KEZAR LAKE

2017 WATER QUALITY REPORT

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

PREPARED BY:
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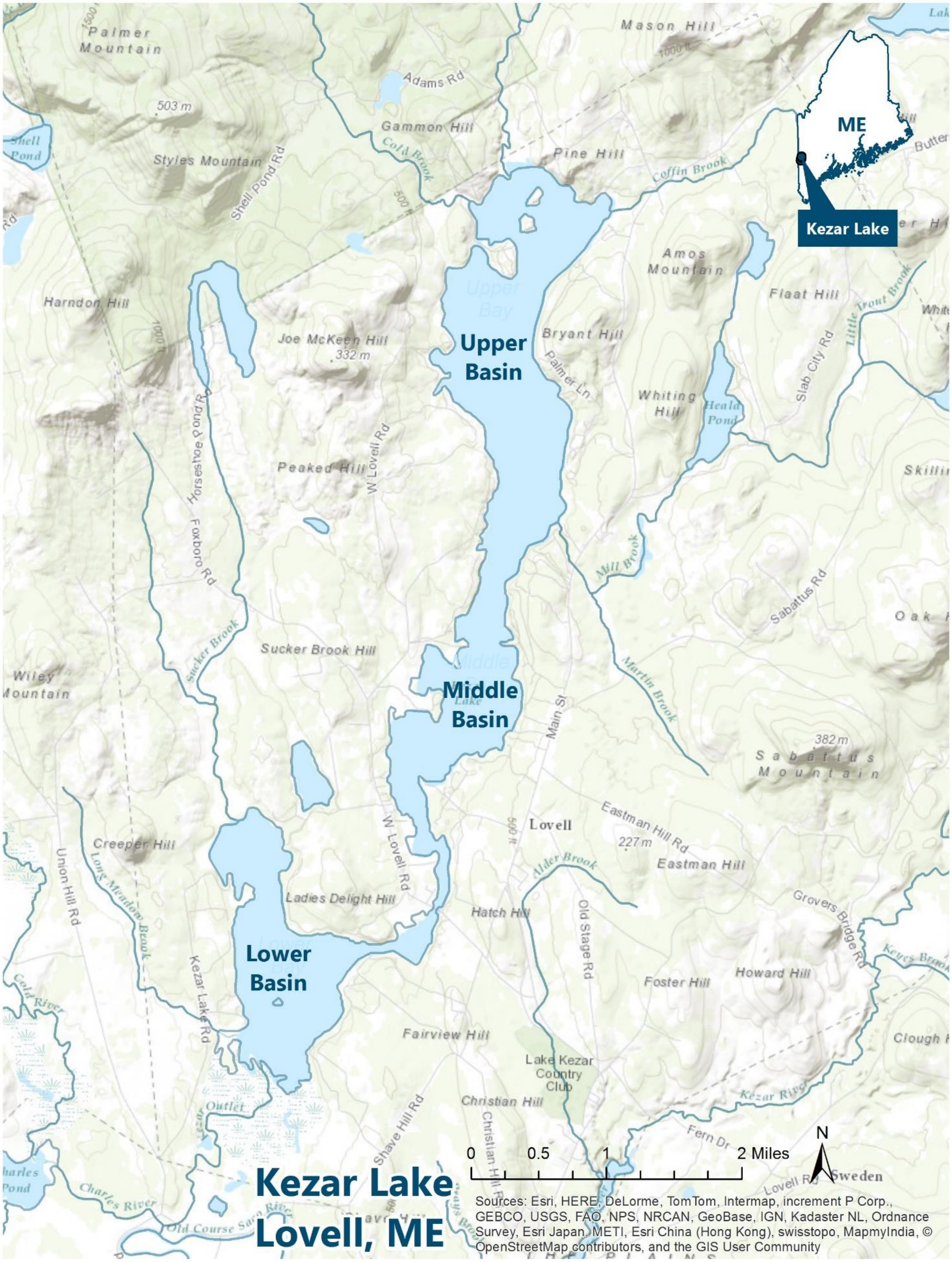
Kezar Lake
Lovell, ME
Upper Basin
Middle Basin
Lower Basin
ME
Kezar Lake
Palmer Mountain
Mason Hill
Adams Rd
Gammon Hill
Styles Mountain
Shell Pond Rd
Pine Hill
Coffin Brook
Cold Brook
Harndon Hill
Joe McKeen Hill
332 m
503 m
Bryant Hill
Palmer Ln
Amos Mountain
Flaat Hill
Little Trout Brook
Slab City Rd
Whiting Hill
Heald Pond
Horseshoe Pond Rd
Peaked Hill
W Lovell Rd
Foxboro Rd
Mill Brook
Sabattus Rd
Sucker Brook Hill
Sucker Brook
Wiley Mountain
Martin Brook
Main St
382 m
Sabattus Mountain
Lovell
Eastman Hill Rd
227 m
Eastman Hill
Creeper Hill
Union Hill Rd
Long Meadow Brook
Ladies Delight Hill
Hatch Hill
Alder Brook
Old Stage Rd
Grovers Bridge Rd
Kezar Lake Rd
Foster Hill
Howard Hill
Cold River
Fairview Hill
Lake Kezar Country Club
Clough Hill
Kezar River
Kezar Outlet
Christian Hill
Christian Hill Rd
Shave Hill Rd
Fern Dr
Lovell Rd
Sweden
Charles River
Old Course Saco River
0 0.5 1 2 Miles
N
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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February 2018

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Special thanks to Jim Stone (KLWA President), Heinrich Wurm and Eric Ernst (KLWA Water Quality Committee), Don Griggs (KLWA CCO Chair), Terri Mulks (Camp Susan Curtis - Trout Pond), David Littell (Farrington Pond), Mrs. Sundstrom (Heald Pond), and the Emond Family (Horseshoe Pond) for providing access, time, and/or equipment for the 2017 water quality monitoring season.

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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 in the lake.

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 and increased phosphorus concentrations.

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 can derive from a number of 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 algal 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 lighter, 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 stratification and is devoid of sunlight for photosynthesis.

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.

GLOSSARY OF KEY TERMS (CONTINUED)

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.

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: Are 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

KLWA Water Quality Program Coordinator Heinrich Wurm worked with FBE to collect 2017 water quality samples. Photo credit: FBE.

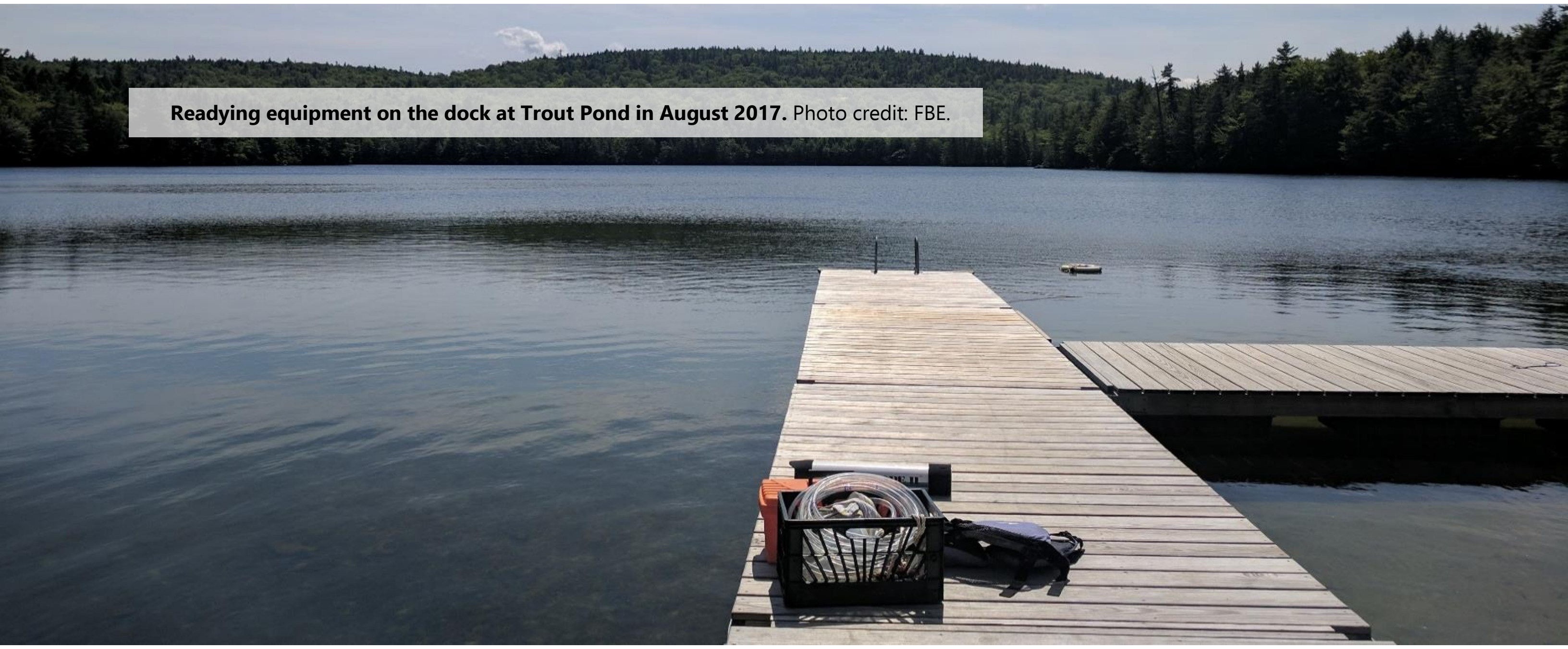
This report documents the results of water quality monitoring conducted by FB Environmental Associates (FBE) for the Kezar Lake Watershed Association (KLWA) in 2017. Deep spot sample stations at the three basins of Kezar Lake were sampled on June 8, August 16, and September 12, 2017; deep spot sample stations at six ponds (Bradley, Cushman, Farrington, Heald, Horseshoe, and Trout Ponds) were sampled on June 8 and August 16, 2017; tributary sample stations along Great Brook (GB-1) and Boulder Brook (BB-3) were sampled on June 8 and September 12, 2017; and a tributary sample station along Cold Brook (CB-1B) and two public beaches (PPB-1 and LTB-1) were sampled on August 16 and September 12, 2017 (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 and 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 Onset HOBO® continuous logging devices for temperature and dissolved oxygen at the upper and lower basins. The lower basin included a conductivity sensor. These buoy-logger systems were deployed from May to November and left intact with logging temperature sensors over winter.
- For **beach monitoring**, FBE, at the request of KLWA, sampled two public beaches twice for *Escherichia coli (E. coli)*. *E.coli* is an indicator of harmful pathogens found in fecal waste.
- For **tributary monitoring**, three sites at three tributaries (Great, Boulder, and Cold Brooks) were sampled for dissolved oxygen, temperature, total phosphorus, pH, and/or *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 of Kezar Lake: Great, Beaver, Coffin, Boulder, Sucker, Bradley, and Long Meadow 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 the Maine Volunteer Lake Monitoring Program (VLMP). All lab samples were analyzed at the Health and Environmental Testing Lab (HETL) in Augusta. Background and historical information on these waterbodies can be found in previous reports (FBE, 2016; FBE, KLWA, & PSU, 2015; FBE, 2013a, 2013b).

