Adams Pond and Knickerbocker Lake
Water Quality and Withdrawal Summary for 2020

Susan Mello
Boothbay Region Water District
February 2021

Executive Summary

Adams Pond and Knickerbocker Lake are the Boothbay Region's public water sources. Maintaining water quality in these lakes is critical to public health and community sustainability. Boothbay Region Water District (BRWD), Maine Department of Environmental Protection (DEP) and Lake Stewards of Maine have monitored water quality in Adams Pond and Knickerbocker Lake since 1977 and 1991, respectively. This report summarizes these monitoring data for major water quality indicators and includes information on lake levels and withdrawals.

Although there is a relatively long time series of water quality data available, lapses in data collection and changes in methods hamper comparisons. Consistent sampling of key parameters during the lake growing season is critical to understanding lake trends. To that end, a Standard Operating Procedure for BRWD water quality sampling was developed in 2017 and updated in 2020. It will be important that this SOP guides water quality monitoring even when staff changes occur.

In general, water quality during the 2020 summer drought period was good, but water quality deterioration, in terms of clarity and phosphorus levels, was noted after fall turnover. In terms of the potential for algae blooms, these late seasons "dips" are of less concern than a midsummer occurrence would be. The combination of reduced daylight and colder water temperatures in fall lowers the risk of algae blooms.

The water quality parameters reported on here are: Secchi disk transparency, total phosphorus, chlorophyll a, anoxia and turbidity.

Secchi disk transparency readings in 2020 were within the expected range for both lakes during the main growing season but fell to levels below this range in fall after lake turnover..

Total phosphorus levels in 2020 were on average within the normal range for mesotrophic lakes and similar to previous years. The maximum midwater total phosphorus level observed in both lakes in 2020 was 14 ug/l.

Chlorophyll a levels were on average within the normal range for mesotrophic lakes and similar to previous years. In both lakes one high reading (7 ug/l) was observed during summer.

Turbidity levels in both lakes from 2020 midwater samples were higher than the 10-year average, maximum and minimum values.

Anoxia was observed in bottom waters of Adams Pond from 7/21 – 8/19 and did not extend above 6.5m. Anoxia in bottom waters of Knickerbocker Lake was observed from 7/21 – 10/28 and was confined to depths below 7.5m.

2020 was a dry year, the second driest in the last 20 years. Lack of precipitation resulted in less runoff and lower contaminant inputs to surface waters, but the lack of incoming water also drove pond levels down. Knickerbocker Lake saw its lowest recorded lake level in 2020, and Adams Pond saw its third lowest level since 2008.

2020 was the second largest water withdrawal year for BRWD since 2008, with a total of 204 million gallons (MG) removed. Water withdrawals from Adams Pond totaled 157 MG in 2020, greater than the 2008-2020 withdrawal average and larger than any year in this series except 2009 (when Knickerbocker was essentially not used). Water withdrawals from Knickerbocker Lake totaled 47.7 MG in 2020, greater than the 2008-2020 withdrawal average and the second largest annual withdrawal since routine use of Knickerbocker Lake began.

Water Quality Summary

Secchi Disk Transparency

Secchi disk transparency is a measure of water clarity and a surrogate for algal productivity. Secchi disk readings decrease with increased algal abundance and declining water clarity. As mesotrophic lakes, Adams Pond and Knickerbocker Lake Secchi readings are expected to range between 4 and 8 meters.

Adams Pond

Secchi disk readings have been taken in Adams Pond since 1977, with varying regularity. The long-term linear trend for Secchi disk transparency data shows increasing water clarity over the entire time period (Figure 1 red dotted line). This long-term trend is likely influenced by low Secchi disk readings in the late 1970s-1980s, when algae blooms were reported. More recent data (2010-2020) indicate that water clarity may be declining in the near term (Figure 2).

Secchi disk transparency readings in Adams Pond in 2020 were similar to long-term observations (Table 1). Secchi disk readings were greater than 4m for most of the sample period but dipped below that level in late October.

Figure 1.

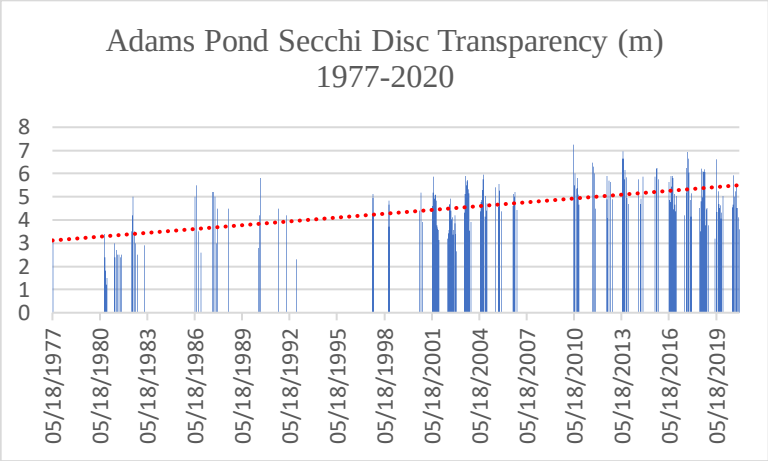


Figure 2.

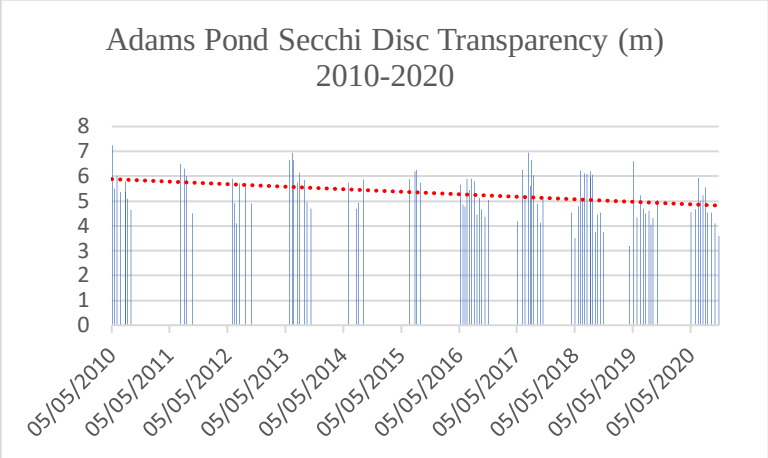


Table 1. Comparison of Adams Pond Secchi disk data over different time periods with 2020 observations.

