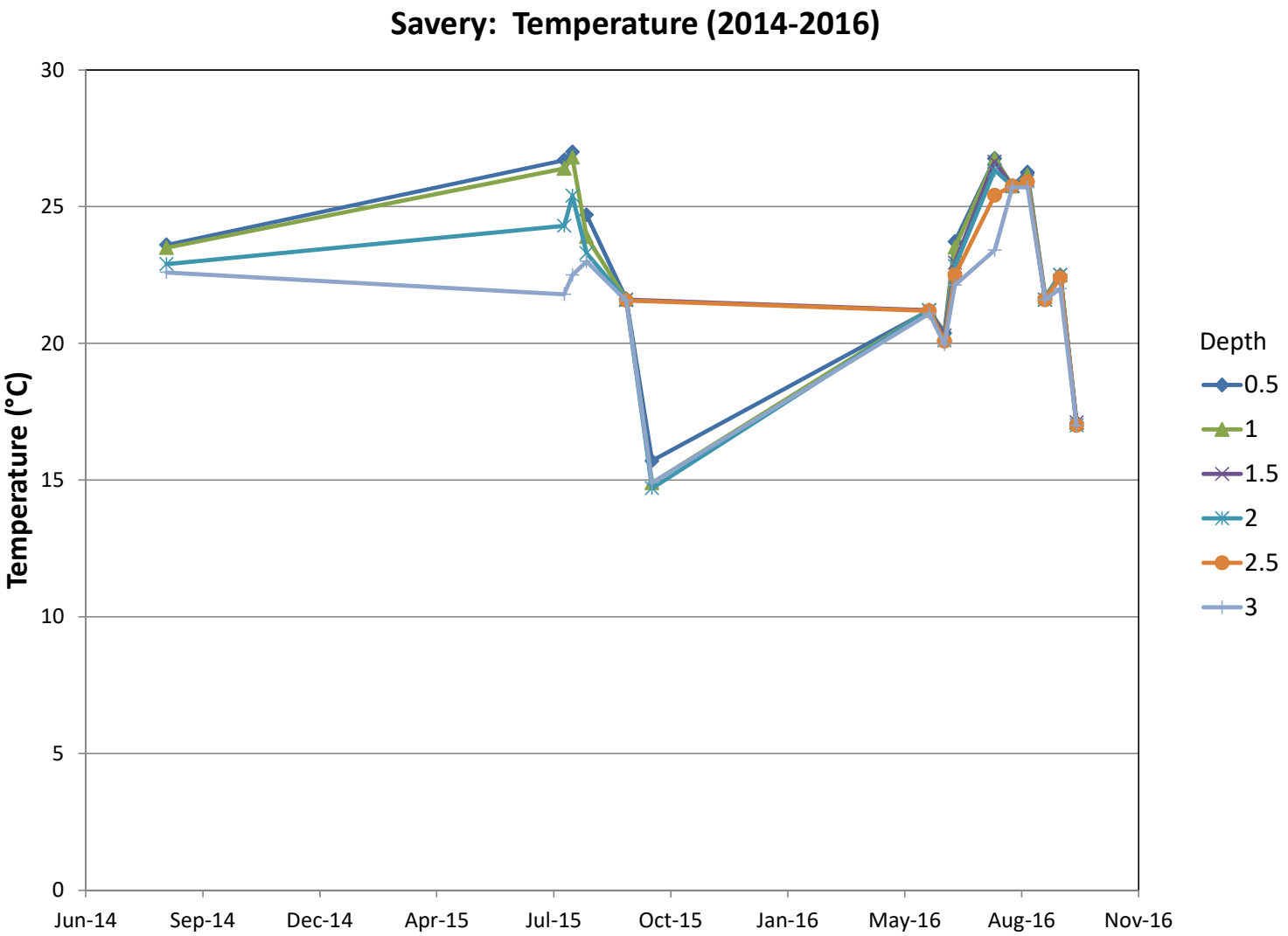

Figure 7. Snapshot Temperature Recordings in Savery Pond (2014-2016). Data includes 2014 PPALS Snapshot, four snapshots in 2015, and nine snapshots in 2016. 2015 readings show thermal layering measured in the 2016 continuous recordings, but the 2016 recordings show this as more limited. The comparison between continuous and snapshot sampling results show the detail and additional understanding of temperature interactions offered by continuous readings.