For the upper basin, six Onset HOBO® U-26 Dissolved Oxygen loggers were deployed at 2, 6, 8, 10, 12, and 45 meters below the surface at the deep spot, recording dissolved oxygen and temperature at 15-minute intervals continuously from 5/18/2017 to 11/9/2017. These depths equate to critical layers in the water column, which becomes thermally-stratified in summer. Onset HOBO® temperature pendants were also deployed at 4, 14, 19, 25, 30, 35, and 40 meters at the deep spot, recording temperature at 15-minute intervals continuously from 5/18/2017 onward (pendants were left over winter). For the lower basin, a Onset HOBO® U-26 Dissolved Oxygen logger and Onset HOBO® U-24 Conductivity logger were deployed at 2 meters below the surface at the deep spot, recording at 15-minute intervals continuously from 5/18/2017 to 11/9/2017. An Onset HOBO® temperature pendant was also deployed at 1 meter at the deep spot, recording temperature at 15-minute intervals continuously from 5/18/2017 onward (pendant was left over winter). The loggers were cleaned and downloaded during each sampling event. Logger data presented in the report shows interpolated data for the entire water column using R statistical program. 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.



Readying equipment on the dock at Trout Pond in August 2017. Photo credit: FBE.

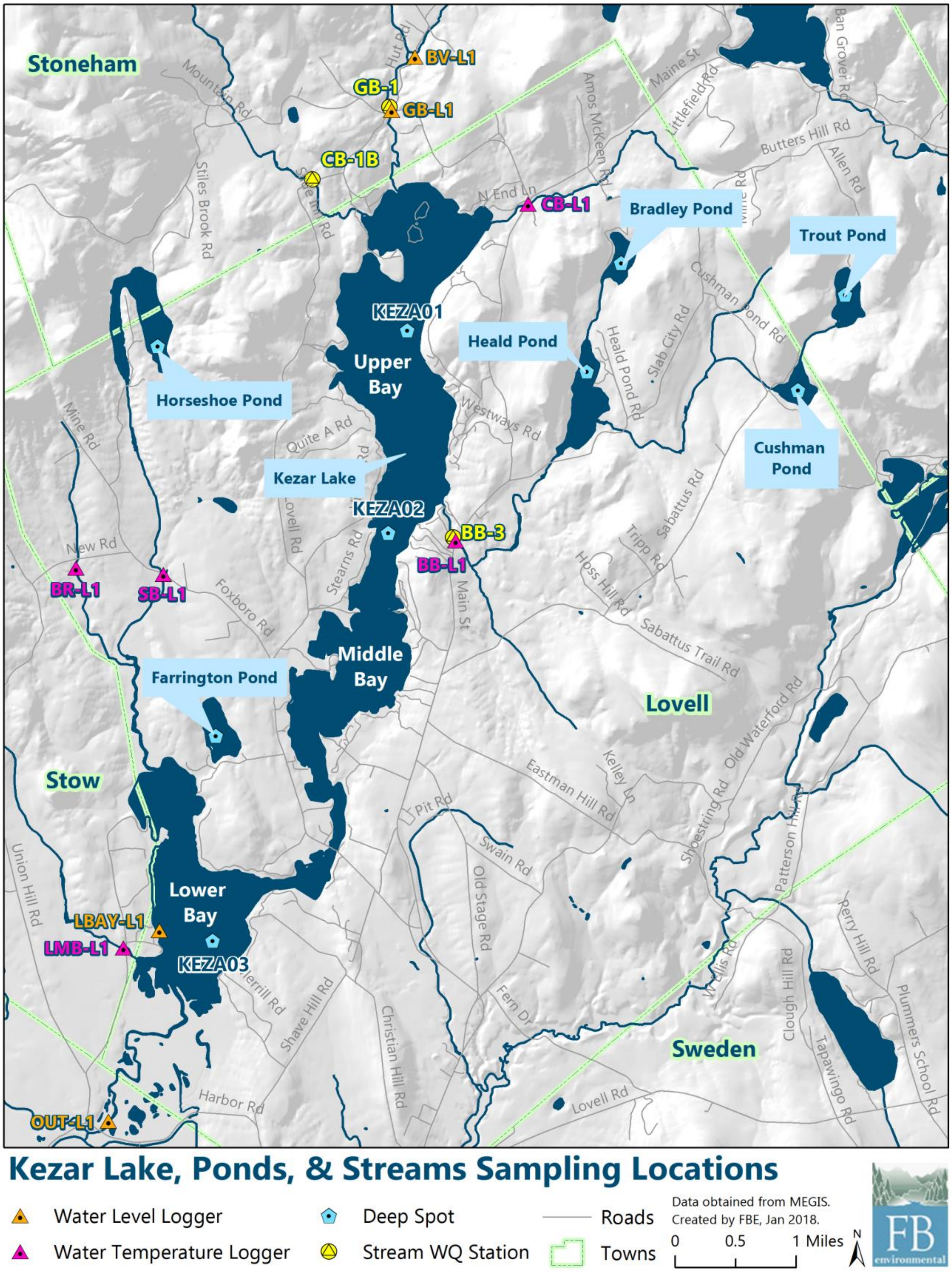
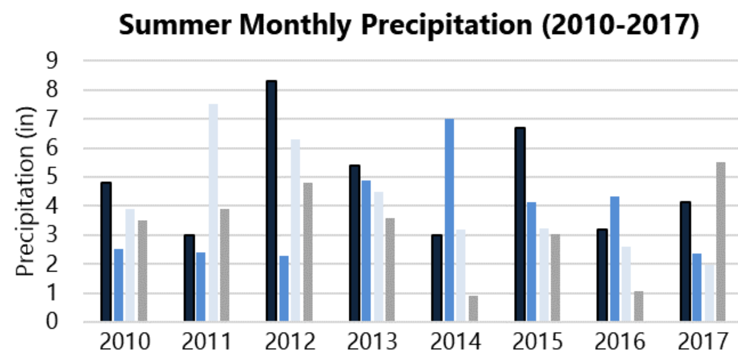


FIGURE 1. Map of lake, pond, and stream sampling locations.

WATER QUALITY MONITORING RESULTS

WEATHER

Weather is one of the major factors influencing inter-annual 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. Summer 2017 experienced relatively low amounts of precipitation, similar to 2014 and 2010, though not as low as summer 2016 (Figure 2).



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

FIGURE 2. Summer (June-September) monthly precipitation amounts from 2010-2017. Data sourced from Weather Underground for the Fryeburg, ME weather station.

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 4.8 meters (VLMP, 2013). 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 7.6 meters; Kezar Lake – middle basin (02) has ranged from 4.6 to 9.2 meters, with a median of 7.1 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 2017, median summer water clarity for the upper, middle, and lower basins of Kezar Lake were 8.5, 8.5, and 3.5 meters, respectively (Figure 3). The lower basin is very shallow (~3 meters deep); the Secchi disk is usually still visible on 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 5.0 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 (12.0 ppb) and has shown a relatively stable trend in phosphorus over the sampling record (Figure 3; VLMP, 2013). In 2017, median total phosphorus for the upper, middle, and lower basins of Kezar Lake were 5.0, 4.0, and 7.0 ppb, respectively (Figure 3).

