KEZAR LAKE

2019 WATER QUALITY REPORT

A REPORT ON THE WATER QUALITY OF KEZAR LAKE, NINE STREAMS, AND SIX WATERSHED PONDS

PREPARED BY:
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February 2020

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The lower basin of Kezar Lake. Photo credit: FBE.

GLOSSARY OF KEY TERMS

Chlorophyll-a (Chl-a): A measurement of the green pigment found in all plants, including microscopic plants like algae. It is used as an estimate of algae biomass; higher Chl-a equates to greater amount of algae.

Color: A measure of the influence of suspended and dissolved particles in water from weathered geologic material, vegetation cover, and land use activity. Colored lakes (>25 PCU) can have reduced water clarity.

Dissolved Oxygen: The concentration of oxygen dissolved in water. DO is critical to the healthy metabolism of many creatures that reside in the water. DO levels in lake water are influenced by a number of factors, including water temperature, amount of algae and other plants in the water, and the amount of nutrients and organic matter that flow into the waterbody from the watershed. DO concentrations may change dramatically with lake depth. Oxygen is produced in the top portion of a lake (where sunlight drives photosynthesis), and oxygen is consumed near the bottom of a lake (where organic matter accumulates and decomposes).

Epilimnion: The top layer of lake water that is directly affected by seasonal air temperature and wind. This layer is well oxygenated by wind and wave action, except when the lake is covered by ice.

***Escherichia coli* (*E. coli*):** An indicator of harmful pathogens from fecal contamination that derive from mammalian sources, including human, canine, and wildlife.

Eutrophication: Process by which lakes become more productive over time. Lakes with high productivity have high levels of phosphorus and chlorophyll-a, low water clarity, and abundant biomass with significant accumulation of organic matter on lake bottom. Eutrophic lakes are susceptible to algae blooms and severe oxygen depletion in the hypolimnion. Lakes naturally become more productive or “age” over thousands of years. In recent geologic time, however, humans have enhanced the rate of enrichment and lake productivity, speeding up this natural process to tens or hundreds of years.

Fall Turnover: The process of complete lake mixing when cooling surface waters become denser and sink, forcing warmer, less-dense water to the surface. This process is critical for the natural exchange of oxygen and nutrients between surface and bottom layers in the lake.

Hypolimnion: The bottom-most layer of the lake. It experiences periods of low oxygen during thermal stratification and can be devoid of sunlight for photosynthesis (in deeper lakes like Kezar Lake).

Integrated Epilimnetic Core: A water sample that is taken with a long tube to determine average nutrient concentration from the lake surface to the top of the thermocline.

pH: The standard measure of the acidity or alkalinity of a solution on a scale of 0-14. Most aquatic species require a pH between 6.5 and 8. As the pH of a lake declines, particularly below 6, the reproductive capacity of fish populations can be greatly impacted as the availability of nutrients and metals changes. pH is influenced by bedrock, acid rain or snow deposition, wastewater discharge, and natural carbon dioxide fluctuations.

Secchi Disk Transparency (SDT) or Water Clarity: A vertical measure of water transparency (ability of light to penetrate water) obtained by lowering a black and white disk into the water until it is no longer visible. Measuring water clarity is one of the most useful ways to show whether a lake is changing from year to year. Changes in water clarity may be due to increased or decreased algae growth or the amount of dissolved or particulate materials in a lake, resulting from human disturbance or other impacts.

Spring Turnover: The process of complete lake mixing following ice-out when surface waters are exposed to wind action, bringing oxygen to the bottom and nutrients to the top of the water column.

Summer Stratification: The development of a thermal barrier that separates warm surface waters from dense, cool bottom waters. Without oxygen replenishment from the surface, bottom-dwelling organisms rapidly consume oxygen throughout the summer and early fall.

GLOSSARY OF KEY TERMS (CONTINUED)

Thermocline: The uppermost point in the water column where the temperature drops at least a degree Celsius per meter of depth.

Total Alkalinity: A measure of the buffering capacity of a lake (i.e., the capacity of water to neutralize acids). The buffering capacity or the concentration of bicarbonate, carbonate, and hydroxide ions in water, is largely determined by the geology of soils and rocks surrounding the lake. Total alkalinity above 20 ppm buffers against drastic changes in pH that could impact aquatic plants and animals.

Total Phosphorus (TP): The total concentration of phosphorus found in water, including organic and inorganic forms. Phosphorus is one of the limiting nutrients needed for plant growth; as phosphorus increases, the amount of algae generally increases. Humans can add excess phosphorus to a lake through stormwater runoff, lawn or garden fertilizers, and leaky or poorly-maintained septic systems.

Trophic State Indicators: Indicators of biological productivity in lake ecosystems, including water clarity, total phosphorus, and chlorophyll-a. The combination of these parameters helps determine the extent and effect of eutrophication in lakes and helps signal changes in lake water quality over time.

Watershed: An area of land that drains water to a point along or the outlet of a stream, river, or lake.

Winter Stratification: The development of a physical ice barrier and snowpack layer that limit the exchange of oxygen and nutrients between surface and bottom waters. A layer of ice forms at the lake surface, protecting waters below from frigid temperatures and wind storms. Cold winters with significant snowpack can block sunlight and limit photosynthesis that would otherwise replenish the lake with oxygen throughout the winter.

BACKGROUND AND METHODS

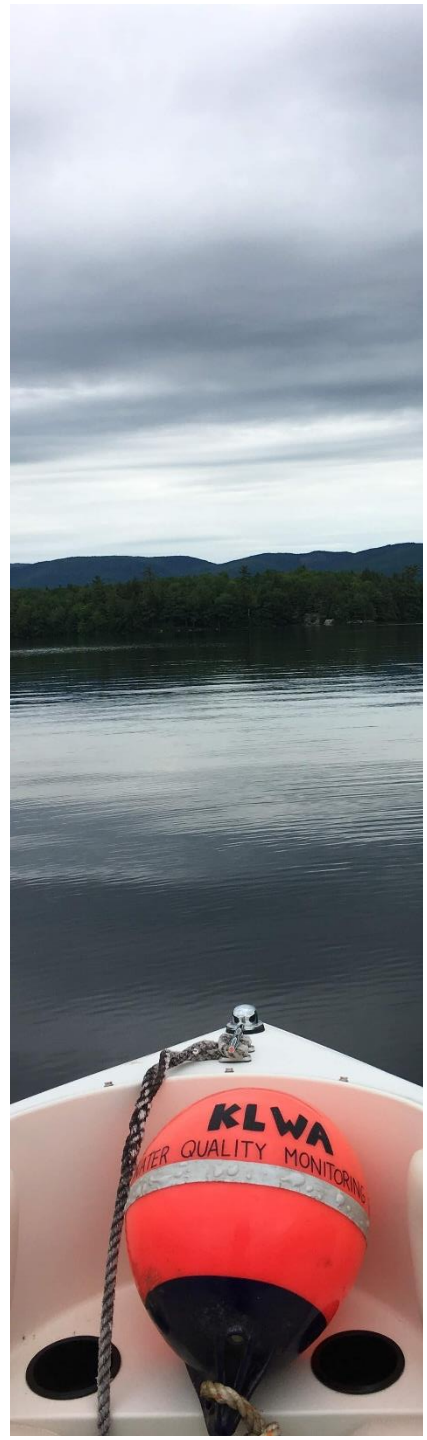
This report documents the results of water quality monitoring conducted by FB Environmental Associates (FBE) for the Kezar Lake Watershed Association (KLWA) in 2019. Deep spot sample stations at the three basins of Kezar Lake were sampled on 6/18/19, 8/20/19, and 9/17/19; deep spot sample stations at six ponds (Bradley, Cushman, Farrington, Heald, Horseshoe, and Trout Ponds) were sampled on 6/18/19 and 8/20/19. Tributary sample stations along Great Brook (GB-1), Beaver Brook (BV-L1), and Boulder Brook (BB-3) were sampled on 6/18/19, 8/20/19, and/or 9/17/19 (Figure 1).

For **lake and pond deep spot monitoring**, FBE, with the help of KLWA volunteers, collected temperature and dissolved oxygen profiles, Secchi disk transparency readings, and integrated epilimnetic cores. Water samples were analyzed for total phosphorus, chlorophyll-a, and chemical parameters (total alkalinity, pH, and color). Trophic state indicators (water clarity, total phosphorus, and chlorophyll-a) are indicators of biological productivity and help determine the extent and effect of eutrophication in lakes.

FBE and KLWA also deployed a buoy with six Onset HOBO® U-26 dissolved oxygen and temperature loggers at 2, 6, 8, 12, and 45 meters below the surface at the upper basin, as well as one Onset HOBO® U-26 dissolved oxygen and temperature logger and one Onset HOBO® U-24 conductivity logger at 2 meters below the surface at the lower basin (all recording at 15 minute intervals from 5/21-11/4/19). These depths equate to critical layers in the water column, which becomes thermally stratified in summer at the upper basin. Onset HOBO® temperature pendants were also deployed at 4, 14, 19, 25, 30, 35, and 40 meters below the surface at the upper basin and at 1 meter below the surface at the lower basin, recording temperature at 15 minute intervals continuously year-round (pendants were left over winter at 2, 4, 6, 10, 19, 30, and 40 meters below the surface at the upper basin and at 2 meters below the surface at the lower basin). The loggers were cleaned and downloaded during each sampling event. Logger data presented in the report shows data for the entire water column using R statistical software. These data will serve as a baseline for future comparisons of water quality to assess long-term changes in temperature and dissolved oxygen. Until more data are collected over the next few years to begin to account for interannual variability, no major conclusions or analyses can be made on this limited dataset aside from general patterns.