Secchi	1977-2019	2010-2019	2020
Average	4.7	5.3	4.8
Max	7.3	7.3	5.9
Min	1.2	3.2	3.6

Knickerbocker Lake

Secchi disk transparency readings have been taken at deep water stations on Knickerbocker Lake since 1991, with varying regularity. There is no strong trend in the data (Figure 3 & 4). Secchi disk transparency readings in 2020 were similar to long-term observations (Table 2). Secchi disk readings were greater than 4m for most of the sample period but two readings in October were well below that level.

Sampling of Little Knickerbocker began in 2017. Since then, Secchi disk transparency has averaged 3.3m with a maximum Secchi of 4.5 m and a minimum of 2.3 m.

Figure 3.

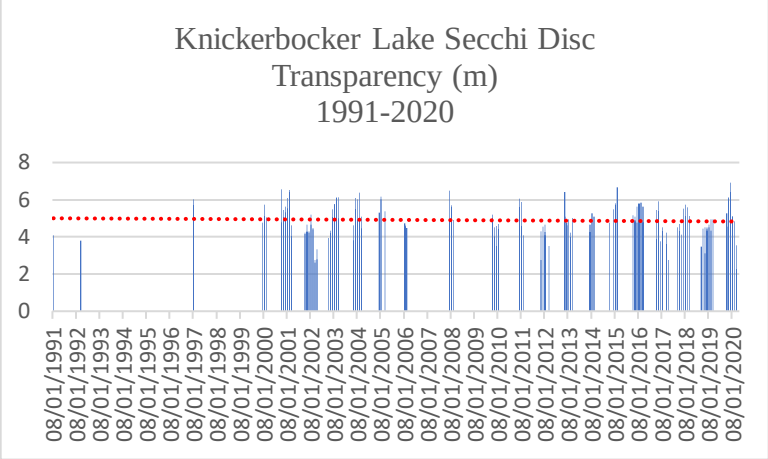


Figure 4.

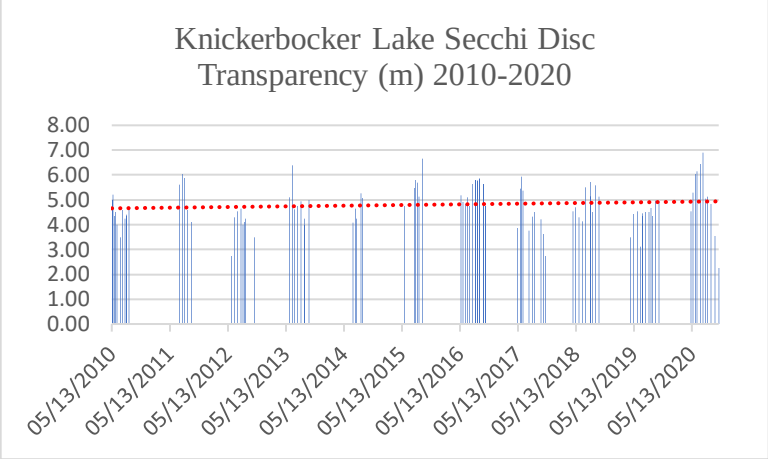


Table 2. Comparison of long-term Knickerbocker Lake Secchi disk transparency data and 2020 observations.

Secchi	1997-2019	2010-2019	2020
Average	4.9	4.8	4.8
Maximum	6.7	6.7	6.9
Minimum	2.6	2.6	2.3

Total Phosphorus

Total phosphorus (TP) level in the water column is the major determinant of algal productivity in freshwater lakes. High TP levels are associated with a higher risk of algae blooms. Mesotrophic lakes, like Adams Pond and Knickerbocker Lake, typically have TP levels that fall between 4.5 and 20 ug/l. Lake Loading Response Models developed by Forrest Bell Environmental Associates for Adams Pond and Knickerbocker Lake suggest that TP levels should remain below 11 ug/l in Adams Pond and 15 ug/l in Knickerbocker Lake if algae blooms are to be avoided (FBE 2018).

Adams Pond

TP concentrations in Adams Pond have been monitored since 1977, with inconsistent frequency. Extremely high TP levels in the 1980s, associated with algae blooms and failing septic systems, have not been recorded since. Long-term TP data (Figure 5) show a strong negative trend in midwater TP levels; more recent data show a negligible decreasing trend (Figure 6). The average TP level in 2020 (11 ug/l) was the same as the 20-year average and at the recommended limit defined by FBE modeling (Table 3). The 2020 maximum level was well below earlier maxima and occurred in October. This late-season increase in TP may be due to recycling of TP from bottom water after fall turnover. Because water temperatures are low and daylight duration shorter, a fall TP pulse is less likely to cause an algae bloom than one during summer. Since 1977, 13% of midwater samples exceeded the 20 ug/l high standard, while 2% surpassed this standard since 2001.

Figure 5.

