BOOTHBAY REGION WATER DISTRICT

Adams Pond
and
Knickerbocker Lake
2017 Water Quality Report

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Executive Summary

Lakes can be categorized based on their level of productivity. In general, oligotrophic lakes have excellent water clarity, high dissolved oxygens levels and low productivity in terms of algae and plant growth. Eutrophic lakes are on the other end of the productivity spectrum with poor water clarity, low dissolved oxygen levels and high plant productivity, which may include algae blooms. Adams Pond and Knickerbocker Lake are currently classified as mesotrophic or medium productivity lakes, with water clarity that falls between 4-8 m, moderate total phosphorus (4.5-20 parts per billion (ppb)) and chlorophyll-a levels (1.5-7 ppb), and occasional anoxia (no oxygen) in bottom waters. Although most water quality values for both lakes fall within the medium productivity range, total phosphorus, chlorophyll-a and water clarity data are closer to the higher end of the productivity spectrum for mesotrophic lakes. If lake water quality values exceed these mesotrophic levels, the lakes will be more susceptible to algae blooms and will require more treatment to serve as public drinking water.

Adams Pond's water quality has been measured on an irregular basis since 1977 and Knickerbocker Lake water quality basis since 1991 (Figure 1). An overall summary of sampling efforts, with recommendations for a more consistent and rigorous approach to sampling was completed in 2016 (BRWD, 2016). This more extensive sampling was begun in 2017, and included a new deep-water sampling station in Little Knickerbocker Lake and watershed tributaries. More consistent and comprehensive data collection should continue into the future to allow a more reliable assessment of trends.

From 1977-2017, Adams Pond average water clarity, as measured by Secchi disk transparency, was 4.6 m, its average chlorophyll-a (Chl-a) level was 6.3 ppb and its average total phosphorus (TP) level was 15 ppb. 2017 sampling results were better than long-term averages. For 2017, Secchi disk transparency averaged 5.5 m, Chl-a, 4.7 ppb, and the average TP was 9.5 ppb. The data show an improving trend in Secchi disk transparency at Adams Pond over the time period. Additionally, high levels of TP and Chl-a seen in the 1980s and 1990s have not been observed in recent years.

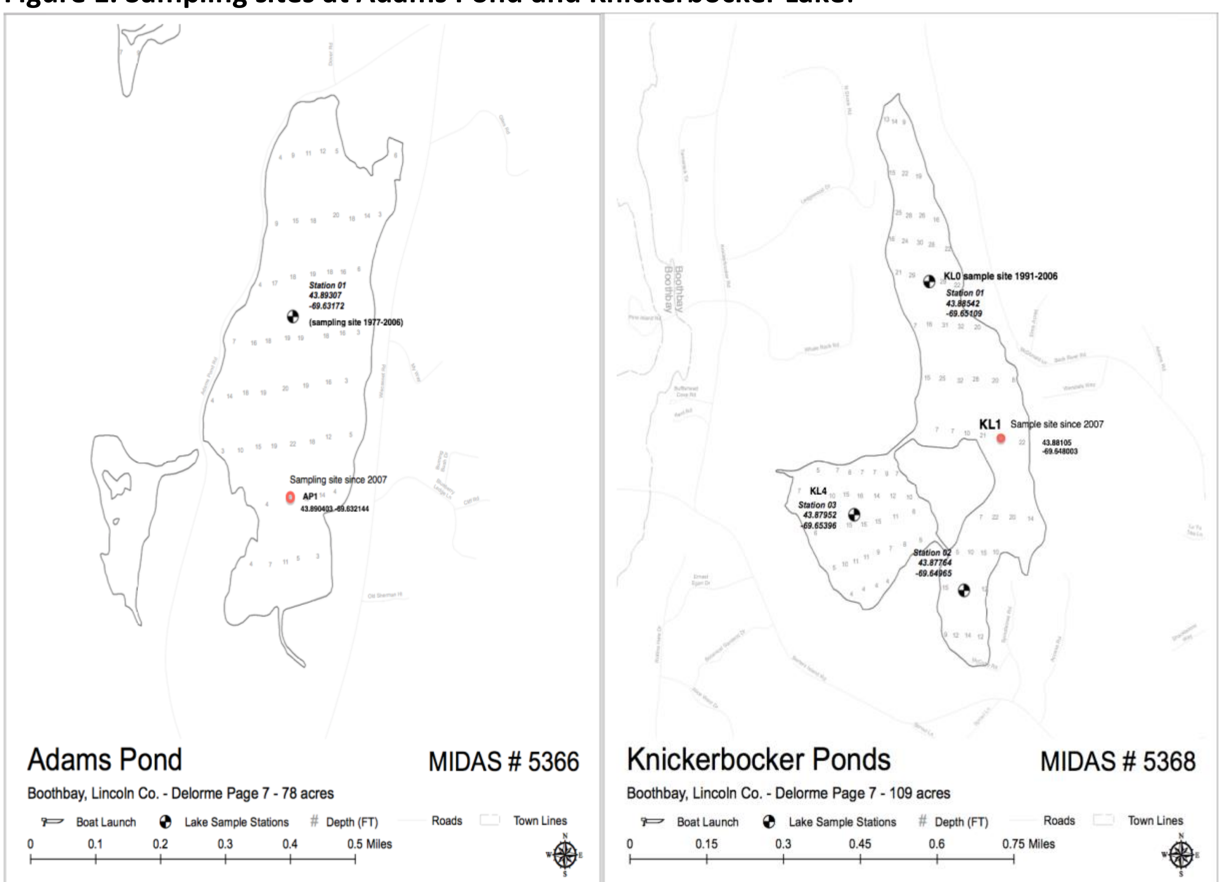
From 1991-2017, Knickerbocker Lake's average Secchi disk transparency was 4.9 m, its average chlorophyll-a level was 6.4 ppb and its average upper water column total phosphorus (TP) level was 12 ppb, its average bottom water TP equaled 22 ppb and the average of all TP samples was 16 ppb. 2017 sampling results were similar to long-term averages. For 2017, Secchi disk averaged 4.4m, chlorophyll-a, 5.7 ppb, and the average of all TP samples was 15 ppb.

Data collected in 2017 indicate that Little Knickerbocker Lake may be approaching a eutrophic state. Bottom anoxia (below 3-4m) was present for most of the sampling period. Water clarity was poor (average, 3.0 m). Upper water column total phosphorus levels averaged 15 ppb, while bottom TP averaged 45 ppb, indicating that recycling of phosphorus from bottom sediments is likely occurring. Three of the five Chl-a samples collected in 2017 were higher than the mesotrophic range (>7.0 ppb) and the average of all samples was 6.2 ppb.

Table 1. **Comparison of Adams Pond, Knickerbocker Lake and Little Knickerbocker Lake average water quality sampling results compared to DEP classification standards for a mesotrophic lake. For chlorophyll-a (Chl-a) and total phosphorus (TP) higher values are worse (more productive); for Secchi depth, higher values indicate better water quality. TP values reported here are for all samples, both upper and lower water column.**

	Chl-a	TP	Secchi
Mesotrophic lake range	1.5-7 ppb	4.5-20 ppb	4-8 m
Adams Pond (all data)	6.3	15	4.6
Adams Pond (2017)	4.7	9.5	5.5
Knickerbocker Lake (all data)	6.4	16	4.9
Knickerbocker Lake (KL1) (2017)	5.7	15	4.4
Little Knickerbocker (KL4) (2017)	6.2	25	3.0

Figure 1. Sampling sites at Adams Pond and Knickerbocker Lake.



Background and methods

Adams Pond and Knickerbocker Lake are the public water supplies for the Boothbay Region, as such their water quality is of utmost important to the health and economic prosperity of the region. Adams Pond has a surface area of about 80 acres, a mean depth of 12 feet, a maximum depth of 22 feet, and a watershed of about 1.5 square miles. Knickerbocker Lake consists of two water bodies connected by narrow channels that were once two separate ponds. The larger of the two is about 80 acres in size with a maximum depth of 34 feet, whereas Little Knickerbocker is about 30 acres with a maximum depth of 19'. No industrial or point discharges affect either lake, but they have been identified as at risk for accelerated eutrophication from non-point pollution sources associated with watershed development.