For **tributary monitoring**, three sites (Great, Beaver, and Boulder Brooks) were sampled for dissolved oxygen, temperature, total phosphorus, pH, and *E. coli.* FBE also monitored water temperature and/or water level using continuous Onset HOBO® loggers at the lower basin, Kezar outlet stream, and seven tributaries to Kezar Lake: Beaver, Boulder, Bradley, Coffin, Great, Long Meadow, and Sucker Brooks.

Sampling was conducted in accordance with standard methods and procedures for lake monitoring established by the Maine Department of Environmental Protection (Maine DEP), the US Environmental Protection Agency (USEPA), and Lake Stewards of Maine (formerly VLMP). All laboratory samples were analyzed at the Health and Environmental Testing Lab (HETL) in Augusta, ME. Background and historical information on these waterbodies can be found in previous reports (FBE, 2016, 2017, 2018; FBE, KLWA, & PSU, 2015; FBE, 2013a, 2013b).



Upper bay buoy deployment in May 2019. Photo Credit: FBE

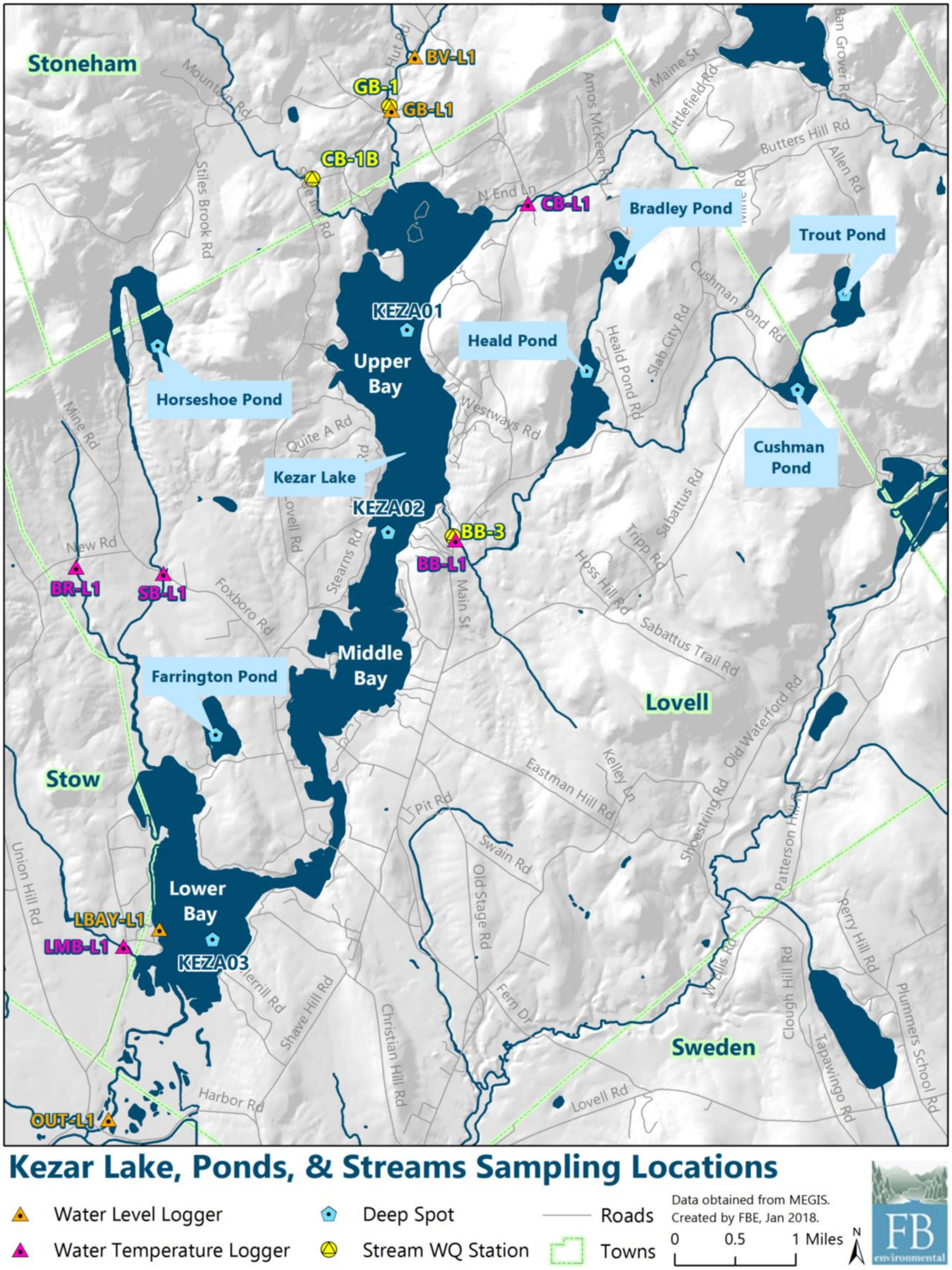
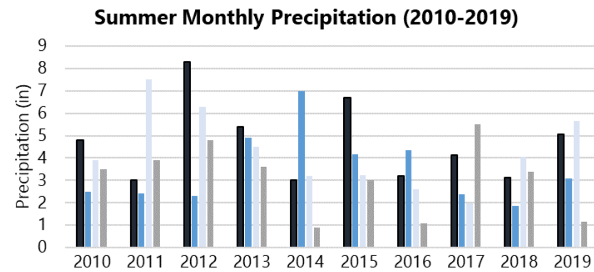


FIGURE 1. Map of lake, pond, and stream sampling locations.

WATER QUALITY MONITORING RESULTS

WEATHER

Weather is one of the major factors influencing interannual variability in lake water quality. Abnormally dry summer conditions reduce the amount of runoff containing sediment and nutrients to the lake and ponds, resulting in improved water quality (e.g., deeper water clarity, lower phosphorus, and lower chlorophyll-a or algae). Conversely, wetter years transport more material from the landscape to the lake and ponds, resulting in degraded water quality. The summer of 2019 experienced moderate amounts of precipitation like in 2010, 2014, and 2017; and not as low as in 2016 or 2018 (Figure 2).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
June	4.8	3.0	8.3	5.4	3.0	6.7	3.2	4.1	3.1	5.1
July	2.5	2.4	2.3	4.9	7.0	4.2	4.3	2.4	1.9	3.1
August	3.9	7.5	6.3	4.5	3.2	3.2	2.6	2.0	4.1	5.6
September	3.5	3.9	4.8	3.6	0.9	3.0	1.1	5.5	3.4	1.1

FIGURE 2. Summer (June-September) monthly precipitation amounts from 2010-2019. Data sourced from Weather Underground for the Fryeburg, ME weather station. July 2019 data added from Center Conway, NH weather station due to incomplete July 2019 Fryeburg data.

KEZAR LAKE

Trophic State Indicators

Water clarity, total phosphorus, and chlorophyll-a are trophic state indicators, or indicators of biological productivity in lake ecosystems. The combination of these parameters helps determine the extent and effect of eutrophication in lakes, such as Kezar Lake, and helps signal changes in lake water quality over time. Measuring water clarity is one of the most useful ways for determining if a lake is changing from year to year. Changes in water clarity may be due to a change in the amount and composition of algae communities or the amount of dissolved or particulate materials in a lake. Such changes are likely the result of human disturbance or other impacts to the lake's watershed. Water clarity varies widely in Maine lakes, ranging from 0.5 to 15.5 meters, with an average of 4.82 meters[1]. Generally, water clarity of 2 meters or less indicates a water quality problem and a higher potential for severe algae blooms. The Maine DEP classifies productive or eutrophic lakes as 4 meters or less, moderately productive or mesotrophic lakes as 4-7 meters, and unproductive or oligotrophic lakes as 7 meters or greater.

Since 1970, median annual water clarity in Kezar Lake – upper basin (01) has ranged from 6.1 to 10.4 meters, with a median of 7.7 meters; Kezar Lake – middle basin (02) has ranged from 4.6 to 9.2 meters, with a median of 7.2 meters; and Kezar Lake – lower basin (03) has ranged from 2.7 to 3.7 meters, with a median of 3.2 meters. Kezar Lake is generally clearer than the average water clarity of Maine lakes and has shown an improving trend in water clarity in all three basins over the sampling record (Figure 3). In 2019, median summer water clarity for the upper, middle, and lower basins of Kezar Lake were 9.44, 8.85, and 3.30 meters, respectively (Figure 3). The lower basin is very shallow (~3 meters deep); the Secchi disk is usually still visible on the lake bottom. Because of this, changes in water clarity in the lower basin reflects variable lake water level only.