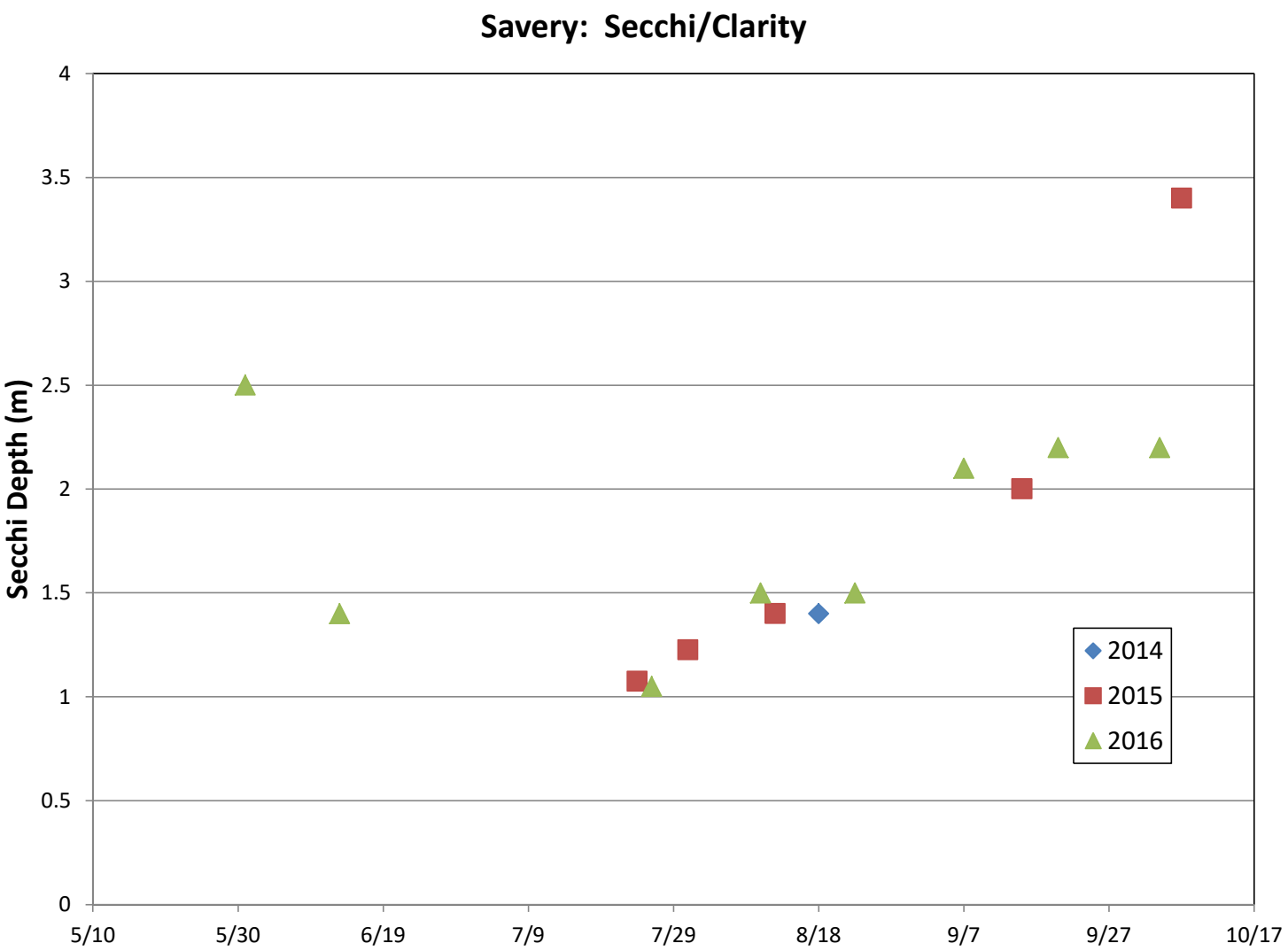

Figure 8. Snapshot Secchi/Clarity in Savery Pond (2014-2016). Data includes 2014 PPALS Snapshot, four snapshots in 2015, and nine snapshots in 2016. 2016 readings showed the decrease in clarity until mid-July followed by a slow increase until mid-September. The Secchi disk could be seen on the bottom in October 2015.

APPENDIX A. 2016 SAVERY POND SNAPSHOT WATER QUALITY DATA

Laboratory Data provided by SMAST Coastal Systems Analytical Facility in New Bedford according to requirements in Plymouth Pond and Lake Stewardship (PPALS) state-approved Quality Assurance Project Plan.

Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	% Secchi	Temp C	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (ug/L)	Phaeo (ug/L)	TP (µg/L)	TN (mg/L)	Water Color	Weather	Wind	Plants	Notes
0.5	5/31/16	3.8	2.5	66%	21.21	8.63	5.55	5.3	2.11	0.48	24.00	0.94	brown	overcast	steady wind	less than 1% waterlilies coverage of pond surface and floating algae. Up to 10% emergent grasses/sedges of surface	
1	5/31/16				21.22	8.63											
1.5	5/31/16				21.21	8.62											
2	5/31/16				21.21	8.53											
2.5	5/31/16				21.19	8.53											
3	5/31/16				21.09	8.53	5.67	5.3	1.72	0.54	24.00	0.97					
3.5	5/31/16				19.37	7.34											
0.5	6/13/16	3.8	1.4	37%	20.39	8.34	5.57	5.7	8.39	0.19	34.91	1.24	green	cloudless	light breeze	10-25% waterlilies coverage of pond surface	small white/green specs of algae in pond
1	6/13/16				20.33	8.36											
1.5	6/13/16				20.29	8.37											
2	6/13/16				20.11	8.16											
2.5	6/13/16				20.08	8.09											
3	6/13/16				19.96	8.00	5.73	5.3	11.90	0.10	45.81	1.33					
3.5	6/13/16				19.85	6.50											
0.5	6/22/16				23.72	9.09	5.76	6.0	6.33	0.12	38.18	1.63	green			10-25% waterlilies coverage, pond weed and emergent grasses/sedges	MA DPH advisory no swimming cyanobacteria levels
1	6/22/16				23.51	9.18											
1.5	6/22/16				22.95	9.12											
2	6/22/16				22.82	8.87											
2.5	6/22/16				22.5	8.47											
3	6/22/16				22.13	7.21	5.69	6.3	7.44	0.03	179.98	1.27					
3.5	6/22/16				21.62	4.7											
0.5	7/26/16	3.9	1.05	27%	26.76	7.73	6.14	9.1	7.95	0.03	27.27	2.52	brown	overcast	strong wind	10-25% waterlilies coverage of pond surface, less than 1% floating alge, up to 10% emergent grasses/sedges	water level slightly lower due to drought
1	7/26/16				26.75	7.40											
1.5	7/26/16				26.64	6.91											
2	7/26/16				26.33	5.61											
2.5	7/26/16				25.42	3.80											
3	7/26/16				23.41	2.13	6.00	21.6	6.14	2.79	33.81	3.53					
3.5	7/26/16				22.39	1.85											
0.5	8/10/16	3.5	1.5	43%	25.76	8.18	5.41	9.4	5.90	1.34	40.36	2.06	brown	cloudless	light breeze	10-25% waterlilies coverage of pond surface	
1	8/10/16				25.76	7.96											
1.5	8/10/16				25.76	7.94											
2	8/10/16				25.75	7.74											
2.5	8/10/16				25.75	7.72	6.40	9.5	6.42	1.49	33.81	1.62					
3	8/10/16				25.71	5.91											
0.5	8/23/16	3.3	1.5	45%	26.26	6.40	6.21	9.3	14.50	5.55	36.00	1.45	brown	overcast		10-25% waterlilies coverage of pond surface	water clear
1	8/23/16				26.15	6.60											
1.5	8/23/16				25.99	6.43											
2	8/23/16				25.93	6.43											
2.5	8/23/16				25.91	6.48	6.17	11.1	16.31	2.84	32.72	1.42					
3	8/23/16				25.71	6.05											

APPENDIX A. 2016 SAVERY POND SNAPSHOT WATER QUALITY DATA (continued)

Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	% Secchi	Temp C	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (ug/L)	Phaeo (ug/L)	TP (µg/L)	TN (mg/L)	Water Color	Weather	Wind	Plants	Notes
0.5	9/7/16	3.5	2.1	60%	21.70	7.01	6.41	7.9	3.55	1.93	24.00	1.36	brown	overcast		10-25% waterlilies coverage of pond surface, up to 10% emergent grasses/sedges	
1	9/7/16				21.70	6.56											
1.5	9/7/16				21.60	6.73											
2	9/7/16				21.60	6.55											
2.5	9/7/16				21.60	6.52	6.47	8.4	3.53	2.17	40.36	1.16					
3	9/7/16				21.60	6.43											
0.5	9/20/16	3.5	2.2	63%	22.50	7.17	6.35	7.4	9.97	3.87	22.91	1.27	brown	pt.cloudy	calm	up to 10% waterlilies coverage of pond surface	Rain 9/19 of 1.5"
1	9/20/16				22.50	7.16											
1.5	9/20/16				22.50	7.16											
2	9/20/16				22.50	6.78											
2.5	9/20/16				22.40	5.70	6.30	8.2	8.76	7.11	24.00	1.24					
3	9/20/16				22.00	3.72											
0.5	10/4/16	3.6	2.2	61%	17.10	9.01											no samples, only field measurements
1	10/4/16				17.10	8.96											
1.5	10/4/16				17.10	8.91											
2	10/4/16				17.00	8.82											
2.5	10/4/16				17.00	8.77											
3	10/4/16				17.00	8.67											