Since 1977, median annual chlorophyll-a in Kezar Lake – upper basin (01) has ranged from 1.1 to 5.3 ppb, with an all data median of 2.2 ppb; Kezar Lake – middle basin (02) has ranged from 1.2 to 2.4 ppb, with an all data median of 1.8 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) and has shown a relatively stable trend in chlorophyll-a over the sampling record, though the upper basin is significantly improving (Figure 3; VLMP, 2013). In 2017, median chlorophyll-a for the upper, middle, and lower basins of Kezar Lake were 1.9, 2.2, and 1.8 ppb, respectively (Figure 3). Because of its shallow nature, the lower basin is susceptible to algae growth due to elevated nutrients in runoff or from bottom sediments.

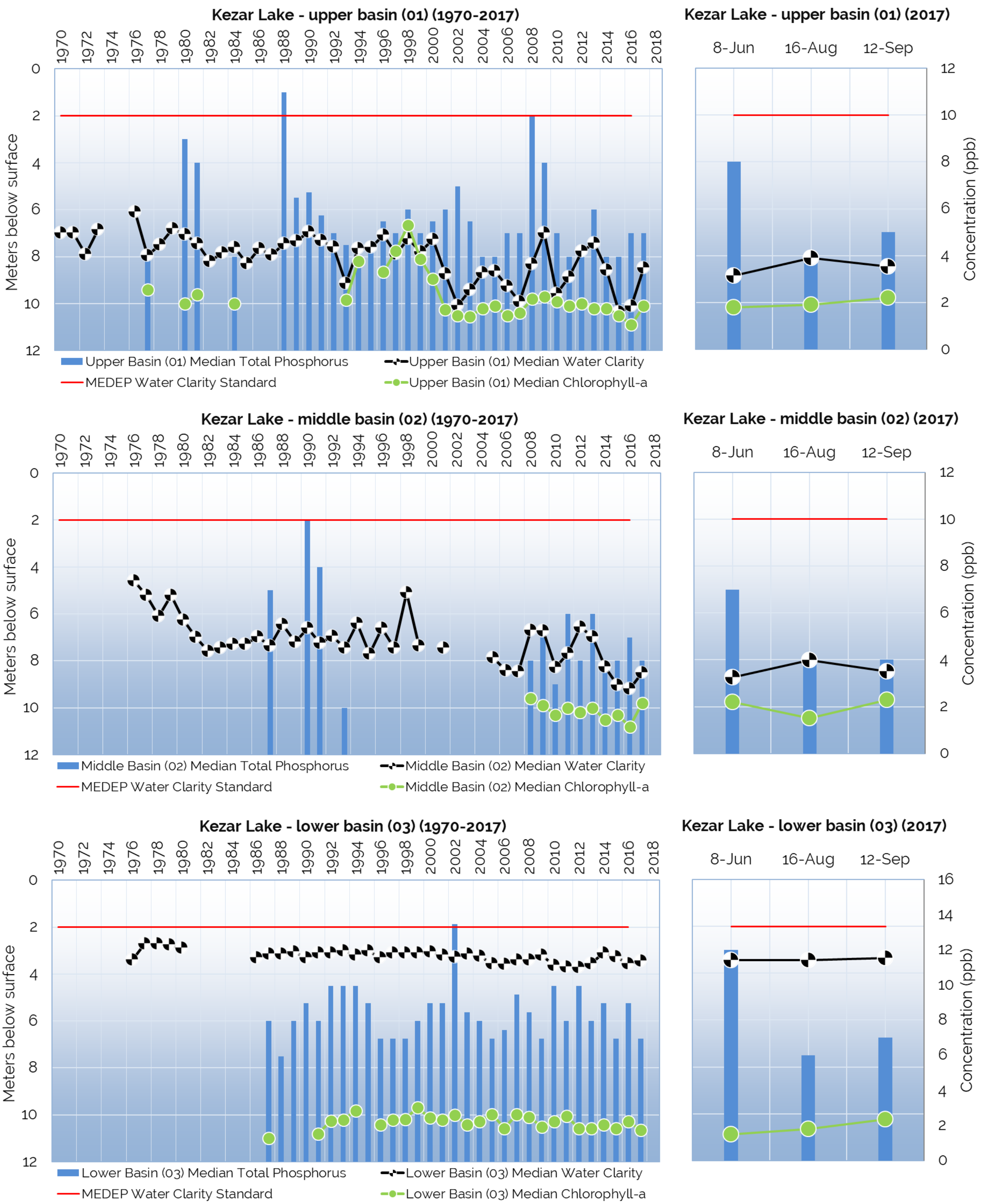


FIGURE 3. Kezar Lake water clarity, total phosphorus, and chlorophyll-a for the three basins for the entire historical record (left) and for 2017 (right). The lower basin (03) is limited by its shallow depth and the Secchi disk typically hits bottom during readings.

Dissolved Oxygen & Temperature


Buoy deployed at the lower basin in 2017. 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 cold-water 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.

In 2017, DO and temperature profiles were taken at the deep spot of the three basins monthly by FBE (Figure 4). DO and temperature were also collected continuously from May-November using Onset HOBO® loggers (Figures 5-7).

Historically, Kezar Lake has experienced some DO depletion in the upper and middle basins in summer. In 2017, no DO depletion was evident at any of the three basins (Figures 4-7). The entire water columns of the upper, middle, and lower basins were well oxygenated, never measuring below 5.7 ppm. Differences in profile depths at the middle basin was due to gusty weather conditions and/or difficulty in pinpointing the deep spot (Figure 4). DO gradually declined at all depths from supersaturation in early May to 6-9 ppm in mid- to late-August when the upper layers from the surface down to 6 meters increased in oxygen. The upper 2 meters were regularly oxygenated by wind action. The increase in oxygen at 6 meters depth may correspond to wind action from several small storm events in late August to early September and/or biological processes as algae growth peaked in the water column. As air temperatures declined into the fall and large storm events (wind and rain) occurred, subsequently deeper layers began to mix with upper layers until dissolved oxygen readings converged. The 45-meter-depth logger was still gradually declining in oxygen as the lake had not yet experienced complete fall turnover by 11/9/2017.

Temperature data at the upper basin showed that the onset of stratification occurred around the day of deployment in May (Figure 6). The water column in the upper 14 meters continued to stratify with warm surface waters reaching a maximum of 27.1°C at 2 meters depth on 7/21/2017. Formation of the metalimnion (thermocline) began between 5 and 9 meters below the surface at the upper and middle basins (Figure 4). Following a large storm event in early September that forced upper lake mixing, temperature of depths down to 6 meters converged. Loggers were retrieved prior to complete fall turnover. Only the upper 10 meters had completely mixed (Figure 5). Temperature pendants remained in place on a winter buoy configuration. Retrieval in the spring will show the date of fall turnover.

A thermocline cannot develop at the lower basin due to shallow water depth. Surface waters at the lower basin reached a maximum of 28.7°C at 1-meter depth on 7/21/2017. Temperature and dissolved oxygen displayed an inverse relationship throughout the deployment (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.

An Onset HOBO® conductivity logger was also deployed at the lower basin. Conductivity can serve as a surrogate measure for the ionic materials (including nutrients) present in water. This logger was deployed 2 meters below the surface (about 1 meter from the bottom). Conductivity was highly erratic in June, suggesting that ions in soil were easily activated during rain events and following the spring snowmelt period. An apparent delay in conductivity response in the lower basin following large rain events suggests that the spikes in conductivity are likely sourced from the upper basin (and the headwaters of the watershed). A large 2.8" storm in late June pushed a large slug of ion-rich water from the landscape to the lake. This storm may have depleted soil ion stock since subsequent storm events did not produce as high of a response in conductivity. The cause of the prolonged spike in conductivity in late September is unknown and unassociated with a storm (unless very localized). The Kezar Outlet Stream did back up into Kezar Lake in the fall, depositing a large plume of sediment. It may also be due to wind or wave action (from motorized boats). It also corresponded with a peak in temperature and reduction in dissolved oxygen; thus, an algae bloom may have been captured in the conductivity readings during that time.