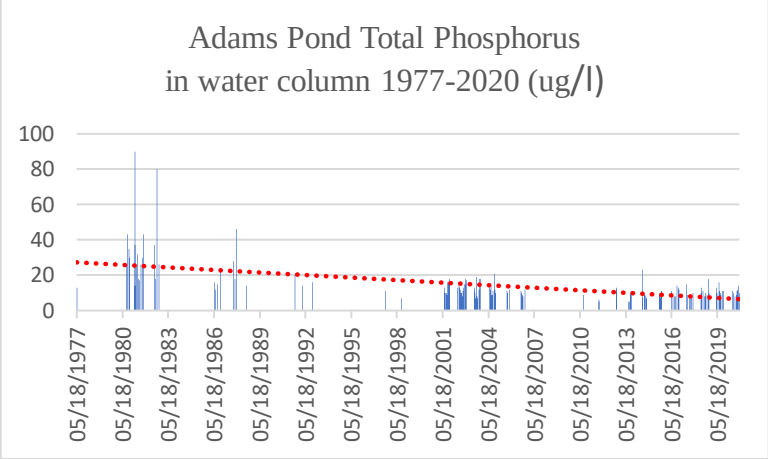
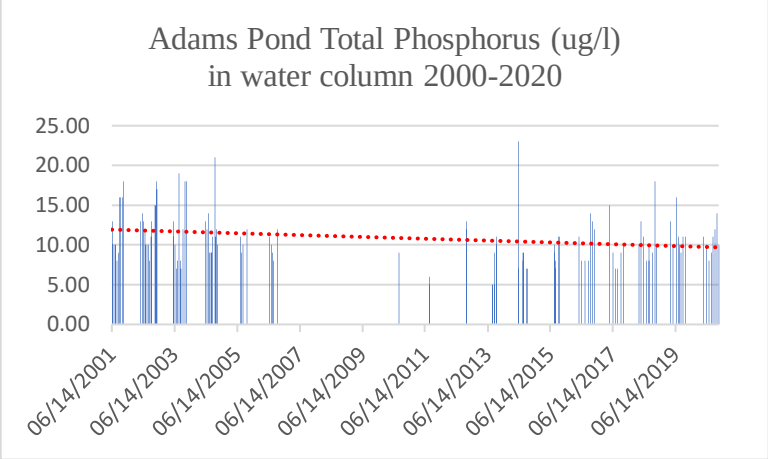


Table 3. Comparison of midwater TP levels in Adams Pond during different time periods with 2020 observations.

	1977-2019	2000-2019	2020
Average	14	11	11
Maximum	90	23	14
Minimum	2	5	8

Figure 6.



During thermal stratification, TP levels in near bottom water may increase due to TP release from sediments under anoxic conditions. During seasonal lake water turnover, this released TP may be mixed into the water column and become available to algae. TP level in bottom water samples was on average higher than water column levels, suggesting that TP may be released from sediments during anoxic periods. Sediment sampling and analyses by DEP support this as well (DEP 2018). Water samples near the lake bottom show no trend TP levels over time (Figure 7).

Figure 7.

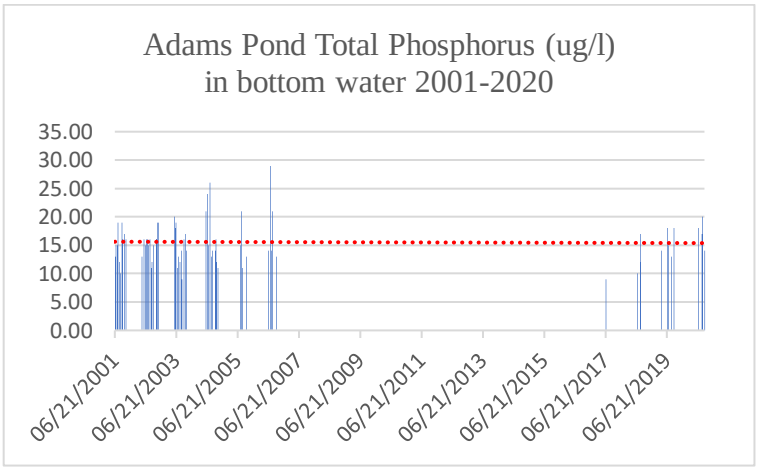


Table 4. Comparison of Adams Pond bottom TP samples long-term data with 2020.

	2001-2019		2020
Average	15		17
Maximum	29		20
Minimum	9		14

Knickerbocker Lake

TP concentrations in Knickerbocker Lake have been monitored since 1991, with few samples prior to 2001. Both long-term and more recent data show a small decreasing trend in midwater TP levels over time (Figures 8 and 9). The average and minimum TP levels observed in 2020 were similar to long-term values, but the maximum observed level in 2020 was much lower (Table 5). The maximum TP for 2020 (14 ug/l) was observed in late summer (9/10/20) when Knickerbocker was still thermally stratified. Since 1991, 3% of midwater samples exceeded the 20 ug/l 'high' TP standard.

Figure 8.

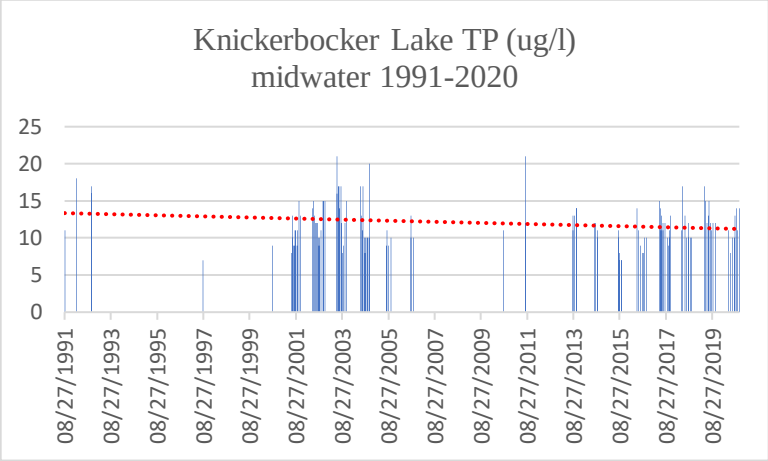


Figure 9.