Water quality data have been collected in Adams Pond since 1977 and in Knickerbocker Lake since 1991 by Boothbay Region Water District (BRWD) staff, the Maine Department of Environmental Protection (DEP) and the Maine Volunteer Lake Monitoring Program (VLMP). Although there is a relatively long time-series for some water quality parameters, there are gaps and inconsistencies in sampling that limit comparisons. Little Knickerbocker has not been the focus of previous sampling efforts but was added to the regular lake sampling program in 2017.

In 2017, water quality sampling occurred from May through November at the deep-water site in Adams Pond (AP1) on 11 dates, at the deep-water site in Knickerbocker Lake (KL1) on 12 dates, and at the deep-water site in Little Knickerbocker Lake (KL4) on 13 dates. Dissolved oxygen/temperature profiles and Secchi disk (water clarity) measurements were collected on each sample date. Once monthly, samples were collected at AP1, KL1 and KL4, and analyzed at the Maine Environmental Health and Testing Laboratory (MEHTL) for TP and Chl- a. In addition, grab samples at 2', 10', 14' and 20' were analyzed at BRWD for pH, conductivity, turbidity, color, iron and manganese.

Water samples were also collected in tributary streams at locations above the influence of the pond and analyzed at MEHTL for TP. Where culverts were present, water velocity was also measured, using a Marsh McBirney Portable Flow Meter Flow Mate. At each culvert, water depth and culvert diameter were measured. Flow rate was calculated using the Hachflow calculator at https://www.hachflow.com/support/flow_calc.cfm.

All sample and analytical procedures followed Maine DEP/VLMP sampling guidelines and procedures outlined in the BRWD Standard Procedures for Lake Water Quality Sampling and Testing manual.
This report summarizes only the most relevant water quality data (DO/Temperature, Chl-a, TP and Secchi disk) results for 2017, with comparisons to historical data.

Results

Precipitation

2017 was a relatively dry summer, with rainfall totals from April-October the third lowest for the 2010-2017 period (Table 2). Higher than average rainfall in early spring (April, May) and fall (October) bracketed much lower than average rainfall from June through September. Rain is an important factor in evaluating lake water quality data since watershed runoff is the largest source of particulates and phosphorus that affects water clarity, nutrient levels and algae populations. Dry years, such as 2017, are expected to produce better than average water quality in lakes.

Table 2. Monthly rainfall totals for April –October 2010-2017, from BRWD weather station at Adams Pond.

	April	May	June	July	August	September	October	7-month total
2010	1.6	1.85	6.2	7.54	2.47	4.03	6.78	30.47
2011	4.33	2.82	5.26	3.2	4.99	2.99	5.53	29.12
2012	3.55	4.11	11.02	2.09	4.91	3.48	3.31	32.47
2013	1.19	4.35	5	2.52	1.63	6.88	1.44	23.01
2014	0.72	3.39	2.04	7.96	2.71	0.78	4.49	22.09
2015	2.32	1.78	4.79	1.14	1.75	1.75	2.58	16.11
2016	1.69	1.61	3.48	2.74	0	0.71	4.63	14.86
2017	3.41	5.82	1.63	0.7	1.8	1.4	5	19.76
Average	2.35	3.22	4.93	3.49	2.53	2.75	4.22	23.49

Dissolved oxygen

The amount of dissolved oxygen (DO) present in lake water is critical to the health, abundance and diversity of aquatic communities. DO concentrations below 5 ppm may adversely affect the function and survival of animal and plant populations, while DO below 2 ppm is lethal to most fishes. Low DO can also increase the toxicity and availability of chemical compounds in sediments and the water column. DO levels below 1 ppm in bottom waters (anoxia) may cause phosphorus in bottom sediments to release into the water column. Prolonged anoxia can result in a significant release of phosphorus from sediments into bottom waters, which can make its way to the upper water column during fall and spring turnover, fueling algae production. DO levels may vary greatly with depth in a lake due to temperature differences and biological, physical and chemical processes. In summer months, many lakes stratify by temperature, and DO concentrations in bottom waters that are cut off from the oxygen introduced by wind and algae can become anoxic. Although summer anoxia in bottom waters is a natural occurrence in many lakes, prolonged anoxia, and phosphorus recycling, can be the result of excess nutrient inputs from the watershed and can accelerate eutrophication processes.

Adams Pond (AP1)

DO/temperature profiles were taken twice monthly at AP1 from May through October. In 2017, Adams Pond was weakly stratified (Figure 2). Anoxia was observed in bottom waters on only one date during the sampling period; low DO (<5 ppm) was observed on 7 dates but was confined to bottom depths (Table 3). From 2010- 2016, anoxia was observed over as much as a six-week period in any year, but was usually shorter in duration, primarily in July and August, and confined to depths greater than 5 m.

Knickerbocker Lake (KL1)

DO/temperature profiles were taken twice monthly at KL1 (Figure 3) from May through October. Anoxia was observed in KL1 below 5-6 m for a period of 9 weeks (August 8 – October 3). Low DO (<5 ppm) was observed on 7 dates but was confined to bottom depths (Table 4). From 2010- 2016, anoxia was observed at KL1 over as much as a six-week period in any year, but was usually shorter in duration, primarily in July and August, and confined to depths greater than 5m.

Little Knickerbocker Lake (KL4)

DO/temperature profiles were taken at the deep-water site in Little Knickerbocker Lake (KL4), which is approximately 19 feet deep, from late May through October. Anoxia was observed in below 3-4 m on all dates, except November 1 when fall turnover had occurred (Table 5). This was the first year of sampling at Little Knickerbocker so there are no historical data for comparison.

Table 3. Dissolved oxygen at Adam Pond deep site in 2017; orange highlighted cells indicates DO less than 5 ppm and pink indicates anoxia (DO<1ppm).

Depth (m)	5-May	17-May	7-Jun	21-Jun	12-Jul	27-Jul	2-Aug	16-Aug	8-Sep	27-Sep	12-Oct
0	11.4	10.2	9.3	8.7	8.6	8.0	8.2	7.9	7.9	8.4	8.3
-1	11.4	10.2	9.3	8.7	8.6	8.0	8.2	7.9	7.9	8.4	8.3
-2	11.4	10.5	9.2	8.7	8.6	7.9	8.1	7.9	7.9	8.6	8.3
-3	11.1	10.4	9.2	8.5	8.4	7.8	8.2	7.8	7.9	8.4	8.2
-4	10.7	10.3	9.2	8.2	8.1	7.3	8.0	7.8	7.9	7.6	8.3
-5	10.0	10.1	7.8	5.4	3.9	2.8	4.2	7.8	7.8	7.1	8.2
-6		9.8	2.3	1.0	2.6		2.7	2.3	7.5	4.6	8.2
-7		9.4							7.5		

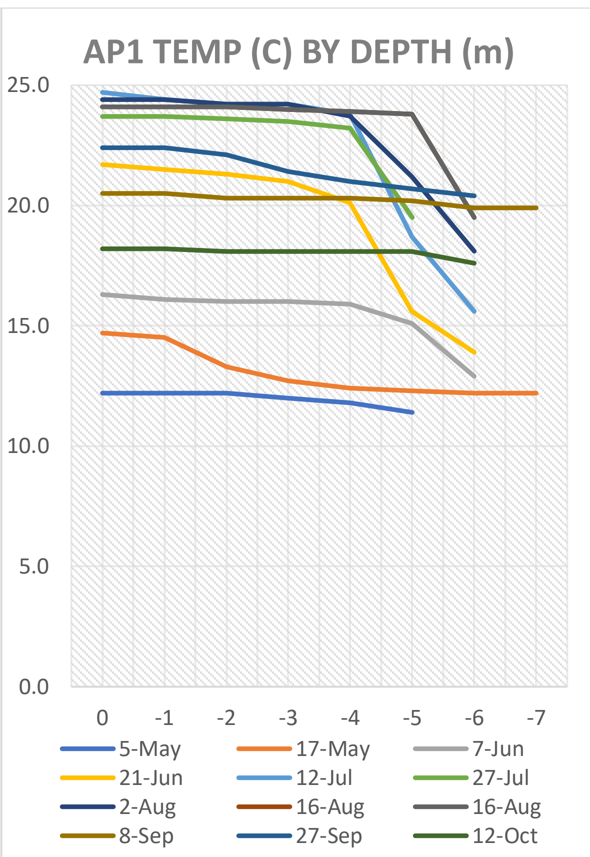
Table 4. Dissolved oxygen (ppm) at Knickerbocker Lake deep site (KL1) in 2017 by depth; orange highlighted cells indicate DO less than 5 ppm and pink cells indicate anoxia (DO<1ppm).