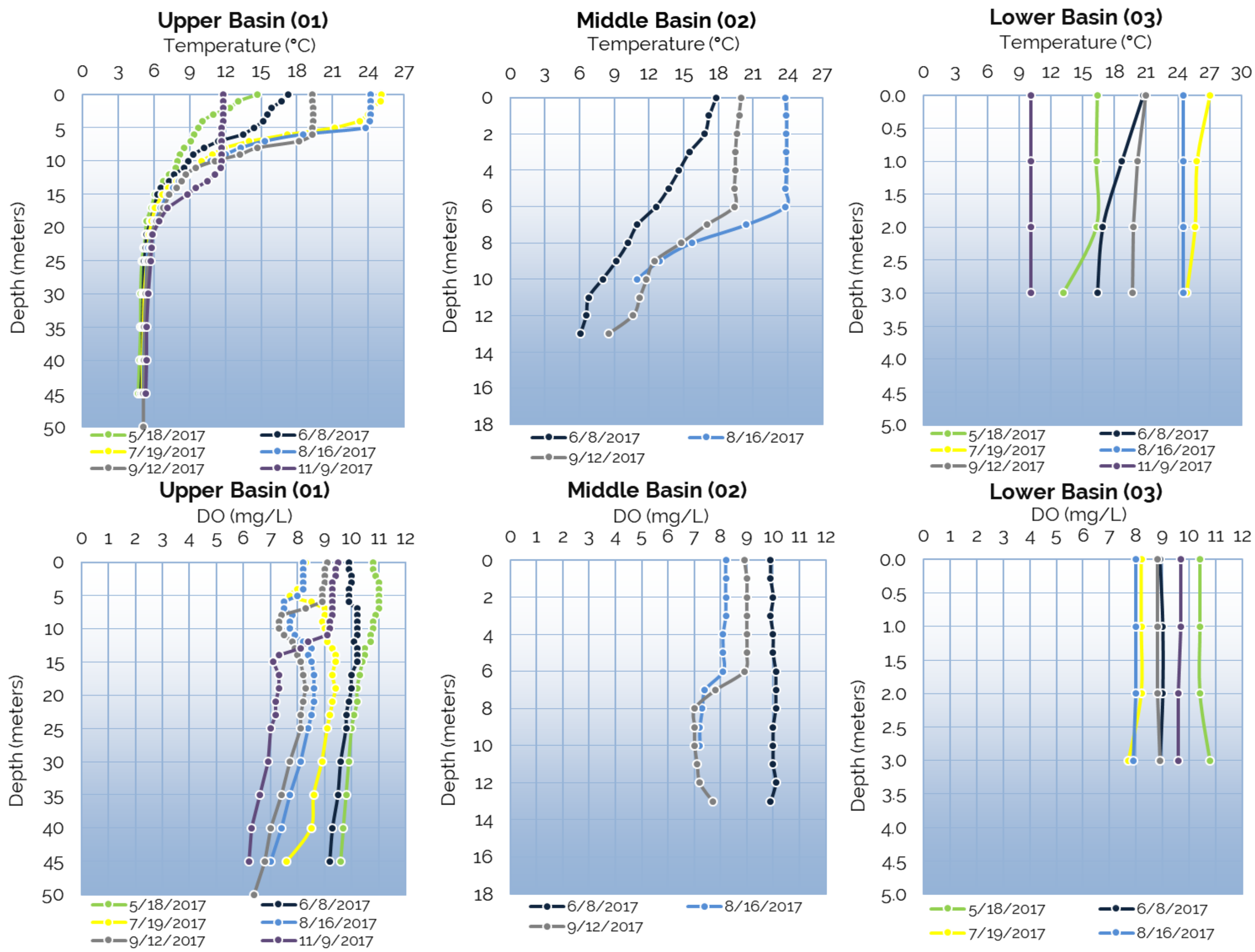


FIGURE 4. 2017 temperature (top panel) and dissolved oxygen (bottom panel) profiles for the upper, middle, and lower basins of Kezar Lake. mg/L= parts per million (ppm).

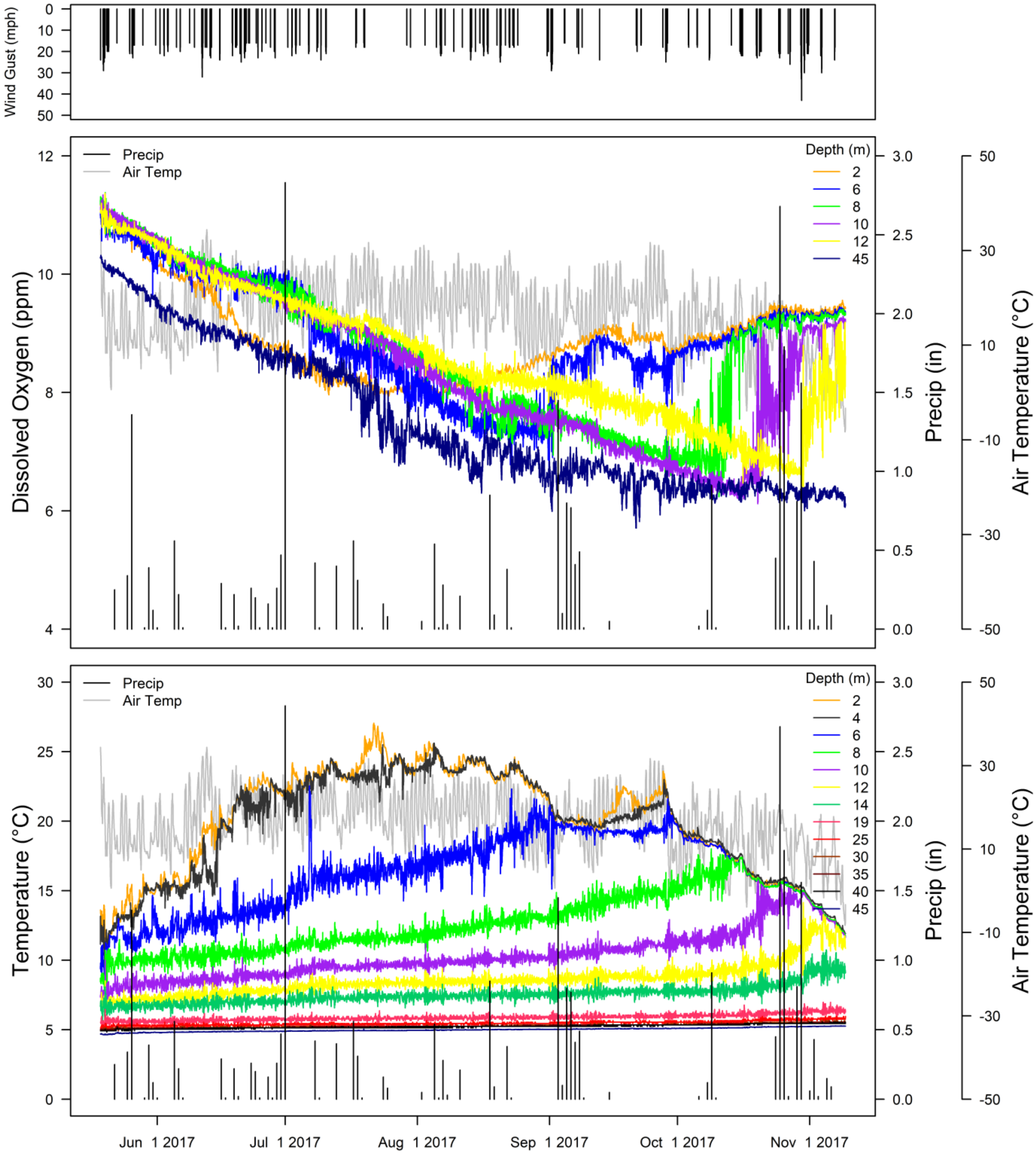


FIGURE 5. Hourly maximum wind gust (top), and dissolved oxygen (middle) and temperature (bottom) readings taken every 15 minutes during the summer at various depths at the deep spot of Kezar Lake's upper basin. Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI station at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