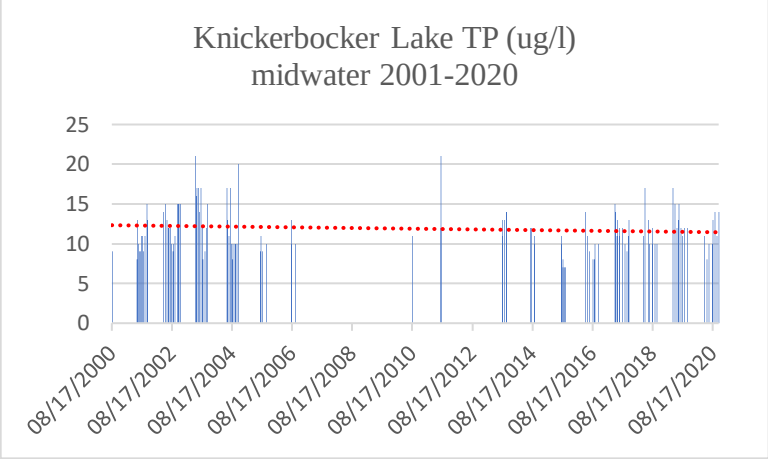


Table 5. Comparison of midwater TP levels in Knickerbocker Lake long-term data with 2020.

	1991-2019	2000-2019	2020
Average	12	12	11
Maximum	21	21	14
Minimum	7	7	8

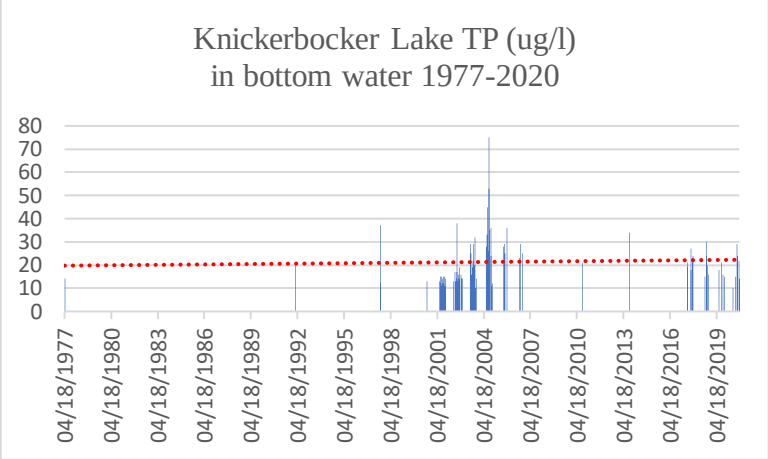
TP samples from Knickerbocker Lake bottom water grabs are on average much higher than water column levels and show higher maximum and minimum levels, suggesting that TP is released from sediments during anoxic periods (Table 6). There is no noticeable trend in bottom TP levels over time (Figure 10).

Data on Little Knickerbocker are limited to recent years. Since 2017, midwater TP levels averaged 16 ug/l, with an observed maximum of 21 ug/l and a minimum of 10 ug/l. TP levels in near bottom water samples averaged 42 ug/l, with an observed maximum of 66 ug/l and a minimum of 12 ug/l.

Table 6. Comparison of long-term bottom water TP levels with 2020 observations.

	1977-2019	2010-2019	2020
Average	22	21	19
Maximum	75	34	29
Minimum	10	15	10

Figure 10.



Chlorophyll a

Chlorophyll a (Chla) is a plant pigment used as a direct measure of algal abundance. Mesotrophic lakes, like Adams Pond and Knickerbocker Lake, have Chla levels that fall between 1.5 and 7 ug/l. Chla levels that exceed 7 ug/l are common in lakes prone to algae blooms.

Adams Pond

Chla concentrations in Adams Pond have been monitored since 1977, with inconsistent frequency. Extremely high levels of Chla were observed in the 1980s, coincident with algae blooms observed at that time. The long-term linear trend for Chla is decreasing over the entire sample period (Figure 11) but appears to be slightly increasing since 2010 (Figure 12). The average of Chla samples in 2020 (4 ug/l) was slightly lower than the long-term average. Although the maximum observed level in 2020 was lower than long-term maxima, it was a high level (7 ug/l) . Since 2001, 19% of Chla samples have equaled or exceeded the 7 ug/l “high” bar.

Figure 11.

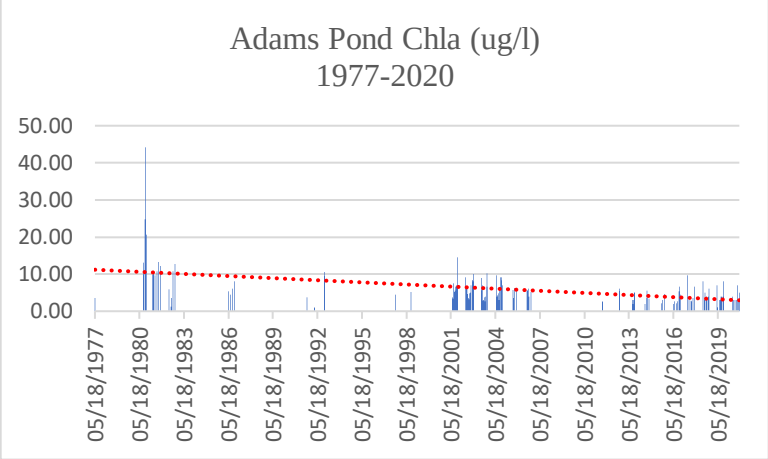


Figure 12.

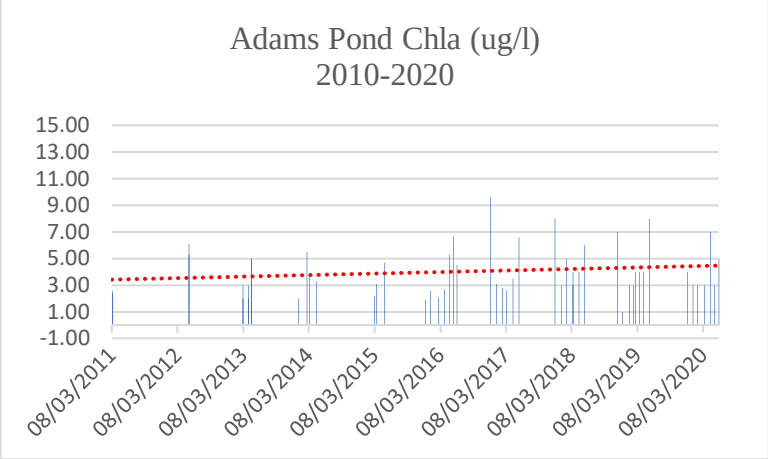


Table 7. Comparison of Adams Pond Chla data over time with 2020 observations.