Since 1977, median annual total phosphorus in Kezar Lake – upper basin (01) has ranged from 4.0 to 11.0 ppb, with an all data median of 5.0 ppb; Kezar Lake – middle basin (02) has ranged from 2.0 to 10.0 ppb, with an all data median of 4.5 ppb; and Kezar Lake – lower basin (03) has ranged from 6.0 to 13.5 ppb, with an all data median of 9.0 ppb. Kezar Lake has low phosphorus compared to average phosphorus levels in Maine Lakes (11.8 ppb[2]) and has shown a relatively stable trend in phosphorus over the sampling record (Figure 3). In 2019, median total phosphorus for the upper, middle, and lower basins of Kezar Lake were 5.0, 5.0, and 10.0 ppb, respectively (Figure 3).

Since 1977, median annual chlorophyll-a in Kezar Lake – upper basin (01) has ranged from 1.0 to 5.3 ppb, with an all data median of 2.1 ppb; Kezar Lake – middle basin (02) has ranged from 1.2 to 2.4 ppb, with an all data median of 2.0 ppb; and Kezar Lake – lower basin (03) has ranged from 1.4 to 3.1 ppb, with an all data median of 2.4 ppb. Kezar Lake has low chlorophyll-a compared to average chlorophyll-a levels in Maine Lakes (5.4 ppb[3]) and has shown a relatively stable trend in chlorophyll-a over the sampling record, though the upper basin is significantly improving (Figure 3). In 2019, median

[1]Data accessed from the Gulf of Maine Knowledge Base (n=1,449). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678
[2]Data accessed from the Gulf of Maine Knowledge Base (n=1,022). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678
[3]Data accessed from the Gulf of Maine Knowledge Base (n=1,066). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678

chlorophyll-a for the upper, middle, and lower basins of Kezar Lake were 2.0, 2.0, and 2.0 ppb, respectively (Figure 3). Because of its shallow nature, the lower basin is susceptible to algal blooms.

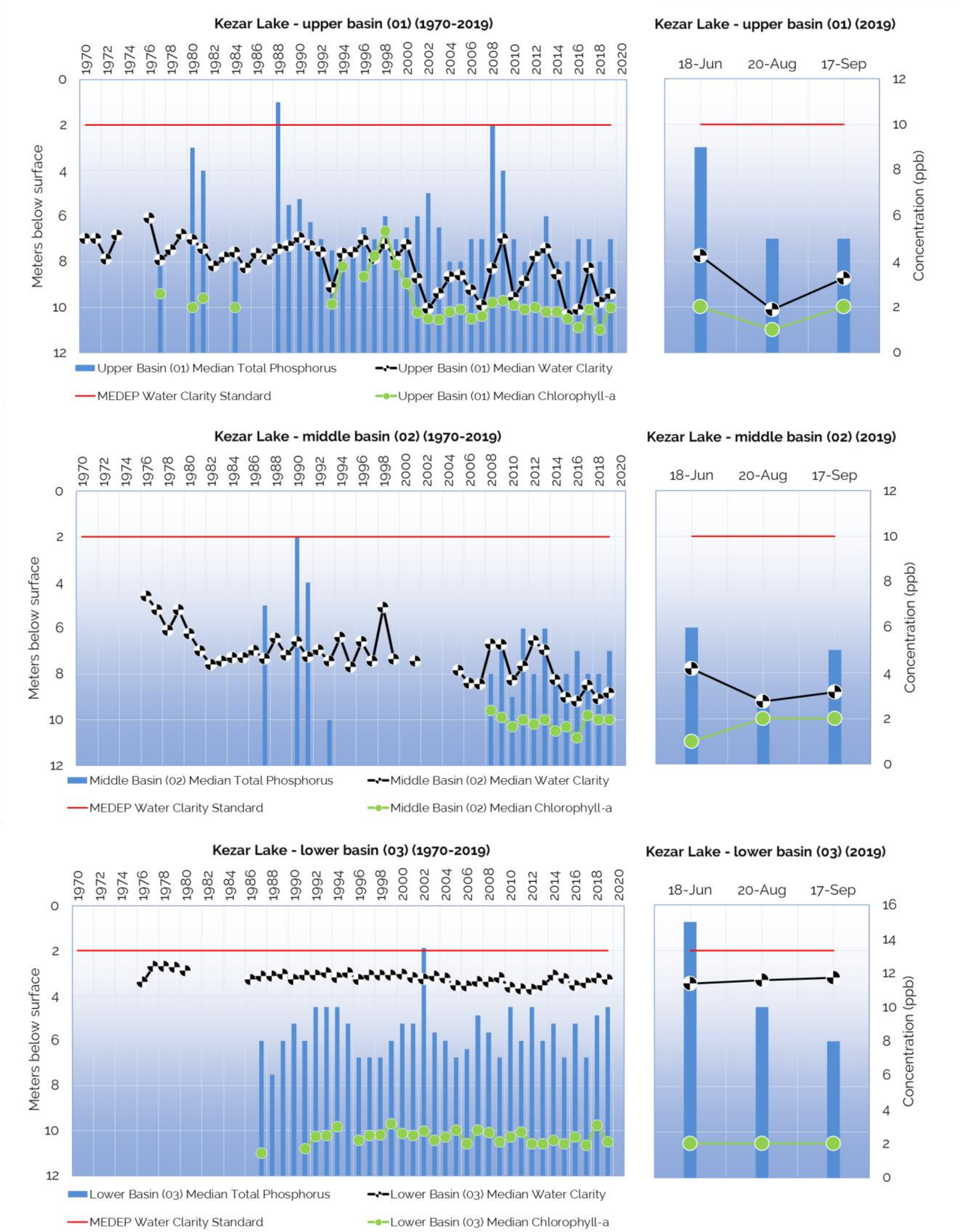


FIGURE 3. Kezar Lake water clarity, total phosphorus, and chlorophyll-a for the three basins for the entire historical record (left) and for 2019 (right). The lower basin (03) is limited by its shallow depth and the Secchi disk typically hits bottom.

Dissolved Oxygen & Temperature

Buoy deployed at the upper basin in 2019. Photo Credit: FBE

A common problem in Maine lakes is the depletion of dissolved oxygen (DO) in the deepest part of lakes throughout the summer months. This occurs when thermal stratification prevents warmer, oxygenated surface waters from mixing with cooler, oxygen-depleted (from chemical and biological processes) bottom waters in the lake. DO levels below 5 ppm (and water temperature above 24 °C) can stress and reduce habitat for coldwater fish and other sensitive aquatic organisms. In addition, anoxia (low DO) at lake bottom can result in the release of sediment-bound phosphorus (otherwise known as internal phosphorus loading), which becomes a readily available food source for algae. While thermal stratification and depletion of oxygen in bottom waters is a natural phenomenon, it is important to keep tracking these parameters to make sure the extent and duration of low oxygen does not change drastically because of human disturbance.

Historically, Kezar Lake has experienced some DO depletion in the upper and middle basins in summer. In 2019, DO depletion (<5 ppm) was not evident at the upper, middle, or lower basins (Figures 4-6). The entire water columns of the middle and lower basins were well oxygenated, never measuring below 6.4 ppm. Differences in depth to lake bottom at the upper basin were due to repositioning of the buoy at the deep spot (Figure 4). The buoy was pulled off track during high winds on the initial deployment attempt on 5/21/19 (Figure 4). The buoy was repositioned shortly thereafter to the DEP deep spot coordinates but was found to be too shallow (~44 meters) with the 45-meter-depth data logger resting on the bottom muck. The buoy was repositioned again on 7/30/19 further south of the DEP deep spot location and measured 48 meters deep. Although the 45-meter-depth data logger should have been well above the bottom, there was interference with the sensor that resulted in variable readings near zero that were not justified by field meter readings at the same depth. Thus, the 2019 data for the 45-meter-depth data logger were flagged as faulty and not shown in Figure 5.

In May (not captured) and November, the upper basin displayed relatively uniform oxygen profiles from the surface to the lake bottom (Figure 5). In June-August, a metalimnetic maximum (a ‘bump’ in oxygen) occurred at the thermocline (~6.0 meters) where non-motile, buoyant algae settled and were producing oxygen through photosynthesis (Figure 4). The pattern reversed in September with an oxygen depression at the thermocline (~ 6.0 meters), likely as a result of decomposition of dead algae. Dissolved oxygen at the middle and lower basins was relatively uniform throughout the vertical profile in all months (Figure 4). At all three basins, the upper two meters were regularly oxygenated by wind action. The upper basin had not yet experienced complete fall turnover when the loggers were removed on 11/4/19, as only the upper 12 meters had been mixed at that point (Figure 5).

Year-round temperature data at the upper basin showed that fall turnover occurred on 11/19/18, while the onset of stratification occurred shortly after spring turnover on 5/1/19 (data not shown). The water column in the upper 14 meters continued to stratify with warm surface waters reaching a maximum of 27.6°C at 2 meters depth on 7/30/19. Formation of the metalimnion (thermocline) began between 7 and 12 meters below the surface at the upper and middle basins (Figure 4). A thermocline cannot develop at the lower basin due to shallow water depth. Surface waters at the lower basin reached a maximum of 29.1°C on 7/21/19. Temperature and dissolved oxygen displayed an inverse relationship throughout the deployment (Figure 6; e.g., as temperature rose, oxygen declined). Warmer waters hold less oxygen and stimulate algae/plant growth, the organic material of which can be decomposed via oxygen consumption.