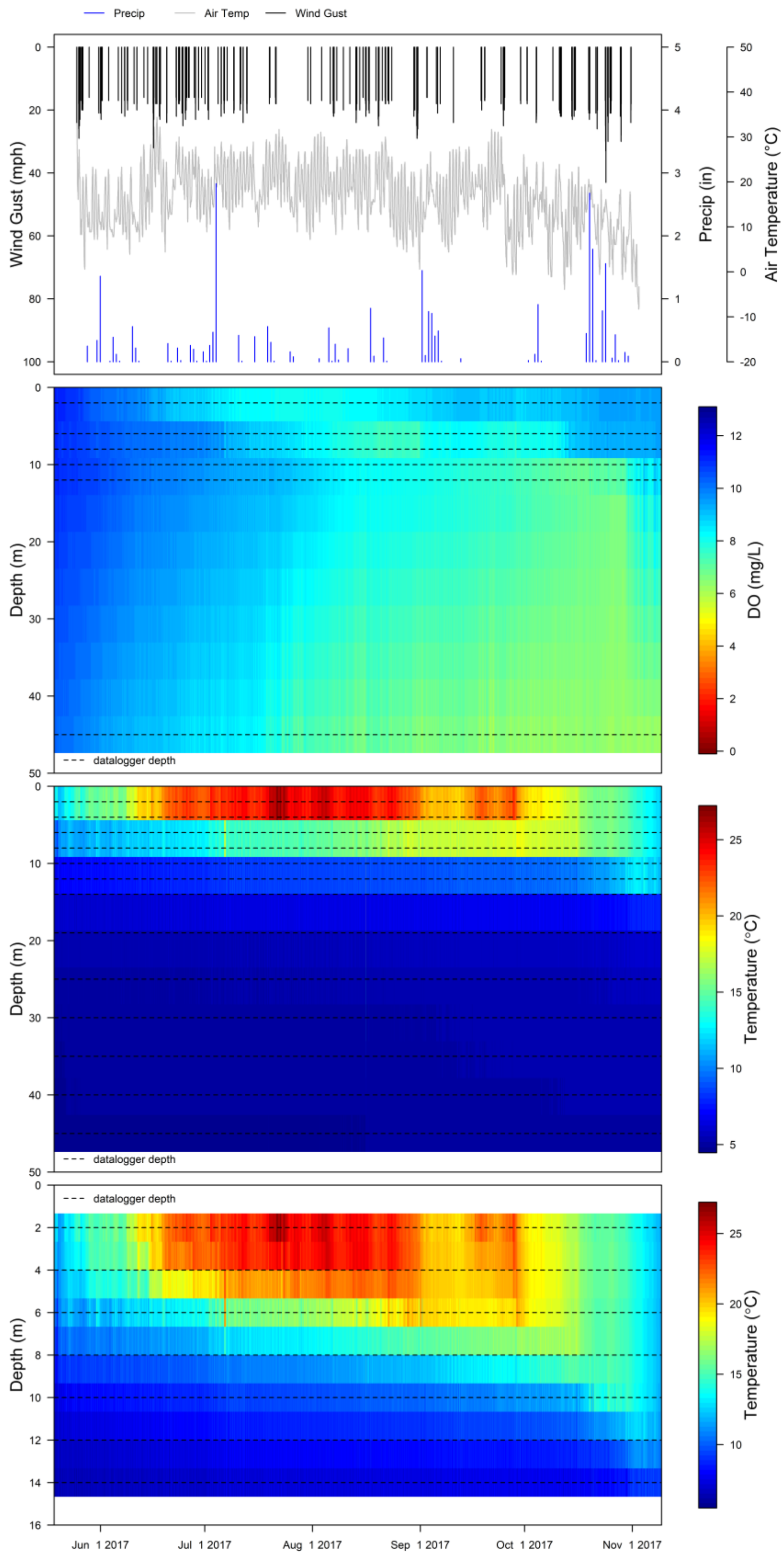


FIGURE 6. Hourly maximum wind gust, air temperature, and precipitation (first, top). Interpolation of dissolved oxygen and temperature readings taken every 15 minutes during the summer at various depths at the deep spot of Kezar Lake's upper basin for the entire water column (second, third, respectively) and temperature from 0-14 meters below the surface (fourth, bottom). Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI station at Fryeburg. Red coloring represents low oxygen or warm surface waters in the lake.

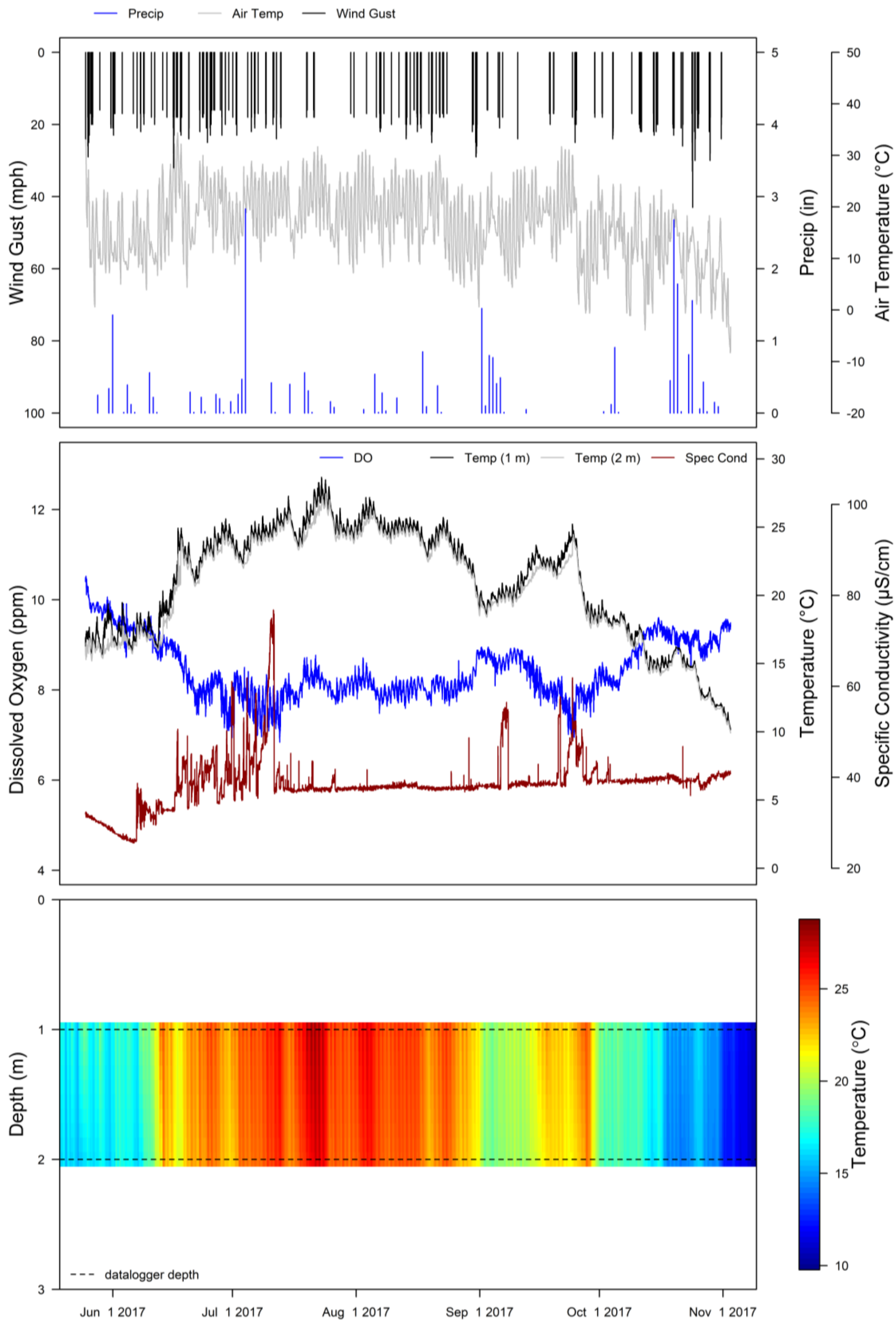


FIGURE 7. Hourly maximum wind gust, air temperature, and precipitation (top). Dissolved oxygen, temperature, and specific conductivity readings taken every 15 minutes during the summer at 2 meters depth (temperature also included 1 meter depth) at the deep spot of Kezar Lake's lower basin (middle). Interpolation of temperature readings taken every 15 minutes during the summer at 1 and 2 meters depth at the deep spot of Kezar Lake's lower basin (bottom). Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI station at Fryeburg. Red coloring represents warm surface waters in the lake.

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 (11.8 ppm) and has shown a decreasing (worsening) trend in total alkalinity over the sampling record for all three basins (Table 1; VLMP, 2013). Since 2012 (including 2017), all three basins in Kezar Lake have averaged 4.0 ppm over the course of each sampling season (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 6.3; and Kezar Lake – lower basin (03) has ranged from 6.1 to 7.0, with an all data median of 6.7. Kezar Lake has slightly more acidic pH compared to average pH levels in Maine Lakes (6.8) and has shown no trend in pH over the sampling record (Table 1; VLMP, 2013). In 2017, pH at all three basins averaged 6.2. These pH values are more acidic than those measured historically and are below the Maine DEP/USEPA recommended range of 6.5 to 8.0 to support aquatic species (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 11.0 PCU; Kezar Lake – middle basin (02) has ranged from 8.0 to 16.0 PCU, with an all data median of 11.5 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. Kezar Lake is a non-colored waterbody (<25 PCU) compared to average color in Maine Lakes (28.0 PCU) and has shown a relatively stable trend in color over the sampling record (Table 1; VLMP, 2013). In 2017, color at the upper, middle, and lower basins averaged 13.0, 14.0, and 16.0, respectively (Table 1).

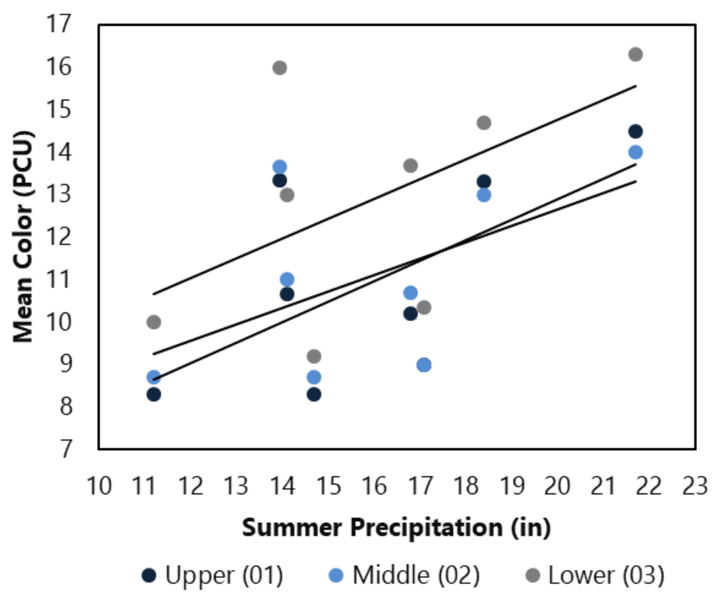


FIGURE 8. Higher summer precipitation amounts wash off more material from the landscape to the lake and contributes to higher color values. Conversely, lower summer precipitation amounts generally allow for better water clarity and reduced color.