	1977-2019	2001-2019	2020
Average	6	5	4
Maximum	44	10	7
Minimum	1	1	3

Knickerbocker Lake

Chla concentrations in Knickerbocker Lake have been monitored since 1991, with inconsistent frequency. Chla levels show a decreasing trend over the entire sample period and a negligible positive trend since 2010 (Figures 13 & 14). The average and maximum Chla levels in 2020 were lower than the long-term values (Table 8). Since 1991, 21% of Chla samples have equaled or exceeded the 7 ug/l "high" bar.

Since 2017, Chla levels in Little Knickerbocker Lake have averaged 5.7 ug/l, with an observed maximum of 14 ug/l and a minimum of 2 ug/l.

Figure 13.

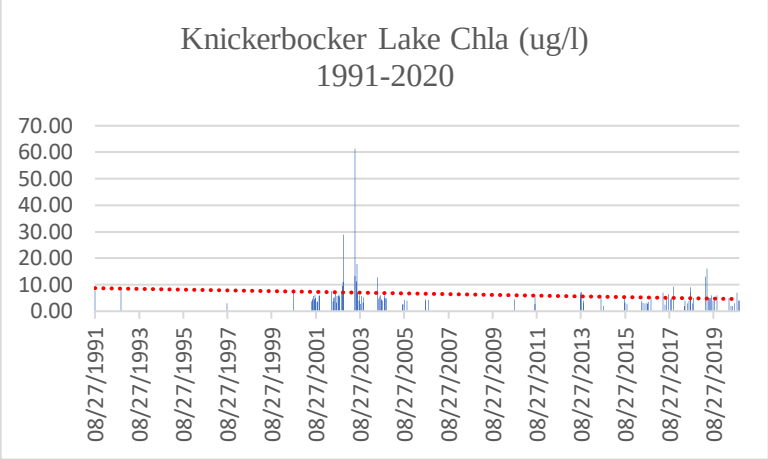


Figure 14.

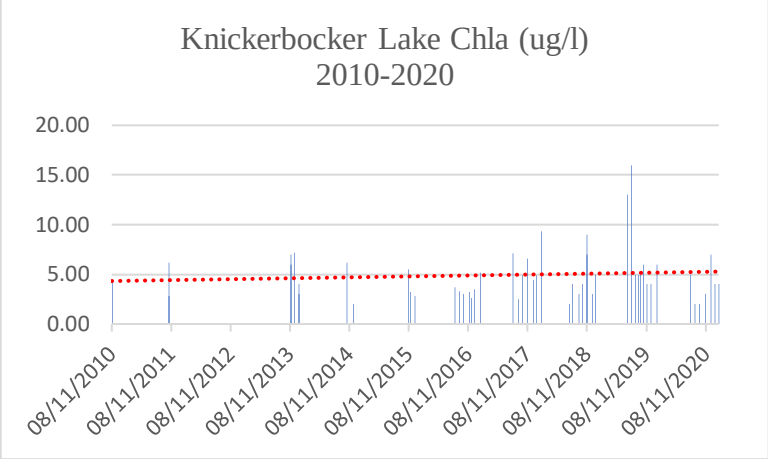


Table 8. Comparison of Knickerbocker Lake Chla data over time with 2020 observations.

	1991-2019	2010-2019	2020
Average	6	5	4
Maximum	61	16	7
Minimum	2	2	2

Turbidity

Turbidity is the degree of water cloudiness caused by floating particles that are generally invisible to the eye. In open waters of lakes, phytoplankton are usually the major source of turbidity. Turbidity can have a significant impact on light penetration, water temperature, dissolved oxygen and aquatic communities and on water treatment processes.

In both lakes, turbidity levels from midwater samples in 2020 were higher than the 10-year average, maxima and minima. Knickerbocker saw its highest recorded level to date in 2020. Highest turbidity levels in both lakes occurred in October and coincided with lowest Secchi disc

transparency readings. Trend data shows an increasing turbidity trend in Adams and a decreasing trend in Knickerbocker Lake (Figures 15 & 16).

Table 9. Turbidity levels from midwater sampling for 2010-2020 and 2020. Turbidity measured in Nephelometric Turbidity Units (NTU).

	2010-2019				2020		
	Average	Max	Min		Average	Max	Min
Adams	0.92	2.6	0.05		1.17	1.58	0.97
Knickerbocker	1.15	3.03	0.53		1.37	3.74	0.67

Figure 15.