Conductivity can serve as a surrogate measure for the ionic materials (including nutrients) present in water. Conductivity spikes throughout the deployment period largely corresponded with rain events, likely due to transport of ion-rich water from the landscape to the lake (Figure 6). Spikes in conductivity not associated with rain events (unless very localized) may have been due to wind or wave action (from motorized boats) or from an algae bloom.

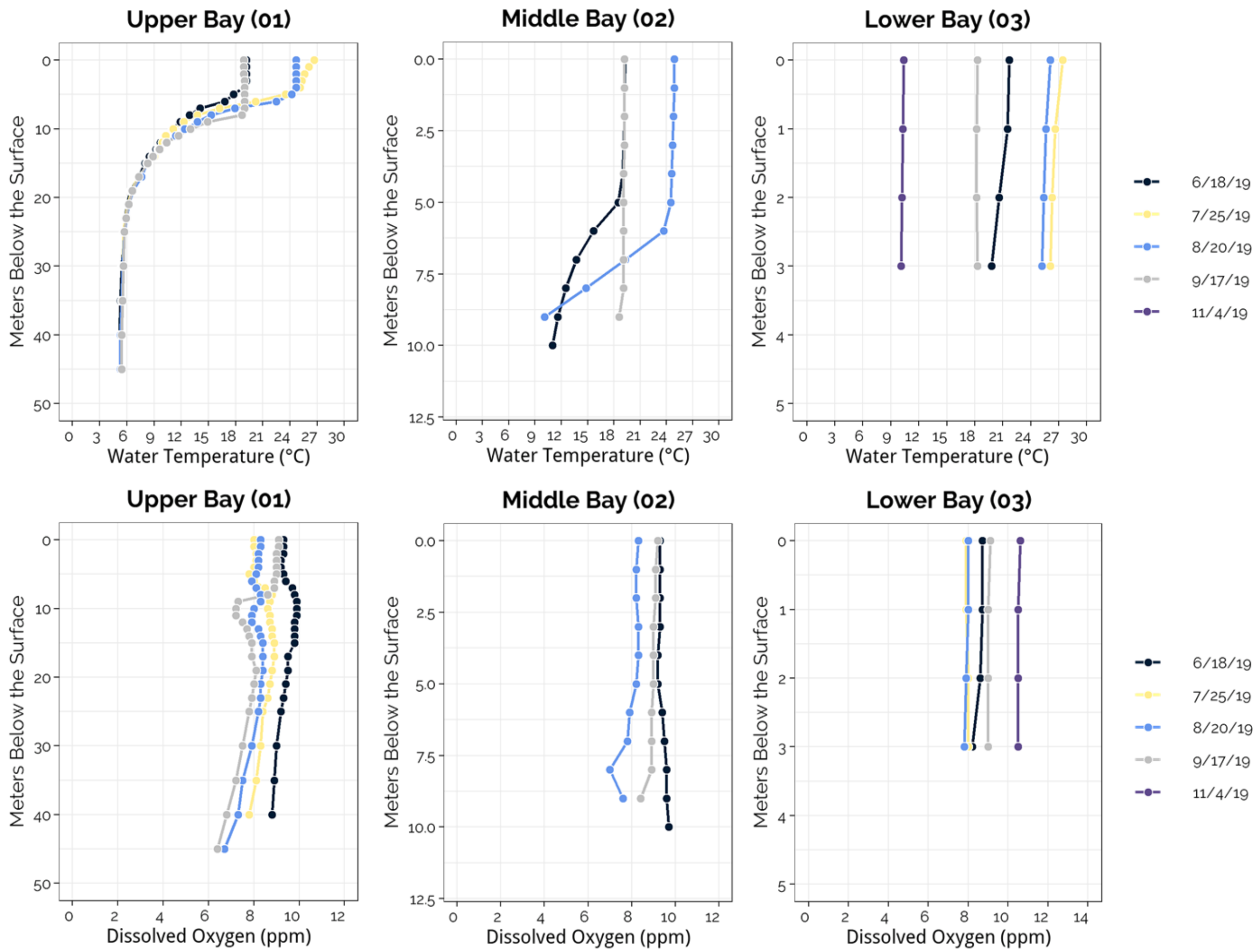


FIGURE 4. 2019 temperature (top panel) and dissolved oxygen (bottom panel) profiles for the upper, middle, and lower basins of Kezar Lake.

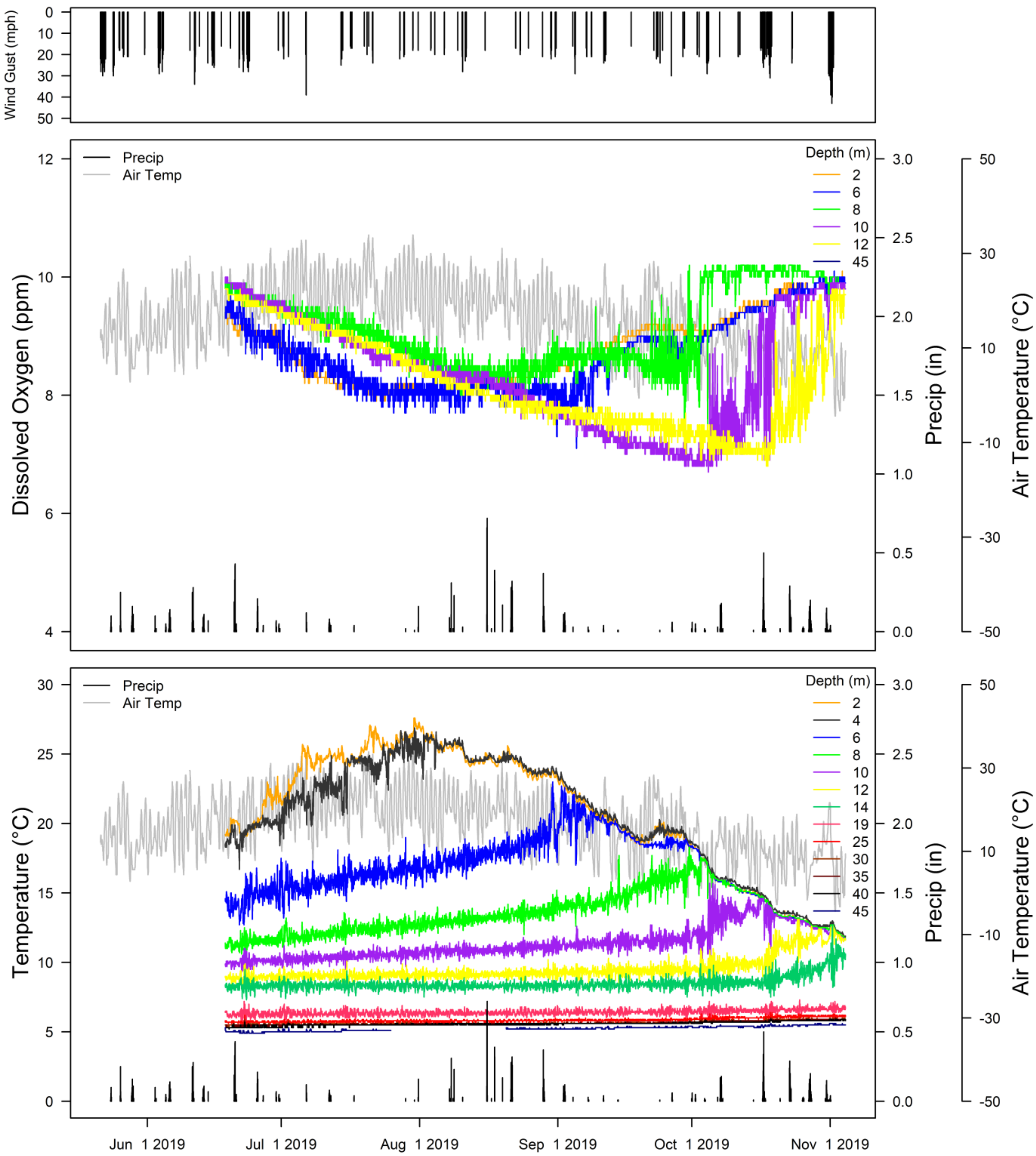


FIGURE 5. Hourly maximum wind gust (top) and dissolved oxygen (middle) and temperature (bottom) readings taken every 15 minutes during the summer at various depths at the deep spot of Kezar Lake's upper basin. Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI QCLCD Fryeburg Eastern Slopes Regional Airport (54772/IZG).