Depth m	10-May	25-May	4-Jun	13-Jun	5-Jul	20-Jul	9-Aug	22-Aug	13-Sep	3-Oct	20-Oct	1-Nov
0	10.6	9.1	9.2	8.8	7.9	8.8	7.8	8.3	8.6	7.8	8.8	9.1
-1	10.6	9.0	9.2	8.8	8.0	8.7	7.8	8.3	8.6	7.8	8.7	9.0
-2	10.6	9.2	9.2	8.9	7.8	8.6	7.8	8.1	8.5	7.8	8.7	8.9
-3	10.5	9.3	8.7	8.6	6.5	7.7	7.7	7.7	8.2	7.7	8.7	8.9
-4	9.9	8.6	7.9	6.8	3.7	3.6	4.8	5.6	7.4	7.8	8.7	9.0
-5	8.8	7.9	6.5	5.1	2.5	1.3	0.5	0.3	6.3	7.5	8.7	9.0
-6	7.6	6.2	5.8	5.0	2.8	1.8	0.3	0.1	0.2	0.1	8.6	8.9
-7	7.3	5.5	5.3	4.7	2.9	1.9	0.0	0.1	0.1	0.1	8.6	8.9

Table 5. Dissolved oxygen (ppm) at Little Knickerbocker Lake deep site (KL4) in 2017 by depth; orange highlighted cells indicate DO less than 5 ppm and pink cells indicate anoxia (DO<1ppm).

Depth m	24-May	4-Jun	13-Jun	21-Jun	5-Jul	20-Jul	9-Aug	22-Aug	13-Sep	26-Sep	2-Oct	23-Oct	1-Nov
0	9.4	8.7	8.0	8.7	7.1	7.9	7.0	7.8	8.5	8.2	7.5	8.3	7.9
-1	9.4	8.7	7.5	8.7	7.2	7.8	6.9	7.7	8.5	8.2	7.4	8.2	7.8
-2	8.6	8.5	7.8	6.6	2.8	3.2	6.7	5.7	7.1	7.8	7.3	8.2	7.8
-3	8.5	3.8	0.1	0.1	0.1	0.0	0.1	0.3	4.1	1.6	6.9	7.7	7.8
-4	0.4	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	4.8	7.6
-5	0.1	0.0	0.0	0.1			0.0	0.1	0.1	0.0	0.1	0.1	7.1
-6	0.0	0.0										0.1	

Figure 2. Temperature and DO profiles for Adams Pond deep site AP1 in 2017



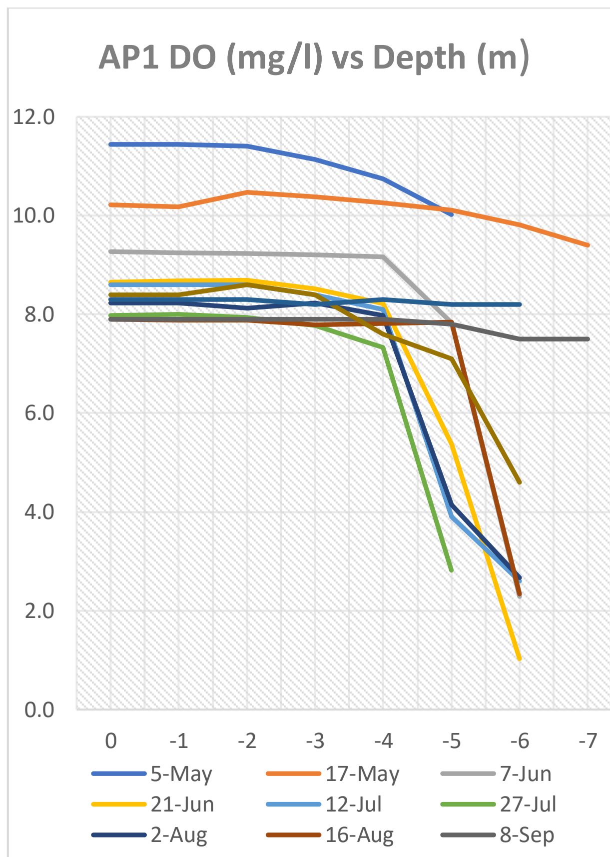


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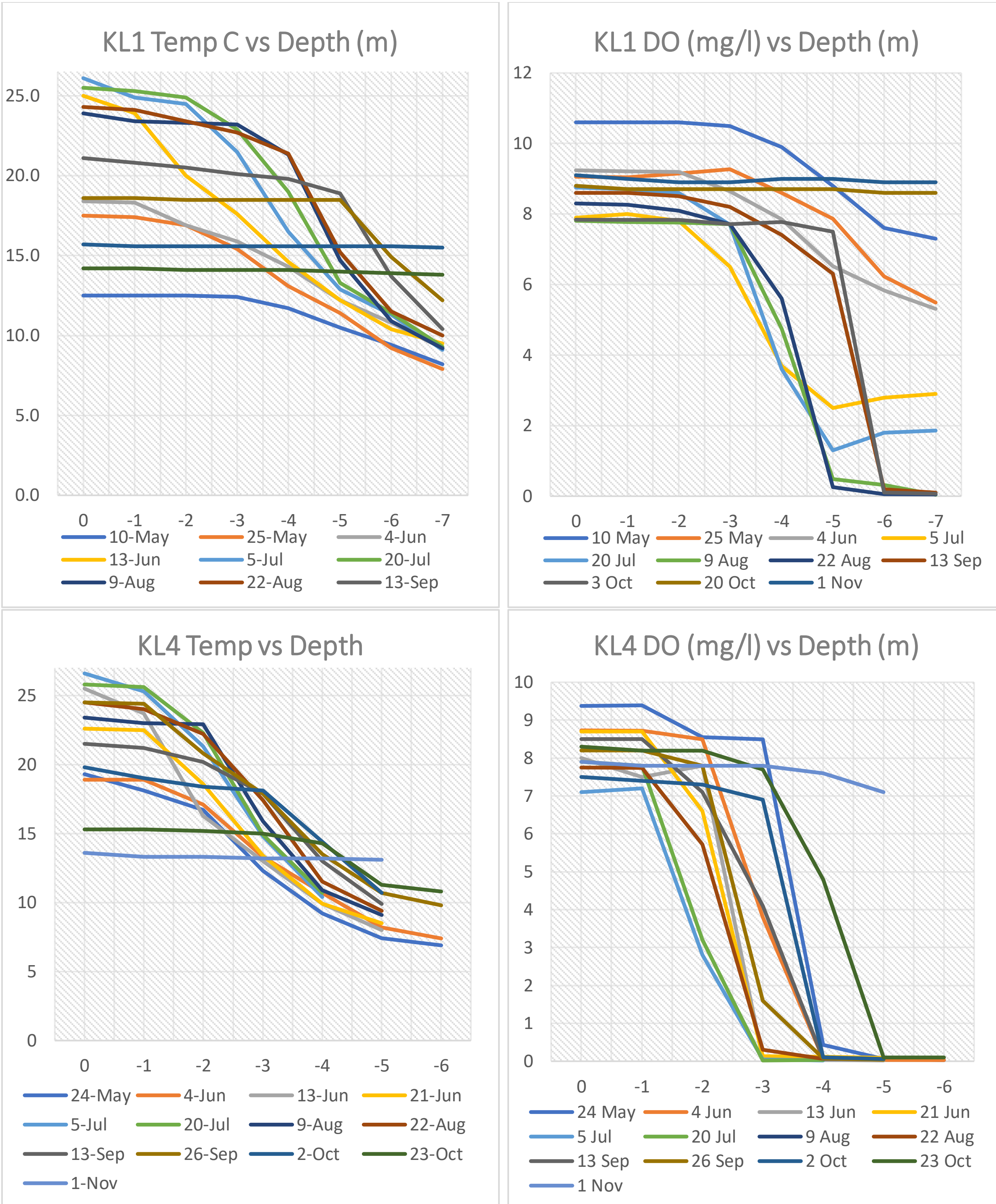
Figure 3. Temperature and DO profiles for Knickerbocker Lake deep site KL1 and KL4 in 2017.