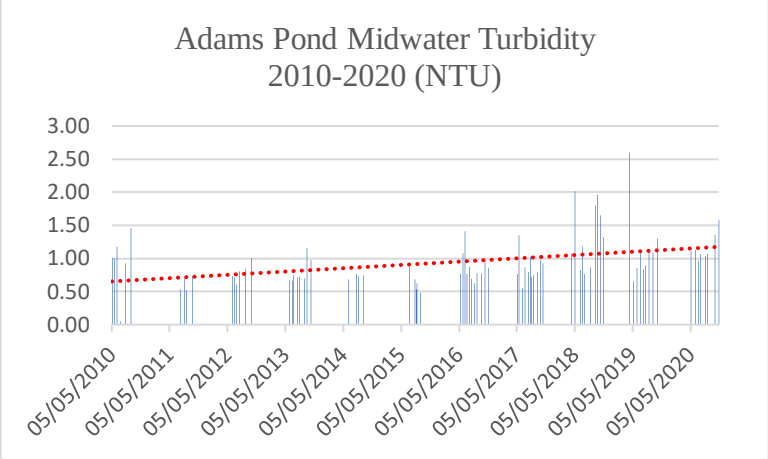
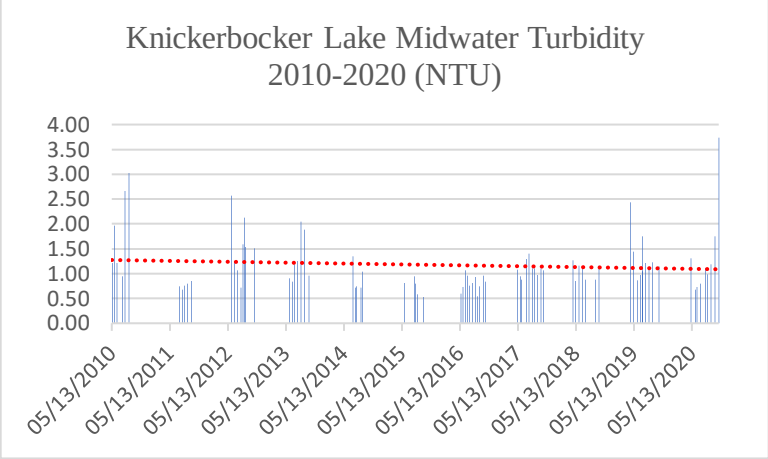


Figure 16.



Dissolved Oxygen (DO) and Anoxia

The dissolved oxygen level in lake water is important to aquatic organisms and has relevance for in-lake chemical reactions. In thermally stratified lakes, the bottom water layer can be isolated from oxygen inputs from the atmosphere and algae photosynthesis. Oxygen is also consumed in decomposition processes further lowering DO levels in this water layer. Low DO levels are not only stressful for animal populations, anoxia in bottom waters can cause phosphorus sequestered

in sediments to be released into the water column. At spring and fall turnovers, this released phosphorus may be resuspended and become available to algae populations in the water column. Under these conditions, the lake itself can be a significant source of phosphorus.

Adams Pond is weakly stratified and occasionally loses stratification during summer storms. In 2020, fall turnover was evident by 9/10/20, when the lake was isothermal and the entire water column was oxygenated. Knickerbocker Lake held its thermal stratification into late October. It was isothermal on the 10/28/20 sample date. However, bottom water samples were still anoxic indicating that complete water column mixing had not yet occurred.

Dissolved oxygen/temperature profile readings have been taken at Adams Pond on 173 days since 1981. On 49 of these sample days (28%), anoxia (DO <1 mg/l) was observed in near bottom water. Anoxia was primarily limited to depths below 6m but 20% of anoxic readings extended up to 5 meters (average total depth at sample site 7.1m; maximum observed depth 7.5 m). As anoxia extends upward in the water column, more of the lake bottom is exposed to anoxic conditions and there is greater potential area of TP release (Figure 17).

Anoxia is more common in Knickerbocker Lake. DO/temperature readings have been taken at Knickerbocker Lake on 158 days since 1991. On 78 of these sample days (49%), anoxia (DO <1 mg/l) was measured in near bottom water. Anoxia was primarily limited to depths below 7m, but 18% of anoxic readings extended up to 6 m and 9% extended to 5m (average total depth at sample site 8.3m; maximum depth 10.4 m). As with Adams, as anoxia spreads to shallower water more of the lake bottom becomes a potential phosphorus source.

DO/temperature readings were taken at Little Knickerbocker on 28 days since 2017. Anoxia was observed on 23 days (82%). The majority of anoxia events were limited to 4m or lower but 46% extended up to 3m.

Figure 17. Extent of Adams Pond bottom exposed to anoxic water (black area) when anoxia extends 7m to 6m and 5m (left to right).

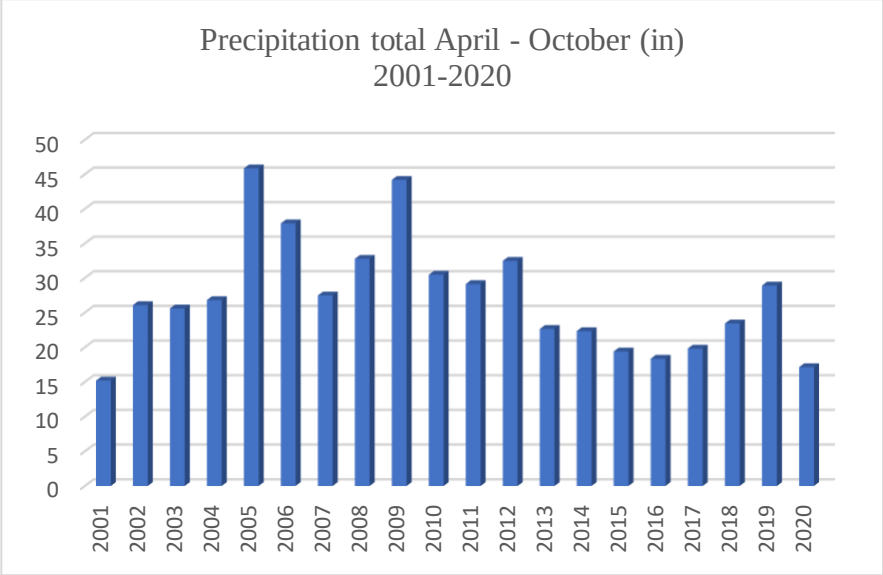
Anoxia has most commonly been observed during July and August in Adams Pond. At Knickerbocker Lake, anoxia has been most common in August and September (Figure 18).

Figure 18.

Precipitation

2020 was a dry year, the second driest in the last 20 years (Figure 19). Drought can have both positive and negative ramifications for water quality. During dry periods, there is no runoff into surface waters, which reduces phosphorus inputs from the watershed. But drought also means less water overall resulting in lower lake levels that can be compounded by water withdrawals. Research indicates that excessive water level changes can destabilize lake ecosystems, increase nutrient loading and decrease water clarity. Climate change is expected to magnify water level fluctuations.