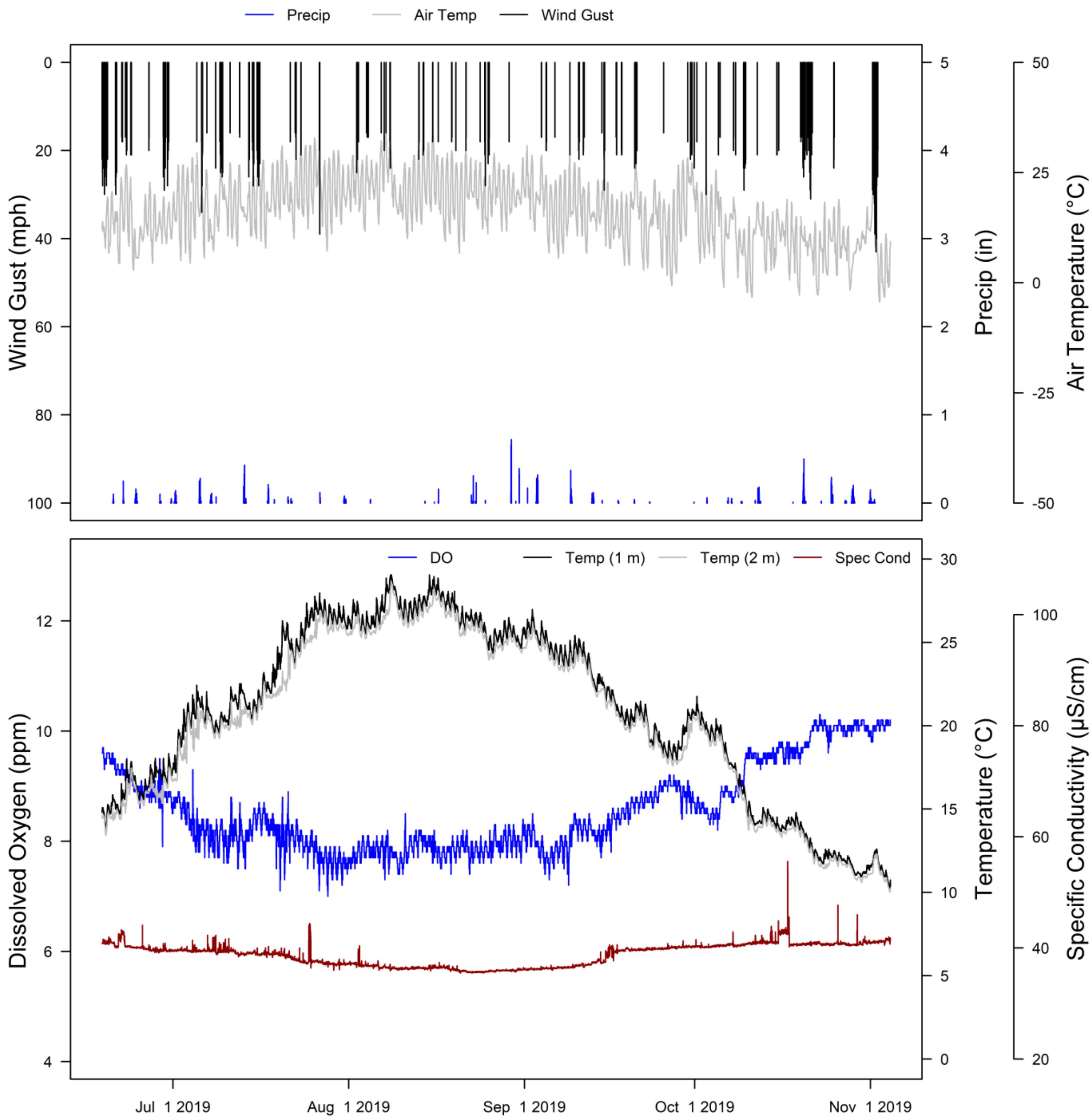


FIGURE 6. Hourly maximum wind gust, air temperature, and precipitation (top). Dissolved oxygen, temperature, and specific conductivity readings taken every 15 minutes during the summer at 2 meters depth (temperature also included 1-meter depth) at the deep spot of Kezar Lake's lower basin (bottom). Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI QCLCD Fryeburg Eastern Slopes Regional Airport (54772/IZG).

Chemical Parameters

Since 1980, median annual total alkalinity in Kezar Lake – upper basin (01) has ranged from 3.0 to 7.0 ppm, with an all data median of 4.0 ppm; Kezar Lake – middle basin (02) has ranged from 3.0 to 5.0 ppm, with an all data median of 4.0 ppm; and Kezar Lake – lower basin (03) has ranged from 2.7 to 6.0 ppm, with an all data median of 4.0 ppm. Kezar Lake has low alkalinity compared to average alkalinity levels in Maine Lakes (11.9 ppm[4]) and has shown a decreasing (worsening) trend in total alkalinity over the sampling record for the upper and lower basins. Since 2012 (including 2019), the upper and middle basins in Kezar Lake have had a median annual alkalinity of 4.0 ppm over the course of each sampling season, with a median annual alkalinity of 4.0 ppm at the lower basin in 2019 as well (Table 1). Kezar Lake has critically low alkalinity (or buffering capacity) because of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid. These low levels make Kezar Lake and its inhabiting aquatic organisms susceptible to both natural and anthropogenic changes in pH (acidity), particularly from acidic deposition in the form of rain or snow.

Since 1977, median annual pH in Kezar Lake – upper basin (01) has ranged from 6.0 to 7.0, with an all data median of 6.7; Kezar Lake – middle basin (02) has ranged from 6.1 to 7.0, with an all data median of 6.6; and Kezar Lake – lower basin (03) has ranged from 6.1 to 7.0, with an all data median of 6.7 (Table 1). Kezar Lake has slightly more acidic pH compared to average pH levels in Maine Lakes (6.8[5]) and has shown no trend in pH over the sampling record. In 2019, the upper, middle, and lower basins had an annual median pH of 6.9, 6.9, and 6.8, respectively. These pH values are on the lower end of the Maine DEP/USEPA recommended range of 6.5 to 8.0 to support freshwater species but are significantly improved from recent the degrading trends in pH from 2014-2017 and record lows in 2016 (Table 1).

Since 1980, median annual color in Kezar Lake – upper basin (01) has ranged from 5.0 to 20 PCU, with an all data median of 10.5 PCU; Kezar Lake – middle basin (02) has ranged from 8.0 to 16.0 PCU, with an all data median of 11.0 PCU; and Kezar Lake – lower basin (03) has ranged from 8.5 to 22.0 PCU, with an all data median of 13.0 PCU (Table 1). Kezar Lake is a non-colored waterbody (<25 PCU) compared to average color in Maine Lakes (22.2 PCU[6]) and has shown a relatively stable trend in color over the sampling record. In 2019, color at the upper, middle, and lower basins averaged 9.0, 10.0, and 12.0, respectively (Table 1). Historical data indicate that high color values are positively correlated to high precipitation years because of increased runoff (Figure 7). Precipitation in summer 2019 was moderate (15 inches from June to September), as were color values.

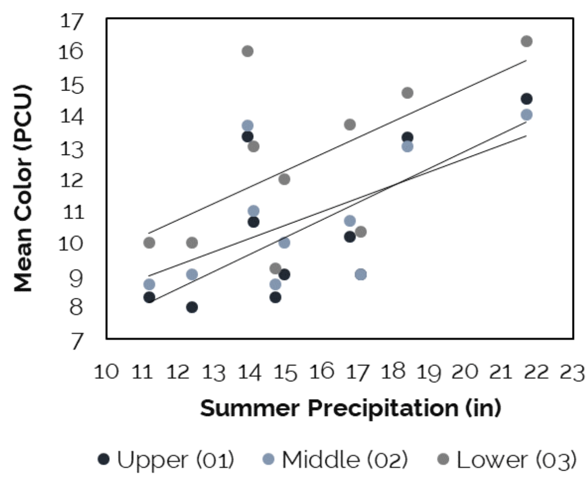


FIGURE 7. Higher summer precipitation washes off more material from the landscape to the lake and contributes to higher color values. Conversely, lower summer precipitation generally allows for better water clarity and reduced color.

PONDS

The following provides a summary of historical and current water quality of the six ponds in the Kezar Lake watershed. Refer to Table 2 and Figure 8. In 2019, phosphorus was significantly elevated in Bradley, Cushman, and Heald Ponds, but without a corresponding response increase in chlorophyll-a. Farrington Pond was found to have the highest median phosphorus and chlorophyll-a historically and had the highest median chlorophyll-a in 2019 and third highest median phosphorus in 2019 out of the six ponds. The shallow nature of Farrington Pond makes it more vulnerable to suspension of phosphorus-laden sediment because of heavy rainfall, windstorms, or watershed disturbances (e.g., shoreline development). Continuing with the recent rebounding trend from a short-term pH degradation lasting from 2014-2017, pH in all six ponds in 2019 was greater than the historic medians. Water clarity was significantly worse in Bradley and Horseshoe Ponds, and alkalinity in the ponds were generally the same in 2019 compared to historic medians. Five of the six ponds (excluding Trout) showed elevated color compared to historic values.

[4] Data accessed from the Gulf of Maine Knowledge Base (n=1,102). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678
[5] Data accessed from the Gulf of Maine Knowledge Base (n=1,105). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678
[6] Data accessed from the Gulf of Maine Knowledge Base (n=714). 2019 data not yet available. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678

TABLE 1. 2019 water quality monitoring results for the upper, middle, and lower basins of Kezar Lake.