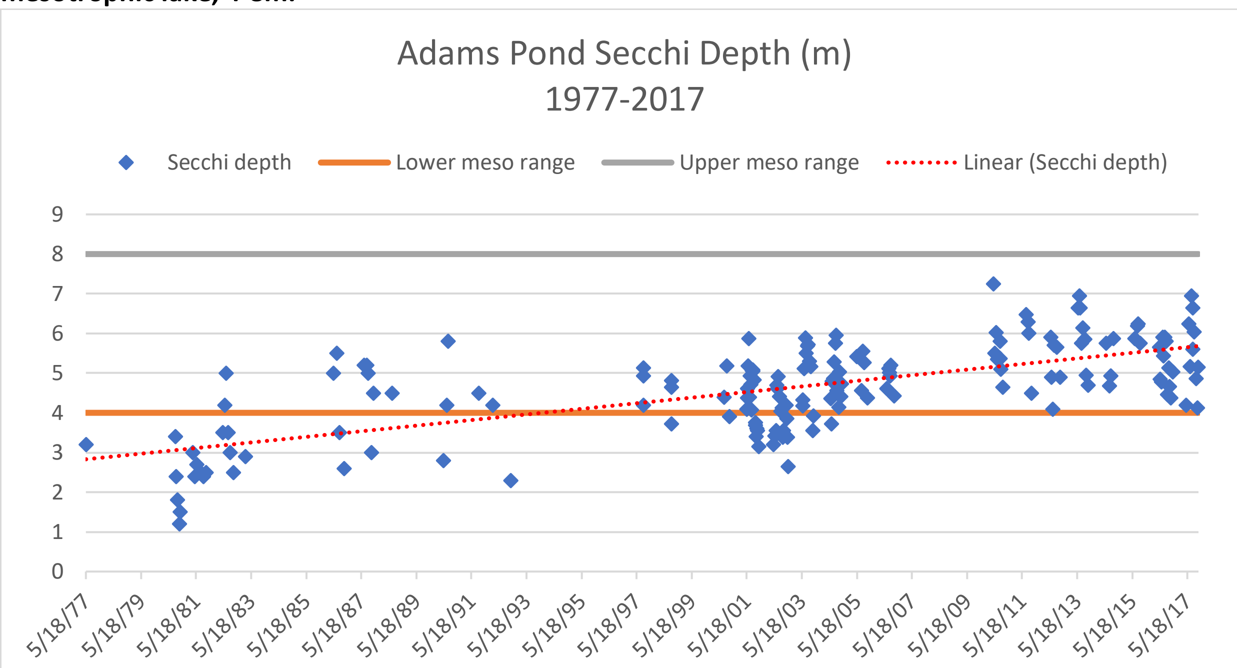
Water clarity

In lakes, water clarity is reduced by increases in algae and dissolved or particulate matter and can be a good indicator of a lake's productivity level. Secchi disk transparency readings are a reliable and simple method to measure water clarity. Natural lake water color can affect Secchi disk transparency readings.

Adams Pond (AP1)

Secchi disk transparency readings were made at AP1 on 10 dates in 2017. The lowest observed Secchi disk reading in 2017 was 4.13 m, the average, 5.5 m, and the maximum, 6.94 m. All readings in 2017 met the DEP mesotrophic standard of 4–8 m. From 1977- 2017, the lowest observed Secchi reading for Adams Pond was 1.2m (1980), the average 4.6 m, and the maximum 6.95 m. The data show an apparent trend of increasing water clarity in Adams Pond over the time period 1977-2017 (Figure 4).

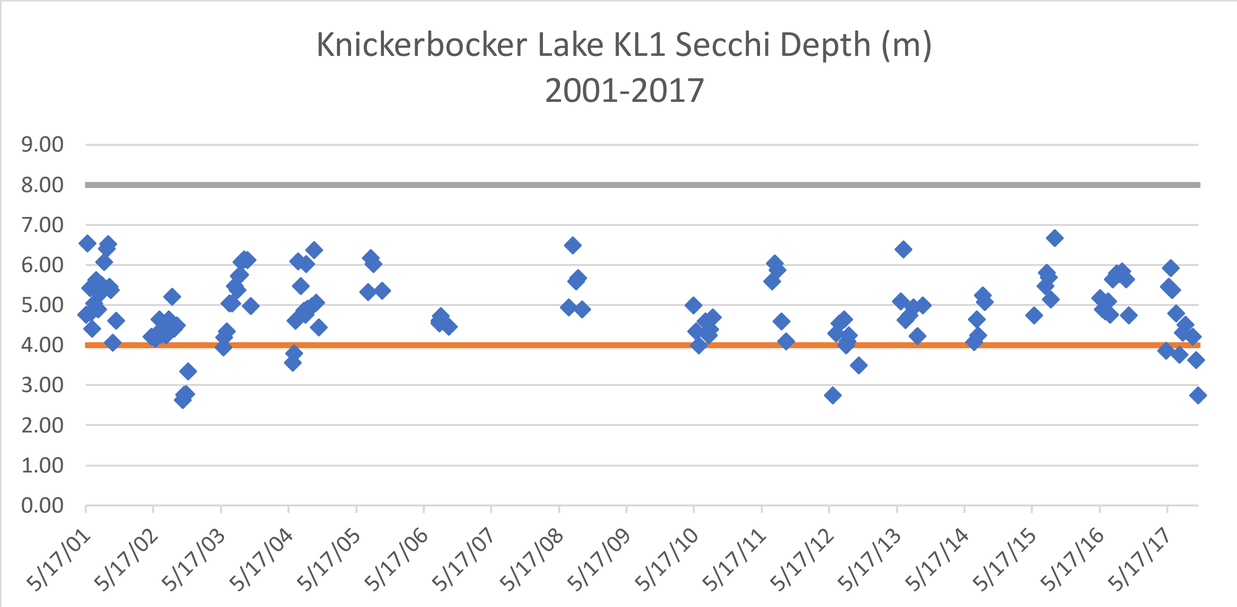
Figure 4. Adams Pond Secchi disk transparency, as compared to the DEP acceptable range for a mesotrophic lake, 4-8m.



Knickerbocker Lake (KL1)

Secchi disk transparency readings were taken at KL1 on 11 dates in 2017. The lowest observed Secchi disk reading in 2017 was 2.75 m, the average, 4.42 m, and the maximum, 5.92 m. Four of the eleven readings in 2017 were below the DEP mesotrophic standard of 4 m. From 2001- 2017, the lowest observed Secchi reading for Knickerbocker Lake was 2.63 m, the average 4.9 m, and the maximum 6.67m (Figure 5). There is no apparent trend in water clarity over the time period; the majority of readings are within the DEP range for a mesotrophic lake. Although Knickerbocker Lake is a colored lake, the average color of the water column from 2001-2017 was 33 PCU, a value too low to significantly affect readings.