Historical data indicate that high color values are positively correlated to high precipitation years because of increased runoff (Figure 8). Precipitation in summer 2017 was relatively low (14.7 inches from June to September) as were color values, which further solidifies this relationship.

TABLE 1. 2017 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)
6/8/2017	Upper (01)	8.9	8.0	1.8	4.0	6.0	15.0
	Middle (02)	8.7	7.0	2.2	5.0	6.0	14.0
	Lower (03)	3.5	12.0	1.5	4.0	6.1	20.0
8/16/2017	Upper (01)	8.1	4.0	1.9	4.0	6.2	13.0
	Middle (02)	8.0	4.0	1.5	5.0	6.3	15.0
	Lower (03)	3.5	6.0	1.8	4.0	6.2	16.0
9/12/2017	Upper (01)	8.5	5.0	2.2	4.0	6.2	12.0
	Middle (02)	8.5	4.0	2.3	4.0	6.2	12.0
	Lower (03)	3.4	7.0	2.4	4.0	6.2	12.0
2017 Median (Kezar Lake)	Upper (01)	8.5	5.0	1.9	4.0	6.2	13.0
	Middle (02)	8.5	4.0	2.2	5.0	6.2	14.0
	Lower (03)	3.5	7.0	1.8	4.0	6.2	16.0
Historical Median[a]	Upper (01)	7.6	5.0	2.2	4.0	6.7	11.0
	Middle (02)	7.1	5.0	1.8	4.0	6.3	11.5
	Lower (03)	3.2	9.0	2.4	4.0	6.7	13.0
Maine Lakes*	Mean	4.8	12.0	5.4	11.8	6.8	28.0

** From Maine VLMP 2013 Lakes Report.*

[a] All data medians do not include any 2015-17 Maine DEP or VLMP data

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 9.

Bradley Pond

- Average water clarity in 2017 (5.0 meters) was the fourth shallowest (worst) annual median behind 2017 (4.7 meters), 2011 (4.6 meters), and 2009 (4.7 meters) and was 0.3 meters shallower (worse) than the all data median (5.3 meters). This was despite the dry summer, which contributed to generally better water clarity in most waterbodies.
- Average total phosphorus in 2017 (10.5 ppb) was the second highest (worst) annual median behind 2017 (10.5 ppb) and was 2.5 ppb higher (worse) than the all data median (8.0 ppb).
- Average chlorophyll-a in 2017 (4.4 ppb) was 1.0 ppb higher (worse) than the all data median (3.4 ppb), and the highest (worse) annual median since 2012 (5.8 ppb).

- DO concentrations dropped below the aquatic life criterion of 5 ppm beginning at 5 meters depth on both sampling dates in 2017. Anoxia at pond bottom should continue to be monitored closely for signs of degradation (i.e., increase in the extent and duration of anoxia experienced in late summer).
- Average pH in 2017 (5.9) tied 2017 for lowest (worst) annual median on record, was 0.6 lower (worse) than the all data median (6.5), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. Bradley Pond has historically experienced the lowest (worst) pH, which may also be tending toward a degrading trend; further monitoring will be needed.
- Average alkalinity in 2017 (3.5 ppm) was slightly lower (worse) than the all data median (4.0 ppm).
- Average color in 2017 (31.5 PCU) tied 2012 for highest (worse) annual median, and was 10.5 PCU higher (worse) than the all data median (21.0 PCU). This is despite the relatively dry summer weather conditions that should have limited material runoff to the pond.

Cushman Pond

- Average water clarity in 2017 (5.3 meters) was 0.2 m shallower (worse) than the all data median, but was improved from previous years.
- Average total phosphorus in 2017 (12.5 ppb) was the highest (worst) annual median on record and was 5.5 ppb higher (worse) than the all data median (7.0 ppb). This may be tending toward a degrading trend since 2006; further monitoring will be needed.
- Average chlorophyll-a in 2017 (1.8 ppb) was 0.5 ppb lower (better) than the all data median (2.3 ppb) and has remained relatively stable since 1997.
- Between 2010 and 2013, DO concentrations dropped below the aquatic life criterion of 5 ppm beginning at 6-7 meters below the surface. Since then, no DO depletion of <5 ppm has been observed at Cushman Pond, except the very bottom reading (7 meters) on 8/16/2017.
- Average pH in 2017 (6.1) tied 2016 for lowest (worst) annual median on record, was 0.6 lower (worse) than the all data median (6.7), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. This may be tending toward a degrading trend; further monitoring will be needed.
- Average alkalinity in 2017 (4.5 ppm) was slightly lower (worse) than the all data median (5.0 ppm). Annual median alkalinity has been decreasing (worsening) since 1997.
- Average color in 2017 (13.0 PCU) was the third highest (worse) annual median behind 1998 (20.0 PCU) and 2013 (19.0 PCU), and was 2.0 PCU higher (worse) than the all data median (11.0 PCU).

Farrington Pond

- Average water clarity in 2017 (4.3 meters) was 0.1 meters shallower (worse) than the all data median (4.4 meters), but was deeper (better) than annual median water clarity since 2013. This may be due to the dry summer, which contributed to generally better water clarity in most waterbodies. Farrington Pond water clarity has occasionally been limited due to the Secchi disk hitting bottom; however, water clarity is the shallowest (worst) of the other ponds and has become consistently shallower (worse) by about 1.0 meter since 2009.
- Average total phosphorus in 2017 (15.5 ppb) was 2.5 ppb higher (worse) than the all data median (13.0 ppb). Year-to-year variability in and absolute concentrations of total phosphorus in Farrington Pond are the highest (worst) compared to the other ponds. The shallow nature of this pond makes it more vulnerable to suspension of phosphorus-laden sediment because of heavy rainfall, wind storms, or watershed disturbances (e.g., shoreline development).
- Average chlorophyll-a in 2017 (4.8 ppb) was 0.5 ppb lower (better) than the all data median (5.3 ppb). Year-to-year variability in and absolute concentrations of chlorophyll-a in Farrington Pond are the highest (worst) compared to the other ponds.
- In 2017, DO concentrations did not drop below the aquatic life criterion of 5 ppm. Because Farrington Pond is so shallow, the entire water column was above 24°C in August, which would have severely limited suitable habitat for cold-water fish species that may only have survived if they sought out cooler pockets of groundwater springs.
- Average pH in 2017 (6.2) was the second lowest (worst) annual median on record behind 2016 (6.1), was 0.5 lower (worse) than the all data median (6.7), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. This may be tending toward a degrading trend since 2013; further monitoring will be needed.
- Average alkalinity in 2017 (4.5 ppm) was slightly higher (better) than the all data median (4.0 ppm) and has statistically-significantly improved in the last 10 years.
- Average color in 2017 (22.3 PCU) was the second highest (worst) annual median on record behind 2004 (23.3 PCU), and was 6.3 PCU higher (worse) than the all data median (16.0 PCU).

Heald Pond

- Average water clarity in 2017 (4.6 meters) was on par the all data median (4.6 meters). Water clarity is the second shallowest (worst) of the other ponds, but Heald Pond water clarity has occasionally been limited due to the Secchi disk hitting bottom.

- Average total phosphorus in 2017 (12.5 ppb) was 3.0 ppb higher (worse) than the all data median (9.5 ppb), and was the third highest (worst) annual median on record behind 1996 (16.0 ppb) and 1990 (15 ppb).
- Average chlorophyll-a in 2017 (5.4 ppb) was 1.5 ppb higher (worse) than the all data median (3.9 ppb). Heald Pond has the second highest (worst) all data median for total phosphorus and chlorophyll-a after Farrington Pond. The shallow nature of Heald pond makes it more vulnerable to suspension of phosphorus-laden sediment (and subsequently, algae growth) because of heavy rainfall, wind storms, or watershed disturbances (e.g., shoreline development).
- In 2017, DO concentrations dropped below the aquatic life criterion of 5 ppm beginning at 3 meters depth on 8/16/2017. This has been a consistent pattern over the historical record for Heald Pond.
- Average pH in 2017 (6.0) was the lowest (worst) annual median on record, was 0.7 lower (worse) than the all data median (6.7), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. pH has statistically-significantly degraded since 1989.
- Average alkalinity in 2017 (5.0 ppm) was slightly lower (worse) than the all data median (5.3 ppm). Heald Pond holds the highest (best) all data median alkalinity of the other ponds, and total alkalinity in Heald Pond has been statistically-significantly improving in the last 10 years,
- Average color in 2017 (40.0 PCU) was higher (worse) than the all data median (23.0 PCU), and was the highest (worst) annual median on record. Heald Pond is the most colored waterbody of the other ponds.