Date	Station	Water Clarity (meters)	Total Phosphorus (ppb)	Chlorophyll-a (ppb)	Alkalinity (ppm)	pH	Color (PCU)
6/18/2019	Upper (01)	7.75	9.0	2.0	3.0	6.7	14.0
	Middle (02)	7.80	6.0	1.0	3.0	6.8	11.0
	Lower (03)	3.45	15.0	2.0	4.0	6.7	19.0
7/25/2019	Upper (01)	10.48					
	Lower (03)	3.30					
8/20/2019	Upper (01)	10.13	5.0	1.0	4.0	6.9	9.0
	Middle (02)	9.25	3.0	2.0	4.0	6.9	10.0
	Lower (03)	3.30	10.0	2.0	4.0	6.8	12.0
9/17/2019	Upper (01)	8.75	5.0	2.0	4.0	6.9	9.0
	Middle (02)	8.85	5.0	2.0	4.0	6.9	9.0
	Lower (03)	3.20	8.0	2.0	3.5	6.8	11.0
11/4/2019	Lower (03)	3.80					
2019 Median (Kezar Lake)	Upper (01)	9.44	5.0	2.0	4.0	6.9	9.0
	Middle (02)	8.85	5.0	2.0	4.0	6.9	10.0
	Lower (03)	3.30	10.0	2.0	4.0	6.8	12.0
Historical Median*	Upper (01)	7.65	5.0	2.1	4.0	6.7	10.5
	Middle (02)	7.23	4.5	2.0	4.0	6.6	11.0
	Lower (03)	3.20	9.0	2.4	4.0	6.7	13.0
Maine Lakes*	Mean	4.82	11.8	5.4	11.9	6.8	22.2

** From the Gulf of Maine Knowledge Base. Includes datapoints through 2018.* http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678

KLWA WQ Program Coordinator Heinrich Wurm helped to collect 2019 water quality samples. Photo credit: FBE.

Amanda Gavin of FBE collecting water quality samples in August 2019. Photo Credit: FBE

TABLE 2. Historical and recent (2019) medians for water quality parameters for six ponds of the Kezar Lake watershed.

Pond	Water Clarity (m)		Total Phosphorus (ppb)		Chlorophyll-a (ppb)		pH		Alkalinity (ppm)		Color (PCU)	
	Historical[b]	Recent 2019[c]	Historical[b]	Recent 2019[c]	Historical[b]	Recent 2019[c]	Historical[b]	Recent 2019[c]	Historical[b]	Recent 2019[c]	Historical[b]	Recent 2019[c]
Bradley	5.2	4.1	8.0	15.0	3.8	4.5	6.5	6.5	4.0	4.0	21.0	28.5
Cushman	5.5	6.3	7.0	10.5	2.3	1.5	6.7	6.8	5.0	4.5	11.0	11.5
Farrington*	4.4	4.4	13.0	11.5	5.8	5.0	6.7	6.7	4.0	4.0	16.0	21.0
Heald	4.7	4.7	10.0	16.5	4.0	3.0	6.7	6.8	5.0	5.5	23.0	28.0
Horseshoe	6.9	5.8	7.0	5.5	3.5	3.0	6.7	6.7	3.0	3.0	10.0	11.0
Trout	7.4	7.0	4.0	4.0	1.8	2.0	6.5	6.6	4.0	4.0	9.0	9.0
Maine Lakes[a]	4.8		11.8		5.4		6.8		11.9		22.2	

** Water clarity limited by lake depth - Secchi disk hits bottom*

[a] From the Gulf of Maine Knowledge Base. Includes datapoints through 2018. http://www.gulfofmaine.org/kb/2.0/record.html?recordid=9678

[b] Median historical values calculated by FBE from all raw data sent by the MEDEP; duplicate values/days were averaged; only epicore samples were used in the analyses; includes FBE-collected-only data for 2015-19

[c] Median values calculated by FBE from 2019 data

Red cells indicate median values from 2019 showing worse water quality compared to the historic median.

Dark blue cells indicate median values from 2019 showing better water quality when compared to the historic median.

Light blue cells indicate median values from 2019 showing no change from the historic median.

Annual variability in water quality is common for freshwater lakes, which is why collection of annual baseline data is important. This information will allow KLWA to assess long-term water quality trends in the Kezar Lake watershed.

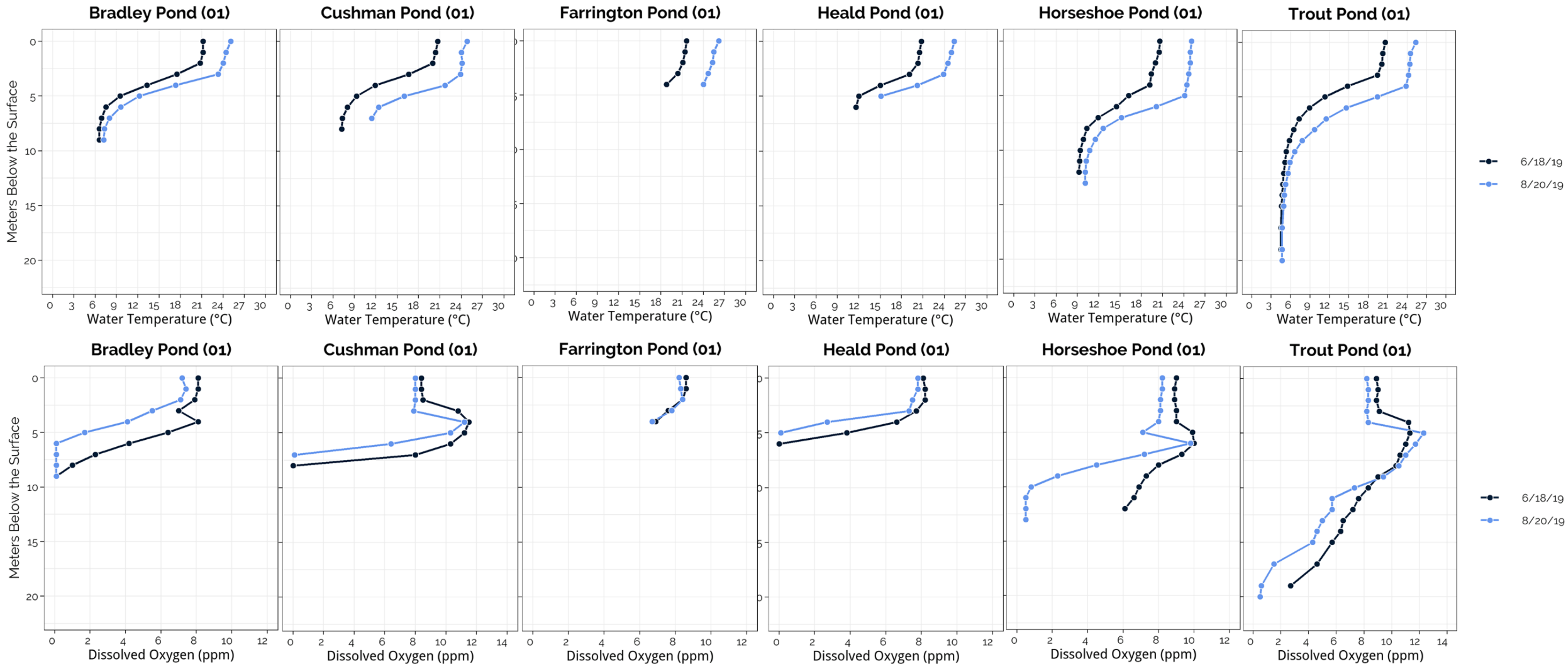


FIGURE 8. Temperature (top panel) and dissolved oxygen (bottom panel) profiles for six ponds of the Kezar Lake watershed. 6/18/19 = dark blue; 8/20/19 = light blue.

TRIBUTARIES

Grab Samples

Dissolved oxygen readings in both Great Brook and Boulder Brook for 2019 averaged above 7 ppm, which is the Maine DEP criterion for Class A streams and the minimum concentration required by sensitive aquatic species for survival and growth (Great Brook averaged 8.5 ppm and Boulder Brook averaged 7.4 ppm; Table 3). Water temperature was below 24°C, which is excellent for coldwater fish species. Note that dissolved oxygen is lowest before 8 am; mid-day sampling usually represents best-case conditions.

pH in Great Brook, Boulder Brook, and Beaver Brook ranged from 6.5 to 6.8, with an average of 6.5 for Great Brook, 6.5 for Boulder Brook, and 6.8 for Beaver Brook in 2019 (Table 3). Over the past few years, pH in the streams has exhibited a degrading trend; however, median annual pH for 2019 was greater (less acidic) than the record lows measured in 2015-16 in Great and Boulder Brooks.

E. coli were well below the Maine DEP instantaneous criterion of 236 col/100mL and the geometric mean of 64 col/100mL for Great and Boulder Brooks in 2019 (Table 3). In 2012, elevated *E. coli* measured at BB-3 (461 col/100mL) and BB-4 (548 col/100mL) prompted continued monitoring at Boulder Brook. Elevated *E. coli* under low flow conditions may indicate fecal contamination from groundwater sources (e.g., septic systems or wildlife). Further sampling and reconnaissance would be needed under wet weather conditions, as well as during peak summer months (July-August), to refine potential sources to Boulder Brook.

Total phosphorus ranged from 5.0 to 27.0 ppb, with an average of 5.8 ppb for Great Brook, 24.0 ppb for Boulder Brook, and 6.0 ppb for Beaver Brook in 2019 (Table 3). Total phosphorus in Great and Boulder Brooks has remained relatively stable, with greater variability observed in Boulder Brook.

TABLE 3. 2019 water quality monitoring results for Kezar Lake tributaries (Great Brook, Boulder Brook, and Beaver Brook). Results for GB-1 on 9/17/2019 was the average of two samples.