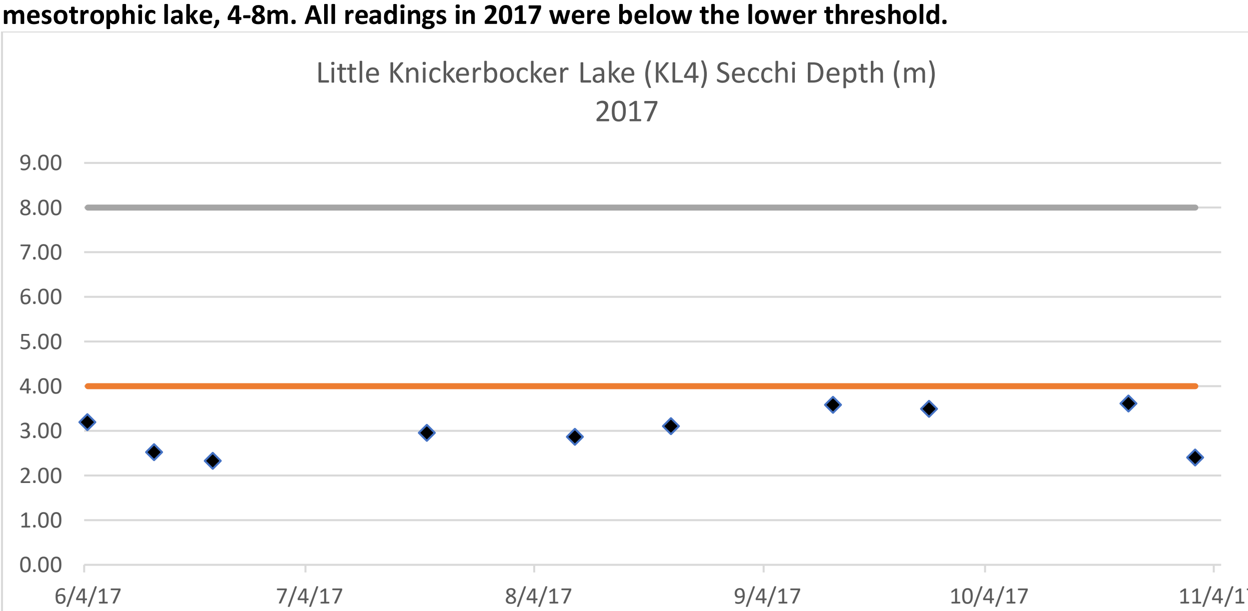
Figure 5. Knickerbocker Lake, KL1, Secchi disk transparency, as compared to the DEP range for a mesotrophic lake, 4-8m.



Little Knickerbocker Lake (KL4)

Secchi disk transparency readings were taken at KL4 on 11 dates in 2017 (Figure 6). The lowest observed Secchi disk reading in 2017 was 2.32m, the average, 2.99m, and the maximum, 3.61m. All of the 2017 readings were below the DEP lowest range for a mesotrophic lake of 4 m. Little Knickerbocker Lake is a colored lake, with an average color reading of 70 PCU between 2' and 10' in 2017. Color may account for some, but not all, of the reduced clarity observed by Secchi disk readings at Little Knickerbocker Lake.

Figure 6. Knickerbocker Lake, KL4, Secchi disk transparency, as compared to the DEP range for a mesotrophic lake, 4-8m. All readings in 2017 were below the lower threshold.



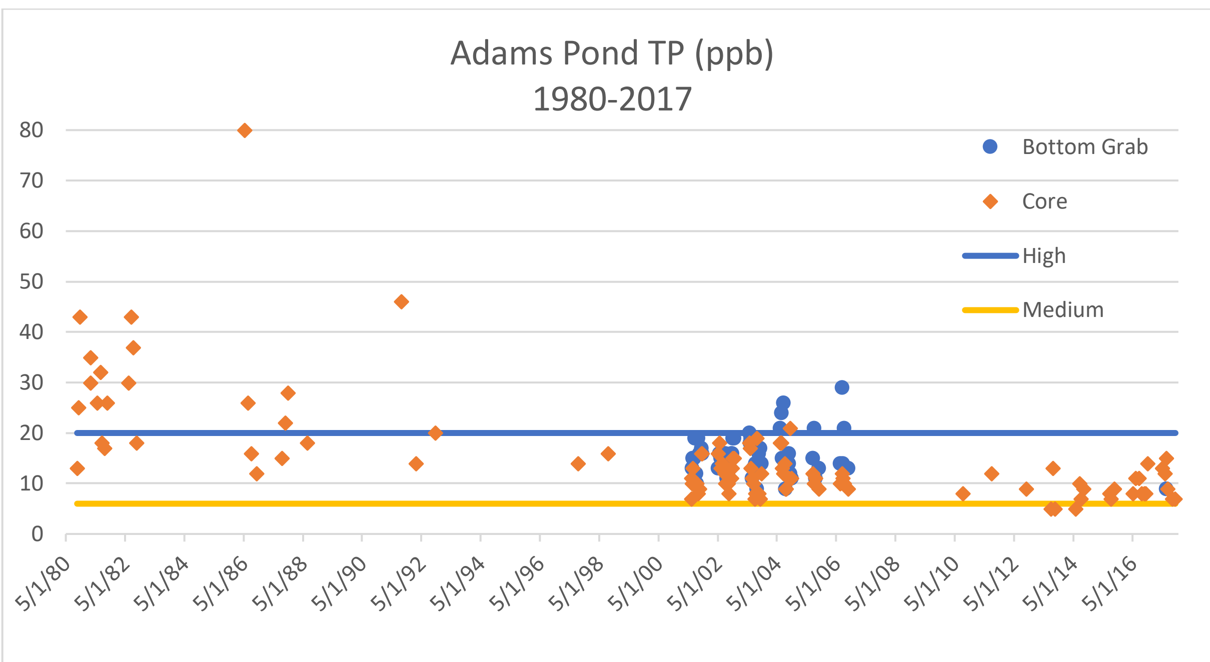
Total phosphorus

Phosphorus is the limiting nutrient for algae populations in most Maine lakes. Levels of TP in lake waters above 20 ppb are considered high by DEP and could lead to algae blooms. Phosphorus may also leave lake bottom sediments under anoxic conditions and be recycled into the water column. This internal recycling from bottom sediments may represent a significant source of TP loading in some lakes.

Adams Pond (AP1)

TP samples were collected monthly from May through October, using a core sample from the upper water column to reflect the availability of phosphorus to algae. In 2017, core TP levels varied from 7 to 15 ppb, with an average of 9.5 ppb. All observed TP values in 2017 were within the DEP range for mesotrophic lakes. From 1980-2017, Adams Pond TP samples varied from 5 to 90 ppb, with an average of 15 ppb. Prior to 1992, several TP samples exceeded 20 ppb, some 2-3 times higher. Sampling since 2002 has shown TP levels consistently within the mesotrophic range (Figure 7). Few bottom TP samples have been collected from Adams Pond over the time period and none in recent years; future sampling should include summer/fall bottom TP samples to assess potential for internal recycling from bottom sediments.

Figure 7. Total phosphorus levels in Adams Pond from core and bottom grabs, 1980-2017, as compared to the range of TP expected in a mesotrophic lake (high = 20ppb, low = 4.5 ppb).