Horseshoe Pond

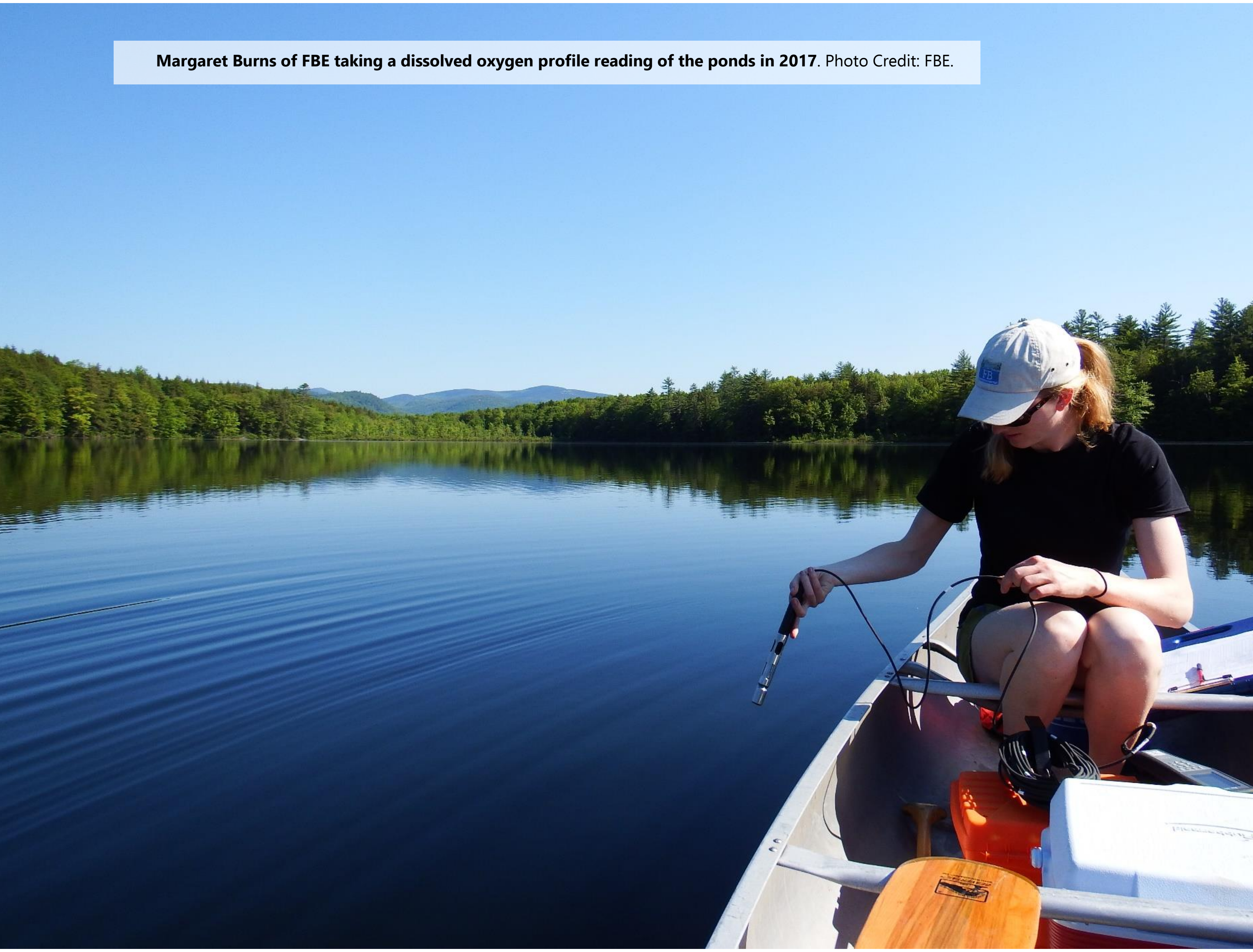
- Average water clarity in 2017 (7.3 meters) was the deepest (best) annual median since 2010 (along with 2016), was 0.4 meters deeper (better) than the all data median (6.9 meters), and was the second deepest (best) annual median compared to the other ponds. This was likely due to the dry summer, which contributed to generally better water clarity in most waterbodies.
- Average total phosphorus in 2017 (8.5 ppb) was the second highest (worst) annual median behind 1999 (9.0 ppb), was 1.5 ppb higher (worse) than the all data median (7.0 ppb), but was the second lowest (best) annual median compared to the other ponds. Horseshoe Pond has historically experienced the lowest (best) total phosphorus after Trout Pond.
- Average chlorophyll-a in 2017 (2.6 ppb) was 0.9 ppb lower (better) than the all data median (3.5 ppb).

- DO concentrations dropped below the aquatic life criterion of 5 ppm beginning at 9 meters depth on 8/16/2018. Anoxia at pond bottom should continue to be monitored closely for signs of degradation (i.e., increase in the extent and duration of anoxia experienced in late summer).
- Average pH in 2017 (6.1) was the second lowest (worst) annual median on record behind 2017 (6.0), was 0.6 lower (worse) than the all data median (6.7), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. pH is statistically-significantly degrading over time.
- Average alkalinity in 2017 (3.0 ppm) was on par with the all data median (3.0 ppm) and was the lowest (worst) annual and historical median of the other ponds. Annual median alkalinity has been significantly decreasing (worsening) by nearly 2.5 ppm since sampling began in 1997.
- Average color in 2017 (13.0 PCU) was the third highest (worst) annual median behind 1998 (14.0 PCU) and 2012 (14.5 PCU), and was 3.0 PCU higher (worse) than the all data median (10.0 PCU).

Trout Pond

- Historically, Trout Pond has experienced the best water quality of the other ponds, with the deepest water clarity, lowest total phosphorus, lowest chlorophyll-a, and lowest color. It is also the deepest (20+ meters) and least developed pond. Development around Trout Pond includes only a single large summer camp on the north end of the lake, known as Camp Susan Curtis.
- Average water clarity in 2017 (7.8 meters) was the deepest (best) annual median since 2010, and was 0.4 meters deeper (better) than the all data median (7.4 meters). Water clarity may be tending toward a degrading trend; further monitoring will be needed.
- Average total phosphorus in 2017 (6.5 ppb) was 2.0 ppb higher (worse) than the all data median (4.5 ppb).
- Average chlorophyll-a in 2017 (2.4 ppb) was 0.7 ppb higher (worse) than the all data median (1.7 ppb).
- DO concentrations dropped below the aquatic life criterion of 5 ppm beginning at 17 and 12 meters depth in June and August 2017, respectively. This was expected and in line with historical measurements since Trout Pond's deeper waters are subject to thermal stratification that prevents oxygenated surface waters from reaching bottom waters. Anoxia at pond bottom should continue to be monitored closely for signs of degradation (i.e., increase in the extent and duration of anoxia experienced in late summer).
- Average pH in 2017 (6.0) was the lowest (worst) annual median on record, was 0.7 lower (worse) than the all data median (6.7), and fell below the optimal aquatic life criteria range of 6.5 to 8.0. This may be tending toward a degrading trend since 2013; further monitoring will be needed.

- Average alkalinity in 2017 (4.0 ppm) was on par with the all data median (4.0 ppm). Annual median alkalinity at Trout Pond has statistically-significantly improved in the last 10 years.
- Average color in 2017 (10.5 PCU) was 1.5 PCU higher (worse) than the all data median (9.0 PCU). Trout Pond is the least colored waterbody of the other ponds.



Margaret Burns of FBE taking a dissolved oxygen profile reading of the ponds in 2017. Photo Credit: FBE.

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.

TABLE 2. Historical and recent (2017) 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 2017[c]	Historical[b]	Recent 2017[c]	Historical[b]	Recent 2017[c]	Historical[b]	Recent 2017[c]	Historical[b]	Recent 2017[c]	Historical[b]	Recent 2017[c]
Bradley	5.3	5.0	8.0	10.5	3.4	4.4	6.5	5.9	4.0	3.5	21.0	31.5
Cushman	5.5	5.3	7.0	12.5	2.3	1.8	6.7	6.1	5.0	4.5	11.0	13.0
Farrington*	4.4	4.3	13.0	15.5	5.3	4.8	6.7	6.2	4.0	4.5	16.0	22.3
Heald*	4.6	4.6	9.5	12.5	3.9	5.4	6.7	6.0	5.3	5.0	23.0	40.0
Horseshoe	6.9	7.3	7.0	8.5	3.5	2.6	6.7	6.1	3.0	3.0	10.0	13.0
Trout	7.4	7.8	4.5	6.5	1.7	2.4	6.7	6.0	4.0	4.0	9.0	10.5
Maine Lakes[a]	4.8		12.0		5.4		6.8		11.8		28.0	