Date	Site Code	Temp (°C)	DO (ppm)	pH	E. coli (col/100mL)	TP (ppb)
Great Brook						
6/18/2019	GB-1	-	-	6.6	29	5.0
8/20/2019	GB-1	19.6	8.1	-	-	-
9/17/2019	GB-1	12.9	8.8	6.5	10	6.0
9/17/2019	GB-1	12.9	8.8	6.5	16	7.0
Duplicate Average	GB-1	12.9	8.8	6.5	13	6.5
2019 Average	**GB-1**	**16.3**	**8.5**	**6.5**	**19**	**5.8**
Boulder Brook						
8/20/2019	BB-3	22.9	6.8	6.5	32	27.0
9/17/2019	BB-3	14.8	8.1	6.6	5	21.0
2019 Average	**BB-3**	**18.9**	**7.4**	**6.5**	**13**	**24.0**
Beaver Brook						
6/18/2019	BV-L1	-	-	6.8	11	6.0

Note: Class A freshwater DEP criteria: 236 col/100mL for 10th percentile of 6+ samples; 64 col/100mL for geomean of 6+ samples
Duplicates were averaged before taking the total average
Blank data entries are data not collected in the field; Beaver Brook was sampled instead of Boulder Brook on 6/18/2019
Field meter readings were collected at Great Brook on 8/20/2019 because they were not collected on 6/18/2019

Continuous Loggers

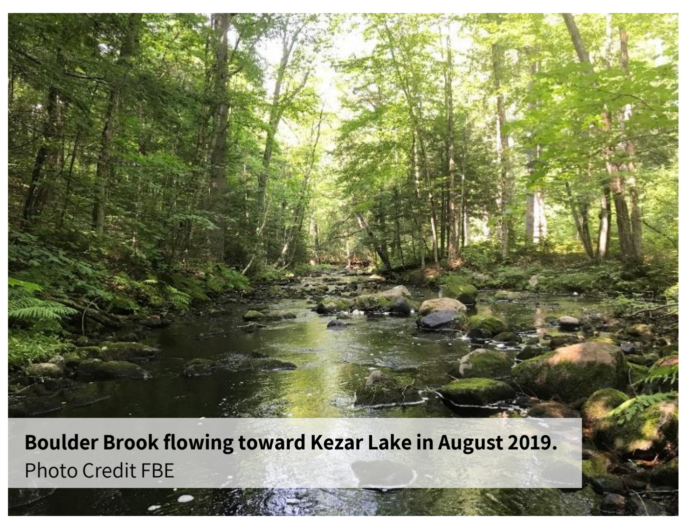
Funded by the Sally Mead Hands Foundation, the Climate Change Observatory (CCO) was established for the Kezar Lake watershed with the mission to evaluate potential impacts of climate change on watershed resources and identify actions to mitigate climate change in the watershed. As part of this mission, the CCO purchased and deployed five Onset HOBO® temperature loggers in Coffin, Boulder, Bradley, Sucker, and Long Meadow Brooks and two Onset HOBO® water level/temperature loggers in Beaver and Great Brooks in 2014. Two water level/temperature sites were added at the lower basin and outlet stream of Kezar Lake in 2015 (Figure 1). Loggers were deployed again at all nine sites in 2019. These data will serve as a baseline for future comparisons of water quality to assess long-term temperature and flow trends in the Kezar Lake watershed.

High flow conditions at Great Brook following a heavy rain in April 2019: Photo Credit FBE

The water temperature and/or water level loggers were deployed on 4/25/19 at Beaver Brook, Coffin Brook, Boulder Brook, Sucker Brook, Bradley Brook, and Long Meadow Brook. Water level loggers at Great Brook, the lower basin, and the outlet stream were not deployed on 4/25/19 because the PVC housing at Great Brook had broken (most likely due to debris floating down the river), and high flow conditions restricted access at the lower basin and the outlet stream. The water level loggers at these remaining three sites were deployed instead on 5/21/19. All loggers were retrieved on 11/4/19 for a total deployment period of 193 days. Maintenance at these sites occurred on 5/21/19, 7/25/19, 8/20/19, and 9/17/19. In most cases, loggers were submerged and in good condition. If a deeper spot was nearby, loggers were repositioned to ensure submergence. The logger at Coffin Brook was found out of water on 11/4/19.

Laura Diemer of FBE downloading data from Coffin Brook in August 2019. Photo Credit FBE

The stilling wells at Great Brook, Beaver Brook, and the outlet stream were in excellent condition in 2019 and lined up with land-based reference marks. The PVC protective housing at Great Brook was replaced on 5/21/19 when the logger was deployed. Due to a slight bend in the bottom of the pipe, the lower basin stilling well was pushed deeper in the lake bottom to ensure stability through the 2019 monitoring season. The staff gauge measured water level 0.78 ft lower in 2019 than in 2018. Previous deployment years at the lower basin will need to be adjusted for new staff gauge height.



Boulder Brook flowing toward Kezar Lake in August 2019. Photo Credit FBE

Water level data were corrected for atmospheric pressure, temperature, and reference field measurements using the Onset HOBO® Barometric Compensation Assistant. Measurement error (i.e., sensor drift) was accounted for by comparing the difference between the logger endpoint and the reference water level measurement at the time of collection; differences greater than or equal to 0.004 m were corrected for, assuming a constant rate of drift for the calibration period (Wagner et al., 2006). Any data flagged as suspect for being out of water or interfered with in some way as to not reflect true stream conditions were removed from the final record. Two stage-discharge measurements were collected at Beaver Brook, Great Brook, and the outlet stream: 5/21/19 in spring during high flows and 7/25/19 during baseflow conditions. A more robust stage-discharge relationship for each site will be needed to convert water level to flow.

The following presents the processed (QA/QC) data from 2019 logger monitoring in the Kezar Lake watershed. Until more data are collected over the next few years to begin to account for interannual variability, no major conclusions or analyses can be made on this limited dataset aside from general patterns.

Water level at the four stations gradually declined from April-October (due to evaporation and moderate precipitation in summer) until a series of October-early November storms increased lake and stream flows (Figure 9). Due to the larger volume of water flowing from the lake through the outlet stream, water level increased and decreased much slower in the lower basin and outlet stream compared to the smaller headwater streams, Great and Beaver Brooks. Water level in Great and Beaver Brooks responded quickly to precipitation.

Water temperature increased at all sites from April to August and then steadily declined until retrieval in November, which followed closely with observed air temperature (Figure 10). Water temperature at all sites began to converge by November. This likely represents leaf senescence in the fall after which all streams were exposed to similar light and air temperatures. Kezar outlet stream, the lower basin, Boulder Brook, Long Meadow Brook, and Sucker Brook experienced higher water temperatures than the other streams, likely due to having more open canopies.

Water level logger locations from left to right: Great Brook (before PVC pipe replacement), Great Brook (after PVC pipe replacement), Beaver Brook, lower basin, and Kezar outlet stream. Photo Credit: FBE.

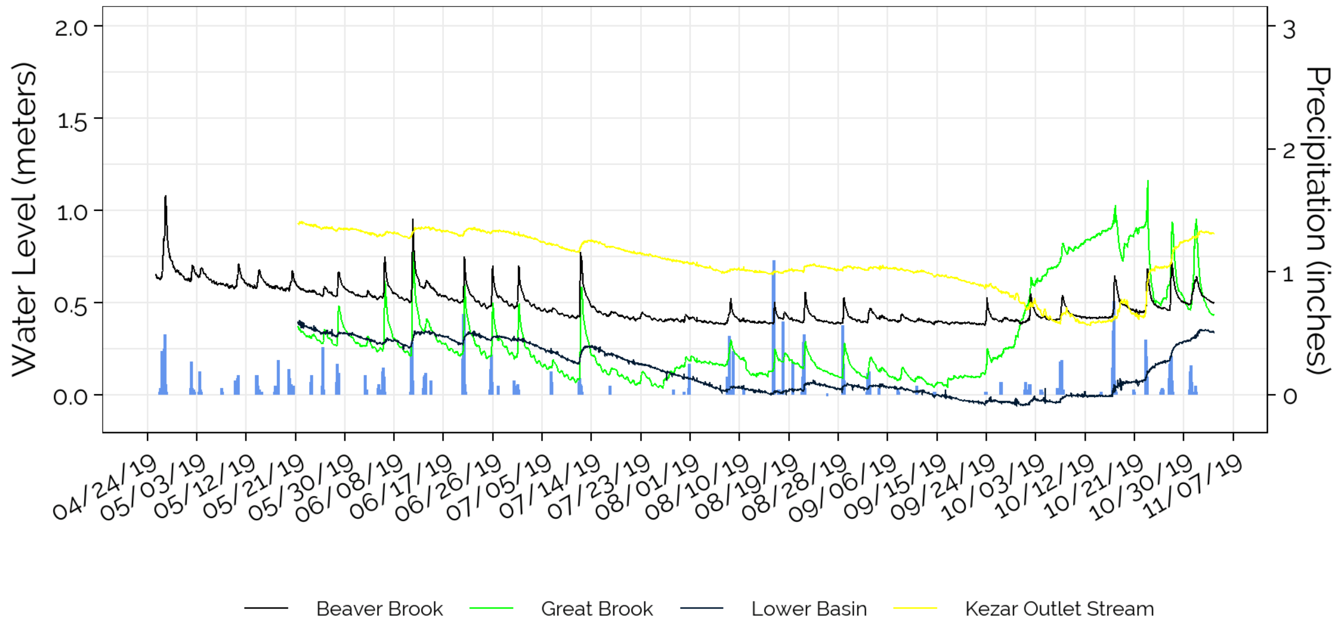


FIGURE 9. Water level data for Great Brook, Beaver Brook, the lower basin, and the Kezar outlet stream from 4/25/19 to 11/4/19. Daily precipitation data were obtained from NOAA NCEI QCLCD Fryeburg Eastern Slopes Regional Airport (54772/IZG).