Figure 19.



Lake levels

Lake surface level on Adams Pond is measured by wet well height when Adams is being withdrawn from and from a set point distance at the Adams Pond dam, seasonally (Figure 20 & 21). Lake surface level is measured at Knickerbocker seasonally, using hourly data from an ultrasonic water level monitoring unit installed at the Knickerbocker intake in 2008.

Figure 22 shows Knickerbocker Lake levels recorded since 2010. The lowest lake level for the time period in Knickerbocker occurred in 2020, with the second lowest level observed in 2016. 2020 and 2016 also saw the lowest and next lowest April-November precipitation total for 2010-2020. Adams Pond surface level measured at the dam provides the best measure of Adams Pond lake level when Knickerbocker is the source. Figure 21 shows Adams Pond lake levels during April–November 2008-2020. 2016 was Adams Pond's lowest observed level over this time period and 2020 marked the third lowest point in the time series. On both lakes, the lowest levels recorded occurred in October.

Figure 20.

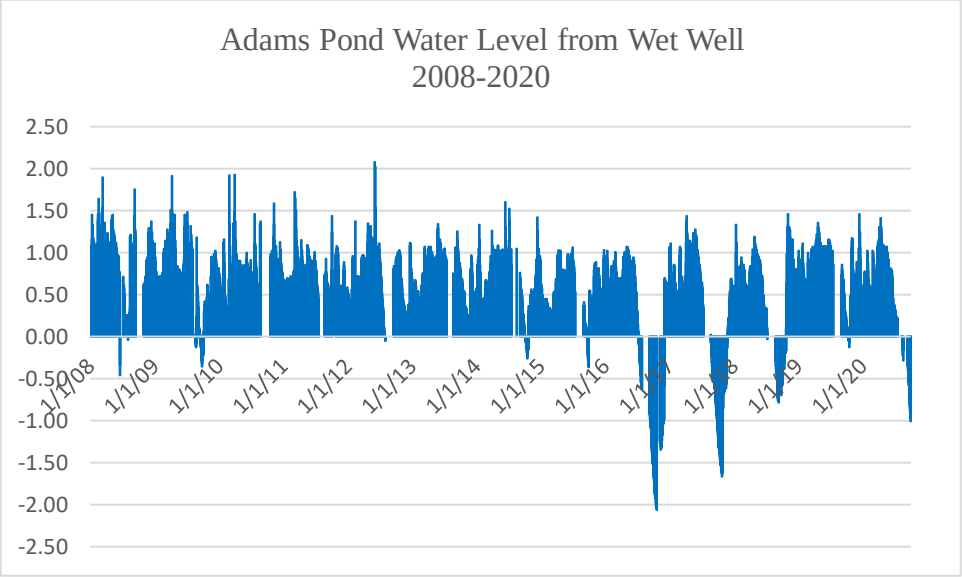


Figure 21.

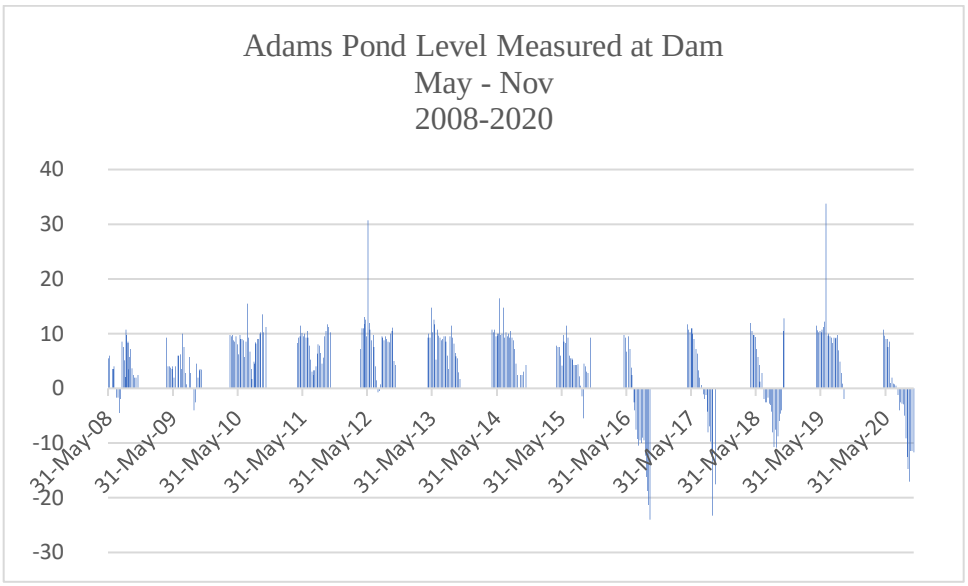
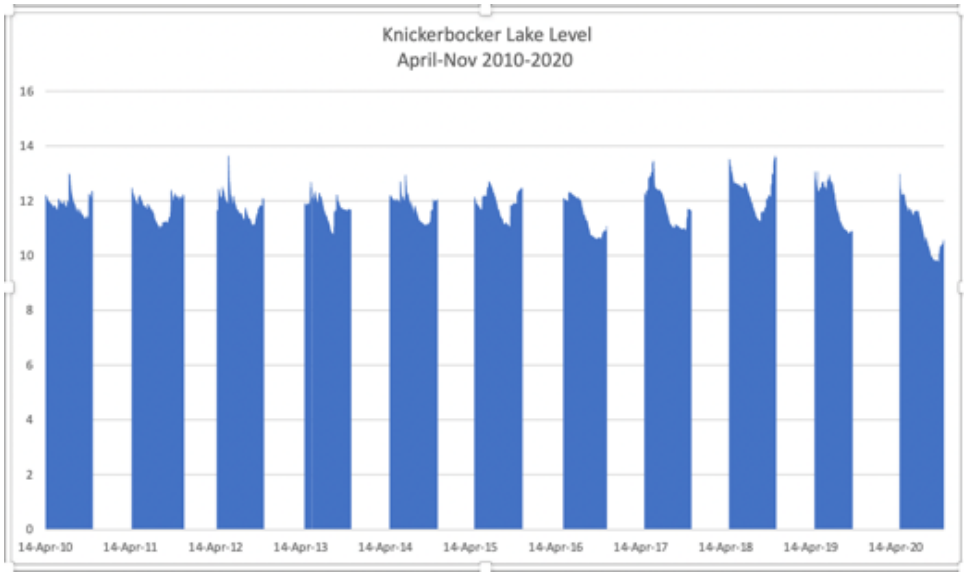


Figure 22. Knickerbocker Lake levels measured at intake site.