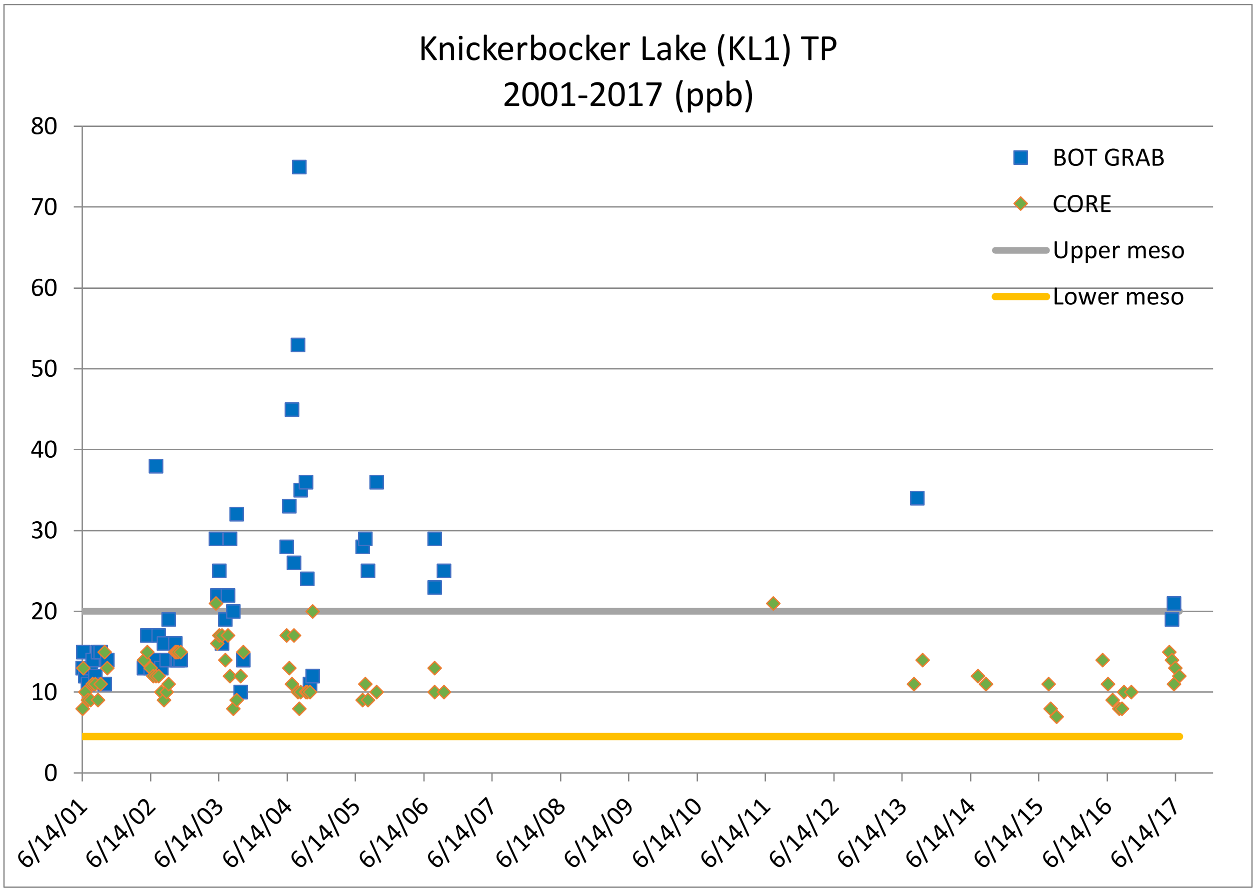


Knickerbocker Lake (KL1)

TP samples were collected monthly from May through October at KL1, using a core sample from the upper water column to assess the availability of phosphorus to algae. Water samples were also collected near the lake bottom on six dates to assess the how much recycling of phosphorus from bottom sediments is occurring. In 2017, TP in the upper water layer core samples varied from 9 to 15 ppb, with an average of 12 ppb. All observed TP values in 2017 were within the DEP range for mesotrophic lakes. From 1999-2017, Knickerbocker Lake, 83 TP upper water column samples varied from 5 to 21 ppb, with an average of 15 ppb. Significant gaps in data collection, both in years and numbers of samples per year, limit data comparisons over the time period (Figure 8).

Bottom water TP samples in 2017 ranged from 18 to 27 ppb, with an average of 22 ppb. From 1999-2017, 59 bottom water samples were collected and analyzed for TP, bottom water TP levels ranged from 10 to 75ppb and average 22 ppb. These data indicate that phosphorus is likely being recycled from bottom sediments.

Figure 8. Total phosphorus levels in Knickerbocker Lake (KL1) from core and bottom grabs, 1980-2017, as compared to the range of TP expected in a mesotrophic lake (high = 20ppb, low = 4.5 ppb).

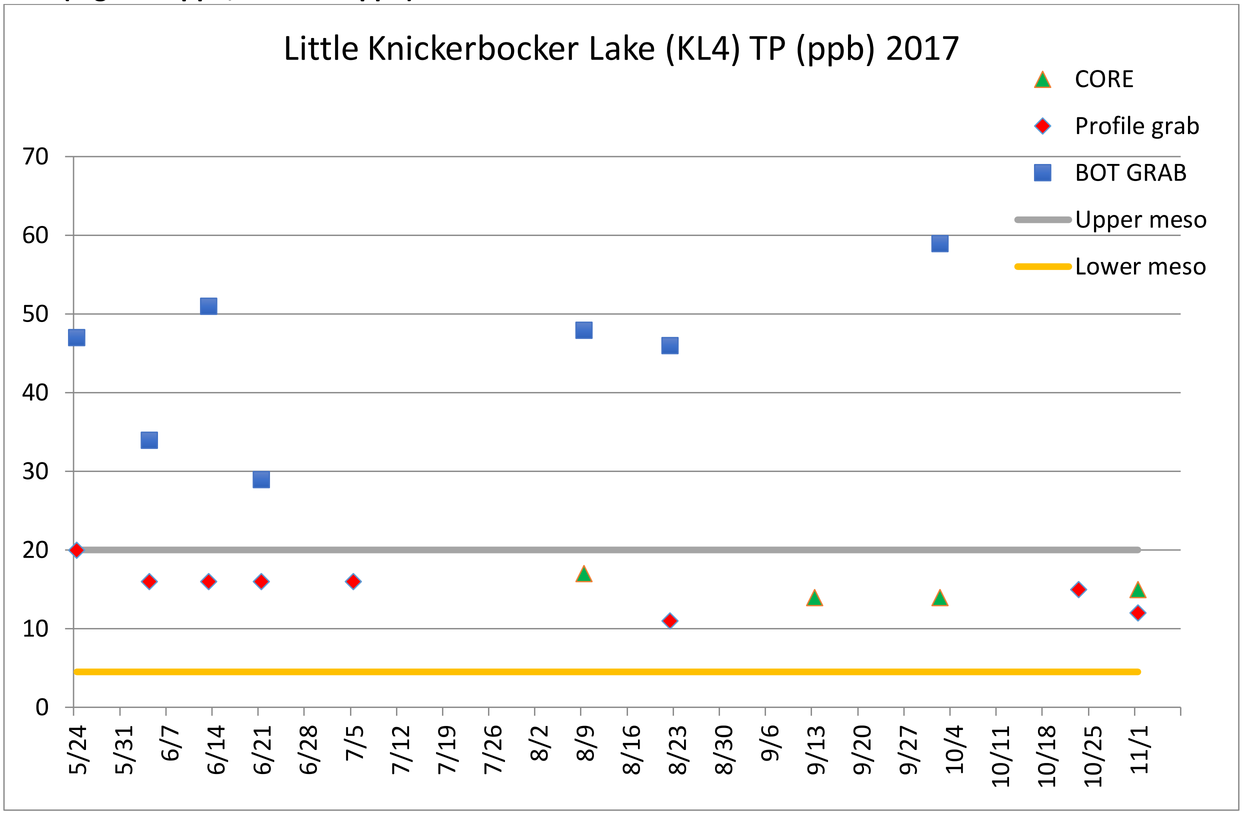


Little Knickerbocker Lake (KL4)

TP samples were collected monthly from May through October at KL4, using a core or grab sample from the upper water column to assess the availability of phosphorus to algae. Water samples were also collected near the lake bottom on six dates to assess the how much recycling of phosphorus from bottom sediments is occurring. In 2017, TP in the upper water layer core samples varied from 11 to 20 ppb, with an average of 15 ppb. All samples, except one which was at the upper limit, were within the DEP range for mesotrophic lakes.