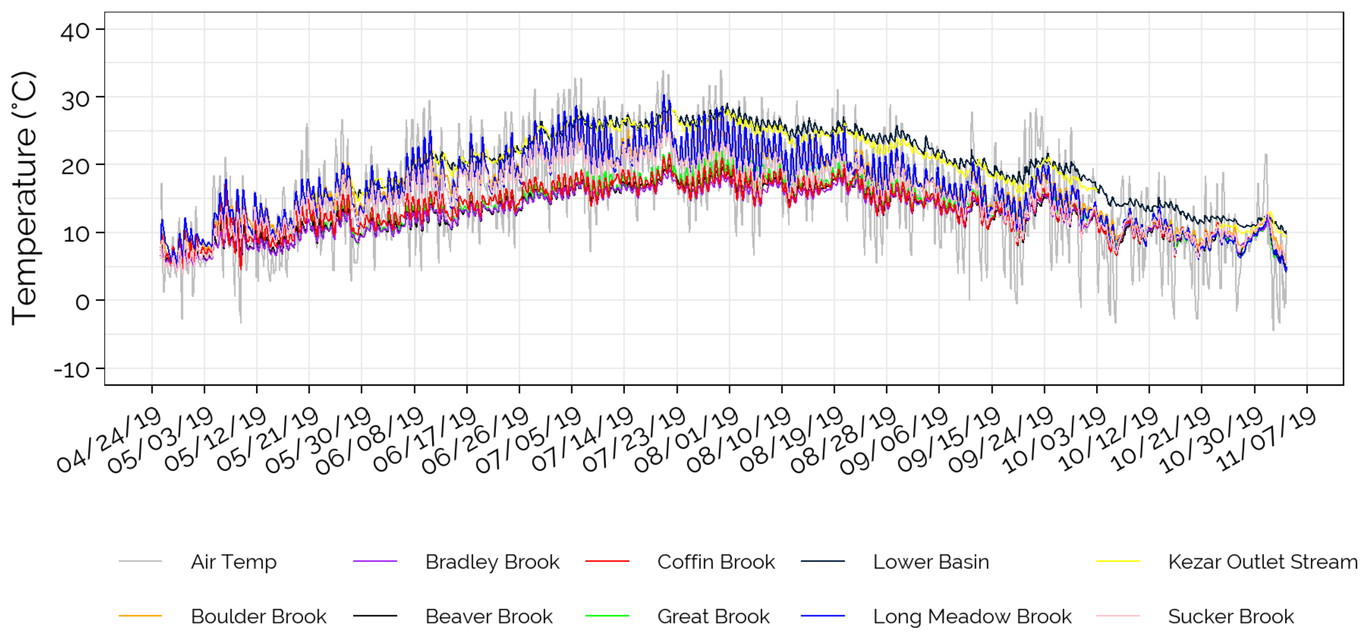
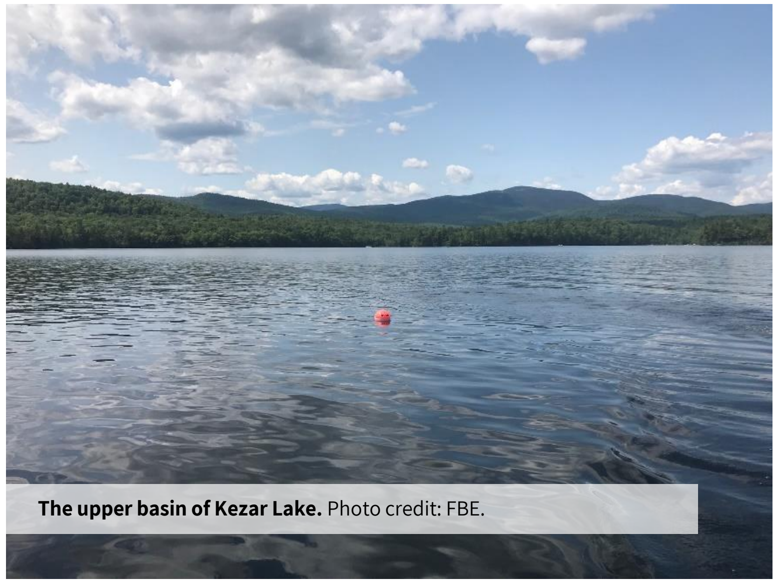


FIGURE 10. Water temperature data for all nine KLWA CCO sites from 4/25/19 to 11/4/19. Hourly air temperature data were obtained from NOAA NCEI QCLCD Fryeburg Eastern Slopes Regional Airport (54772/IZG).

SUMMARY



The upper basin of Kezar Lake. Photo credit: FBE.

Kezar Lake remains one of Maine's cleanest and clearest lakes, with above average water quality and clarity. Historically and in the current monitoring year, Kezar Lake's trophic state indicators (water clarity, total phosphorus, and chlorophyll-a) have been better than both statewide and most historic averages. Water clarity is statistically[7] significantly improving in all three basins and chlorophyll-a is statistically significantly improving in the upper basin. The water columns of all three basins of Kezar Lake were well-oxygenated, which helped coldwater fish species survive the warmest months of the year. pH in the lake in 2019 was higher than the historic mean at all three basins. The upper and lower basins are experiencing a statistically significant degradation in total alkalinity, which would otherwise help to buffer against dramatic changes in pH. Color in 2019 was below historic medians for all three basins despite the moderate rainfall from June-September.

Due to the moderate rainfall from June-September 2019, the ponds experienced increased color in all but Trout Pond, as well as reduced water clarity in Bradley and Horseshoe Ponds and increased phosphorus at Bradley, Cushman, and Heald Ponds. Fortunately, there was little response in chlorophyll-a in all six ponds above historic medians. Total alkalinity remained relatively unchanged in all six ponds, while pH increased slightly in most ponds compared to historic medians.

FUTURE MONITORING RECOMMENDATIONS

While the water quality of Kezar Lake and its tributaries and ponds is generally excellent, these waterbodies are sensitive to change. Continuing to monitor Kezar Lake, the nine streams, and six ponds will help KLWA better understand long and short-term trends in water quality and maintain the high quality of the water in the Kezar Lake watershed for future generations. The establishment of the Climate Change Observatory (CCO) can help guide future water quality monitoring efforts that support ongoing collection of long-term baseline data in the watershed.

The following provides additional recommendations for future monitoring of Kezar Lake, ponds, and streams that expand the baseline monitoring program:

- Continue regular annual lake, pond, and tributary sampling.
    a. Consider adding additional sample analyses to existing suite, including total organic carbon, dissolved organic carbon, total nitrogen, and specific conductivity profiles.
        i. Consider also adding total and dissolved aluminum and iron, ortho-phosphate, and cations/anions.
    b. Collect bottom grab samples of phosphorus in August and September to monitor and quantify the impact of internal phosphorus loading because of low oxygen conditions.
    c. Consider including spring and fall samples during turnover events when these systems are most vulnerable to external and internal material loading.
    d. Collect winter DO-temperature profiles and epicore sampling of key parameters in February (it has been shown that biological and chemical processes that occur over winter dictate the productivity of lakes in summer).
- Establish a volunteer-driven cyanobacteria baseline monitoring program for Kezar Lake and ponds using kits from cyanos.org for speciation and enumeration.

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[7] Based on Mann-Kendall trend test in R statistical programming (*rkt* package).

- Collect sediment samples for analysis of aluminum, iron, and phosphorus in all ponds and the lower bay.
- Investigate Boulder Brook for possible human-sourced pollution to the stream.
- Continue to deploy and maintain a string of continuous dissolved oxygen and temperature loggers on a buoy line at the upper and lower basins of Kezar Lake (seek funding for 2021 and beyond).
- Continue to deploy and maintain water level and temperature loggers in the lower basin, the Kezar outlet stream, and the seven tributaries.
    a. Consider upgrading all existing stream sites to water level and temperature monitoring (pending a sustainable funding source).
    b. Consider deploying other continuous loggers (e.g., specific conductivity, turbidity, pH, etc.) at existing stream sites (pending a sustainable funding source), most especially Beaver and Great Brooks to monitor for potential changes in water quality during and after any timber harvests in the White Mountain National Forest.
    c. Ensure a sustainable funding program is in place to continue water level and temperature monitoring at existing stream sites.
- Continue the pH-alkalinity tributary study that includes samples for aluminum and calcium and determine the potential impact of these parameters on aquatic organisms.
- Conduct stream macroinvertebrate analysis to determine macroinvertebrate richness and abundance during stream baseflow periods (late August - late September). This monitoring will provide baseline data for these streams and can be replicated on a five-year (or more) cycle.
- Develop a watershed management plan for the lake that summarizes water quality conditions, sets a water quality goal, and details next steps for improvements.

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