Water withdrawals

Adams Pond has been the primary public water source for the Boothbay Region since the 1800s. Knickerbocker Lake was permitted for routine use in 2008. Water withdrawals from both sources since 2008 are summarized in Table 10.

Since 2008, BRWD has withdrawn between 136 and 190 million gallons per year (MGY) from Adams Pond, with an average annual withdrawal of 150 MGY. The average daily withdrawal has been 0.47 MG and BRWD has withdrawn from Adams on average 318 days per year. The Maine Drinking Water Program (DWP) calculated the safe yield for Adams at 352 MGY, which suggests a daily safe yield of 0.96 MG (DWP, 2010). Since 2008, withdrawals from Adams have

exceeded the predicted daily safe yield of 0.96 MG on 108 days, 2.6% of the total withdrawal days.

Under the 2008 NRPA permit, DEP has limited withdrawals from Knickerbocker to 51.5 MGY and to no more than 33 MG between May 1 and July 1. Since 2008, BRWD has withdrawn between 0.49 and 50 MGY from Knickerbocker Lake. Excluding 2009, when withdrawal was stopped soon after beginning, the average annual withdrawal was 43 MGY and the average daily withdrawal ranged from 0.63 MG to 0.99 MG. Excluding 2009, BRWD has withdrawn from Knickerbocker Lake an average of 48 days per year. DWP calculated the safe yield for Knickerbocker Lake at 570 MGY, which implies a daily safe yield of 1.56 MG (DWP, 2010). However, the Maine DEP Knickerbocker Lake NRPA permit states that "This maximum daily demand exceeds the most optimistic estimate of 1.0 MGD maximum safe yield for the Knickerbocker Lakes" (DEP 2003). The source for the DEP's safe yield estimate is not clear. No withdrawals from Knickerbocker Lake have exceeded 1.56 MG. Withdrawals greater than 1.0 MGD have occurred on 136 days, 22% of the total days with withdrawals occurring. Clarity around the safe yield of both waterbodies would be useful for long-term management.

2020 was the second largest water withdrawal year since 2008, with a total of 204 MG removed. Water withdrawals from Adams Pond totaled 157 MG in 2020, greater than the 2008-2020 withdrawal average and larger than any year in this series except 2009 (when Knickerbocker was essentially not used). Water withdrawals from Knickerbocker Lake totaled 47.7 MG in 2020, greater than the 2008-2020 withdrawal average and second largest annual withdrawal for the time period.

Table 10. Water withdrawals by source by year 2008-2020. In 2011 and 2016, Knickerbocker Lake withdrawals occurred in a summer period and then a separate fall period. For 2011, July-August average MGD was 0.93 and October average was 0.43 MGD. For 2016, July-Sept average MGD 1.0 and Oct-Nov average MGD 0.34. In all other years, Knickerbocker Lake withdrawals were continuous.

Year	Adams MGY	Knick MGY	Total MGY	# days on Adams	# days on Knick	AVG MGD Adams	AVG MGD Knick	Max MGD Adams	Max MGD Knick
2008	164.3	40.9	205.2	304	65	0.54	0.63	1.64	1.18
2009	189.9	0.5	190.3	365	2	0.52	0.25	1.06	0.39
2010	133.4	41.6	175.0	303	63	0.44	0.66	1.10	1.08
2011	140.1	40.0	180.1	303	56	0.46	0.71	1.04	1.21
2012	141.1	40.7	181.9	311	48	0.45	0.85	1.06	1.11
2013	141.6	36.2	177.8	328	40	0.43	0.91	1.08	1.06
2014	136.2	40.7	176.9	316	51	0.43	0.80	1.19	0.96
2015	143.9	45.0	188.9	317	51	0.45	0.88	0.95	1.18
2016	154.1	50.0	204.1	304	64	0.51	0.78	1.12	1.27
2017	144.1	40.3	184.4	325	41	0.44	0.98	0.95	1.26
2018	147.5	44.6	192.1	321	45	0.46	0.99	1.00	1.20
2019	151.9	44.4	196.3	317	49	0.48	0.91	1.04	1.17
2020	156.6	47.7	204.3	314	53	0.50	0.90	1.14	1.19

AVERAGE	149.6	39.4	189.0	318	48	0.47	0.79	1.11	1.10
AVERAGE exclude 2009	146.2	42.7	188.9	314	52	0.47	0.83	1.11	1.16

References cited

Forrest Bell Environmental Associates. 2018. Adams Pond Lake Loading Response Model. Report to Boothbay Region Water District. 20 pages.

Forrest Bell Environmental Associates. 2018. Knickerbocker Lake Lake Loading Response Model. Report to Boothbay Region Water District. 23 pages.

Maine Department of Environmental Protection. 2003. Findings of Fact and Order, Knickerbocker Lakes Withdrawal L-16707-2B-D-M, May 8, 2003, 11 pages.

Maine Department of Environmental Protection. 2018. Unpublished sediment core data for Adams Pond and Knickerbocker Lake. Unpublished data courtesy of Linda Bacon, DEP.

Maine Drinking Water Program. 2010. Letter from Andrew L. Tolman, Assistant Director to Jonathan E. Ziegra, District Manager, dated February 5, 2010. 1 page.