Bottom water TP samples at KL4 in 2017 ranged from 29 to 59 ppb, with an average of 45 ppb. All observed bottom water TP values above the DEP range for mesotrophic lakes, and on average 30 ppb higher than the upper water column (Figure 9). These data, in conjunction, with DO/temperature profiles indicate that phosphorus is being released from Little Knickerbocker bottom sediments under anoxic conditions.

Figure 9. Total phosphorus levels in Knickerbocker Lake (KL4) from upper water column (profile grab and core) and bottom water grabs in 2017, as compared to the range of TP expected in a mesotrophic lake (high = 20ppb, low = 4.5 ppb).



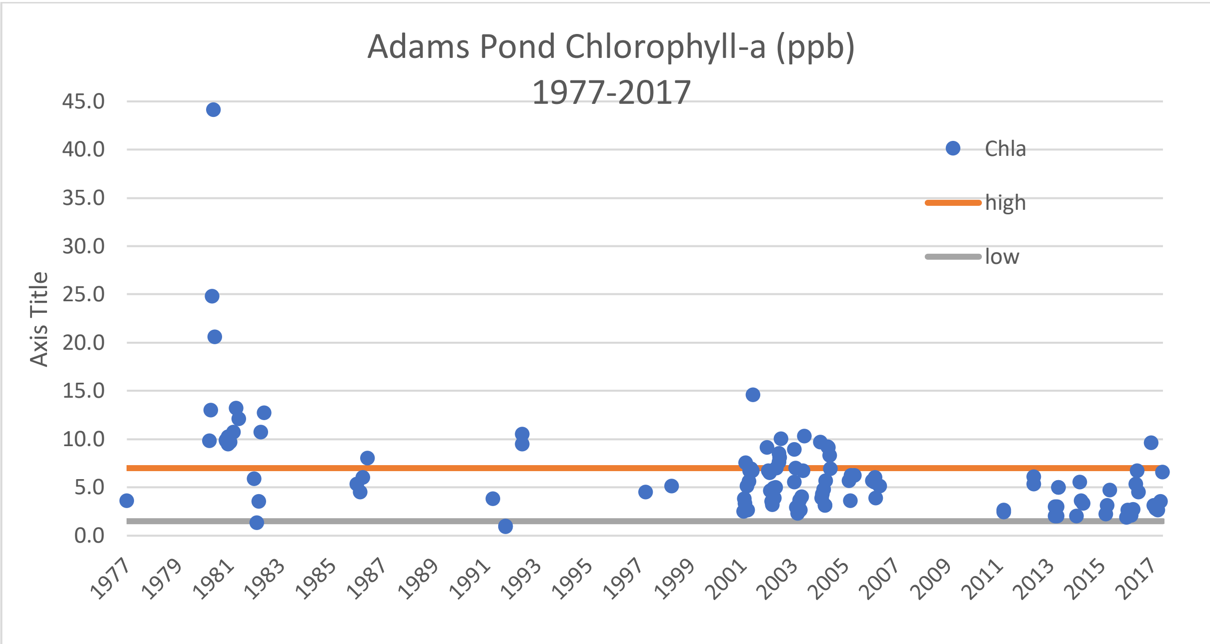
Chlorophyll-a

Chlorophyll-a, a plant pigment, levels are a reliable measure of algae populations, which are the best direct measure of a lake's productivity. Core samples taken within the water column zone where light penetrates and optimal temperatures occur provide a good indication of the abundance of algae.

Adams Pond (AP1)

Chl-a samples were collected monthly from May through October, using a core sample of the upper water column. In 2017, observed Chl-a levels in Adams Pond varied from 2.5 ppb to 9.6 ppb, with an average of 4.7 ppb. The May Chl-a sample (9.6 ppb) was greater than the DEP standard for mesotrophic lakes. From 1977-2017, Chl-a levels ranged from 0.9 to 44 ppb, with an average of 6.3 ppb (Figure 10).

Figure 10. Chlorophyll-a levels in Adams Pond, 1980-2017, as compared to the range of chlorophyll-a expected in a mesotrophic lake (high = 7 ppb, low = 1.5 ppb).



Knickerbocker Lake (KL1)

In 2017, upper layer water core samples were collected once monthly at KL1 from May through November and analyzed for Chl-a. Observed Chl-a levels in the seven KL1 samples varied from 2.5 ppb to 9.3 ppb, with an average of 5.7 ppb. Two samples exceeded the upper DEP boundary for mesotrophic lakes and the average is close to the maximum. From 2001-2017, chlorophyll-a levels in Knickerbocker Lake ranged from 2.0 to 61 ppb, with an average of 6.4 ppb (Figure 11).

Little Knickerbocker (KL4)

Five water samples were collected from Little Knickerbocker (KL4) for Chl-a analysis in 2017. Samples ranged from 3.4 to 10 ppb, with an average of 6.2 ppb. Three of the five samples were higher than the DEP upper boundary for mesotrophic lakes and the average of all samples is close to the upper boundary (Figure 12).

Figure 11. Chlorophyll-a levels in Knickerbocker Lake (KL1), 2001-2017, as compared to the range of chlorophyll-a expected in a mesotrophic lake (high = 7 ppb, low = 1.5 ppb).

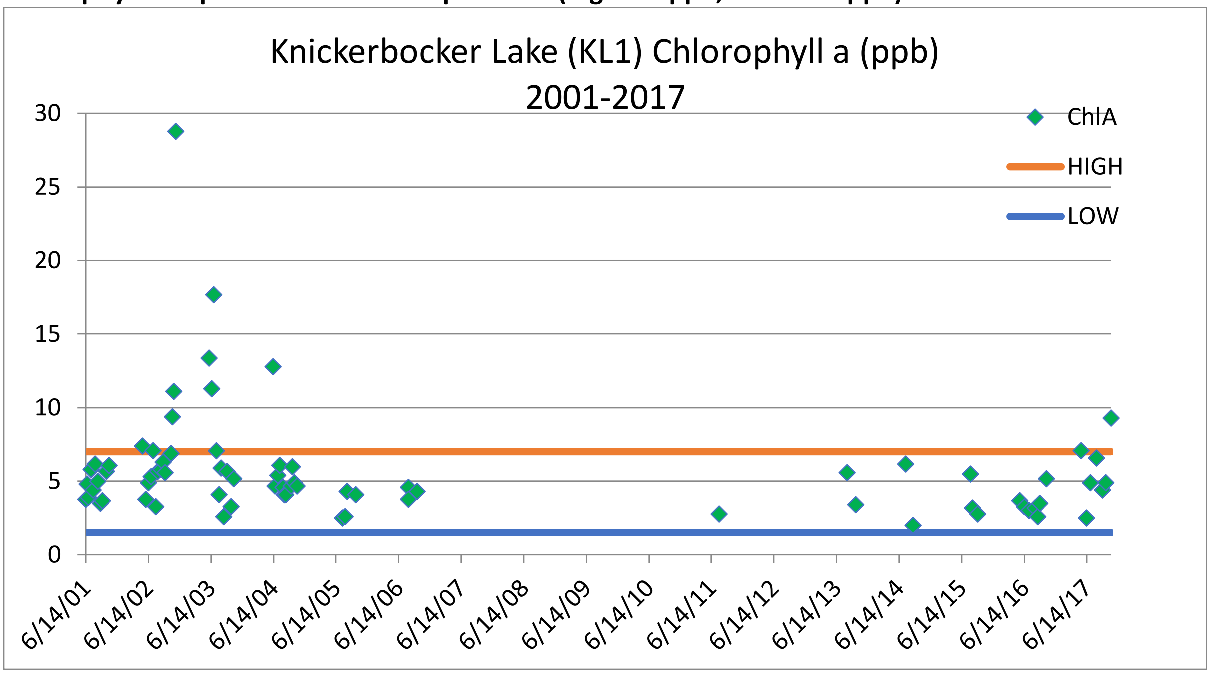
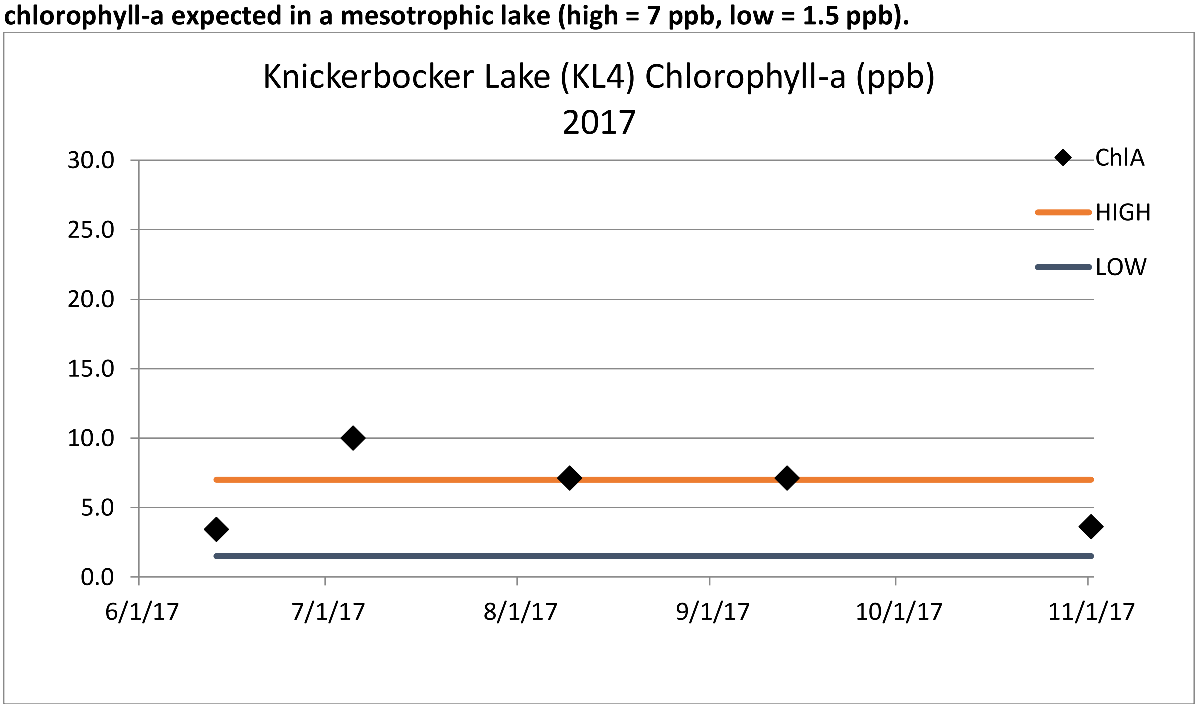


Figure 12. Chlorophyll-a levels in Knickerbocker Lake (KL4) in 2017, as compared to the range of chlorophyll-a expected in a mesotrophic lake (high = 7 ppb, low = 1.5 ppb).



Summary

Based on water quality data, both Adams Pond and Knickerbocker Lake are mesotrophic lakes with water clarity that falls between 4-8 m, moderate phosphorus (4.5-20 ppb) and chlorophyll-a levels (1.5-7 ppb) and occasional anoxia in bottom waters. Although most water quality values for both lakes fall within the medium productivity range, TP, Chl-a and water clarity data are closer to the higher end of the productivity spectrum for mesotrophic lakes. If lake water quality values exceed these mesotrophic levels, the lakes will be more susceptible to algae blooms and will require more treatment to serve as public drinking water. Little Knickerbocker Lake's water quality appears to be degraded relative to both Adams Pond and the deeper Knickerbocker Lake and the DEP standards for mesotrophic lakes.

In 2017, a relatively dry year, Secchi disk transparency at Adams Pond averaged 5.5 m, Chl-a, 4.7 ppb, and the average TP was 9.5 ppb. Anoxia was not observed during bi-weekly sampling from May through October. Historical data show a trend of increasing water clarity in Adams Pond over the 1977-2017 period. Data gaps in TP and Chl-a sampling make trend analysis more difficult for these parameters. However, the extremely high levels of TP and Chl-a observed in the 1980s and 1990s have not been noted in Adams Pond since 2001.

In 2017, Secchi disk transparency at the deep-water site of Knickerbocker Lake (KL1) averaged 4.4m, chlorophyll-a, 5.7 ppb, and the average of all TP samples was 15 ppb. Anoxia in bottom waters was observed for a period of 9 weeks. 2017 water quality was similar to long-term averages for these parameters.

Data collected in 2017 indicate that Little Knickerbocker Lake may be approaching a eutrophic state. Bottom anoxia (below 3-4 m) was present on 12 of the 13 sampling dates. Water clarity was poor (average, 3.0 m). Upper water column TP levels averaged 15 ppb, while bottom TP averaged 45 ppb, indicating that recycling of phosphorus from bottom sediments is significant. Three of the five Chl-a samples collected in 2017 were higher than the mesotrophic range (>7.0 ppb) and the average of all samples was 6.2 ppb.

Forrest Bell Environmental Associates (2018) modelled Adams Pond and Knickerbocker Lakes phosphorus loading to predict both historical water quality and the likely effects to water quality of current and future watershed development and conservation. Their work demonstrates the significance of human development to lake water quality and the need for a conservative approach to future watershed development and land conservation. While developed areas currently cover only about 13% of the Adams Pond watershed, these developed areas contribute 71% of the total phosphorus load to the lake. At Knickerbocker Lake, developed areas currently cover about 7% of the watershed and contribute 57% of the total phosphorus load to the lake.

FBE determined that for both Adams Pond and Knickerbocker Lake, watershed runoff and base flow was the largest contributor to phosphorus load, 65% and 28% respectively. At Little Knickerbocker Lake, FBE concluded that internal recycling of phosphorus from bottom sediments is the largest (41%) phosphorus contributor, followed by watershed runoff and base flow (35%). Little Knickerbocker's water quality picture is concerning, not only for what it means for Little Knickerbocker but for its effects on the larger Knickerbocker Lake to which it contributes about 18% of the total TP load.

FBE concluded that although both Adams Pond and Knickerbocker Lake may be able to assimilate up to a 1-3 ppb increase in TP without being pushed over the tipping point, there is “no room for increase in in-lake total phosphorus concentrations in Little Knickerbocker Lake, which is already experiencing degraded water clarity at 3 meters and elevated chlorophyll-a above 7 ppb." They also concluded that current zoning ordinances, even if up to one-third of the watershed was protected from development, would not be enough to keep Adams Pond and Knickerbocker Lake's water quality from becoming severely degraded under full development of the watershed.

Although some of the phosphorus load to both lakes cannot be controlled, it's clear that preserving natural forested lands, wetlands and shoreline buffers, and managing significant phosphorus sources associated with human development should be the primary goals for protecting the public water supply. FBE's modeling showed that protecting more undeveloped watershed land from development will be essential to preserving water quality. The model indicates that protecting up to one-third of the watershed would not be enough to maintain water quality under full buildout, and protected land in both watersheds is considerably below even that level. Most of Adams Pond immediate shoreline is held in conservation and there is a total of about 160 acres, roughly 17%, of its 960-acre watershed currently protected. At Knickerbocker Lake, most of the shoreline is privately held and about 30 acres, or 3%, of its 980-acre watershed are in conservation. Watershed land conservation through easements, outright purchase and open-space requirements on new development will be a necessity if water quality is to be protected as the watershed is developed.

With so much of both watersheds in private ownership and undeveloped, zoning ordinances that encourage low impact development on both undeveloped and already-developed properties must also play a major role in protecting Adams Pond and Knickerbocker Lake's water quality into the future. Boothbay's zoning ordinance are currently under revision and this is a great opportunity to provide the necessary protections for future watershed development. Septic systems are another significant nutrient source in both watersheds and are projected to become a greater problem as the watersheds are developed. Proper siting, monitoring and maintenance of septic systems will also be essential. Since 2015, BRWD has worked with private and public property owners to remediate non-point source (NPS) pollution sites in the watershed. Work on addressing existing NPS problems while avoiding new ones is another necessary step to protecting the public water supply.

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