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

[a] Mean values obtained from VLMP's 2013 Maine Lakes Report

[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 2015-17

[c] Median values calculated by FBE from 2017 data

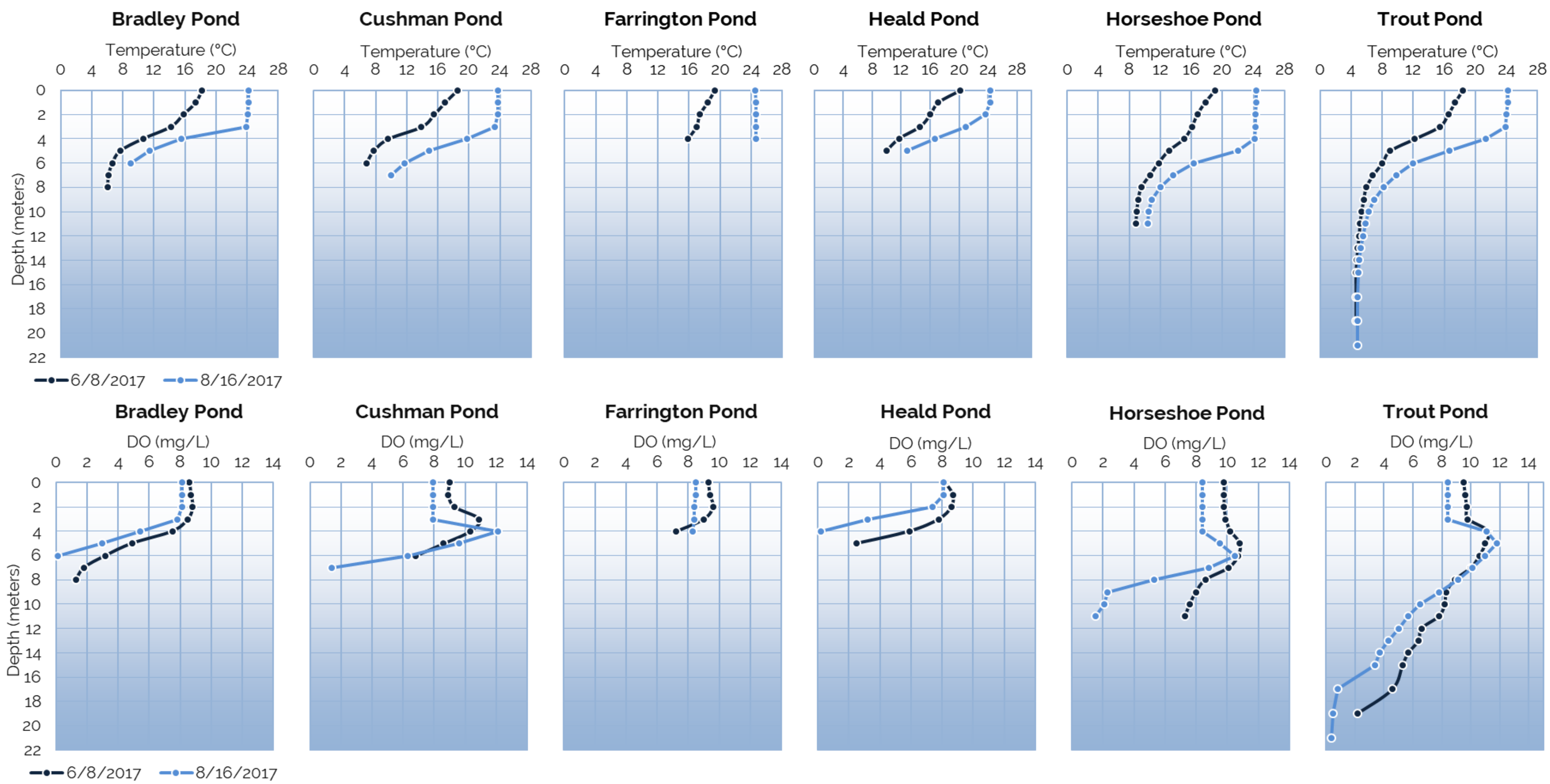


FIGURE 9. Temperature (top panel) and dissolved oxygen (bottom panel) profiles for six ponds of the Kezar Lake watershed.

TRIBUTARIES

Grab Samples

Great Brook was sampled upstream of the Adams Road crossing adjacent to Hut Road (GB-1). Boulder Brook was sampled downstream (BB-3) of the Route 5 crossing. Cold Brook was sampled upstream of the Slide Inn Road crossing (CD-1B). Temperature, dissolved oxygen, pH, *E. coli*, and/or total phosphorus were measured on 6/8/17, 8/16/17, and/or 9/12/17 at the three stream sites; though some temperature and dissolved oxygen readings were missed in 2017 (Table 3). At the request of KLWA, *E. coli* samples were also collected on 8/16/17 and 9/12/17 at Pleasant Point Beach and Lovell Town Beach. Counts were low and of no concern for primary contact recreation; though post-storm sampling should be conducted to ensure low counts are consistent (Table 3).

Dissolved oxygen readings in Great Brook and Boulder Brook for 2017 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 9.8 ppm and Boulder Brook averaged 8.7 ppm; Table 3). Water temperature was below 24°C, which is excellent for cold-water fish. Note that dissolved oxygen is lowest before 8 am and mid-day sampling usually represents best-case conditions.

pH in the tributaries ranged from 5.9 to 6.2 with an average of 5.9 for both Great and Boulder Brooks and 6.2 for Cold Brook in 2017 (Table 3). pH may be tending toward a degrading trend for Great and Boulder Brooks streams; further monitoring is needed.

Total phosphorus ranged from 5.0 to 12.0 ppb with an average of 5.0 ppb for Great Brook, 11.0 ppb for Boulder Brook, and 12.0 ppb for Cold Brook in 2017 (Table 3). While total phosphorus in Great Brook has remained relatively stable, total phosphorus in Boulder Brook was tending toward a degrading trend from 2012-2016.

E. coli were well below the Maine DEP instantaneous criterion of 194 col/100mL for Great, Boulder, and Cold Brooks in 2017, though the geometric mean for Boulder Brook was slightly above the Maine DEP geometric mean criterion of 29 col/100mL. 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.

TABLE 3. 2017 water quality monitoring results for Kezar Lake tributaries (Great Brook, Boulder Brook, and Cold Brook) and two public beaches (Pleasant Point Beach and Lovell Town Beach).

Date	Site Code	Temp (°C)	DO (mg/L)	pH	E. coli (col/100mL)	TP (ppb)
Great Brook						
6/8/2017	GB-1	13.7	10.4	5.9	18	5
9/12/2017	GB-1	15.9	9.2	6.0	29	5
2017 Average	**GB-1**	**14.8**	**9.8**	**5.9**	**23**	**5**
Boulder Brook						
6/8/2017	BB-3	19.6	8.7	5.9	20	11
9/12/2017	BB-3	18.0	8.7	6.0	54	11
2017 Average	**BB-3**	**18.8**	**8.7**	**5.9**	**33**	**11**
Cold Brook						
8/16/2017	CB-1B	--	--	--	6	12
9/12/2017	CB-1B	--	--	6.2	8	11
2017 Average	**CB-1B**	**--**	**--**	**6.2**	**7**	**12**
Beaches						
8/16/2017	LTB-1	--	--	--	12	--
9/12/2017	LTB-1	--	--	--	10	--
8/16/2017	PPB-1	--	--	--	58	--
9/12/2017	PPB-1	--	--	--	3	--

Note: DEP Standard 194 col/100mL for single sample; 29 col/100mL for geomean of multiple samples
Duplicates were averaged before taking the total average

Cold Brook in August of 2017. Photo Credit: FBE.

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 2017. 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.

The water temperature loggers were deployed on 4/24/17 at five sites (Coffin, Boulder, Bradley, Sucker, and Long Meadow Brooks) and retrieved on 11/9/17 for a total deployment period of 199 days. These sites were checked on 6/8/17, 7/19/17, 8/16/17, and 9/12/17. In most cases, loggers were submerged and in good condition. If a deeper spot was nearby, loggers were repositioned. The logger at Coffin Brook was found out of water on 6/8/17, 7/19/17, and 11/9/17. The logger at Bradley Brook was found partially or fully buried in sediment on 6/8/17, 7/19/17, and 11/9/17.

The water level/temperature loggers were deployed on 4/24/17 at the Kezar outlet stream and on 5/18/17 at Great Brook, Beaver Brook, and the lower basin (Heinrich Wurm's property) and retrieved on 11/9/17 for a total deployment period of 175-199 days. The stilling wells at Great Brook, Beaver Brook, and the Kezar outlet stream were in excellent condition during 2017 and lined up with land-based reference marks. The stilling well at the lower basin was re-installed slightly offshore using galvanized docking pipe to secure the staff gauge and PVC protective housing with logger with hose clamps. Previous deployment years at the lower basin will need to be adjusted for new staff gauge height. Water level/temperature loggers at these four sites were checked on 6/8/17, 7/19/17, 8/16/17, 9/6/17 (during flow monitoring), and 9/12/17.

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 in some way as to not reflect true stream conditions were deleted from the record. Two stage-discharge measurements were collected at Great Brook, Beaver Brook, and the Kezar outlet stream: 8/16/17 during baseflow conditions and 9/6/17 following a storm event. A more robust stage-discharge relationship for each site will be needed to convert water level to flow.

Water level logger locations from left to right: Great Brook, Beaver Brook, lower basin, and Kezar outlet stream. Photo Credit: FBE & KLWA.

The following presents the processed (QA/QC) data from 2017 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 lower basin gradually declined from May-October (due to summer evaporation and lack of early fall storms) until a series of late October-early November storms increased lake level (Figure 10). Water level at the fish control structure on the Kezar outlet stream followed a similar manner throughout the deployment period, gradually declining from April-October until the large 10/30/17 storm event. Due to the larger volume of water flowing from the lake through the outlet stream, water level increased and decreased much more slowly 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. Both streams experienced the greatest flows during the fall storm event right before retrieval.

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 11). Water temperatures 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.

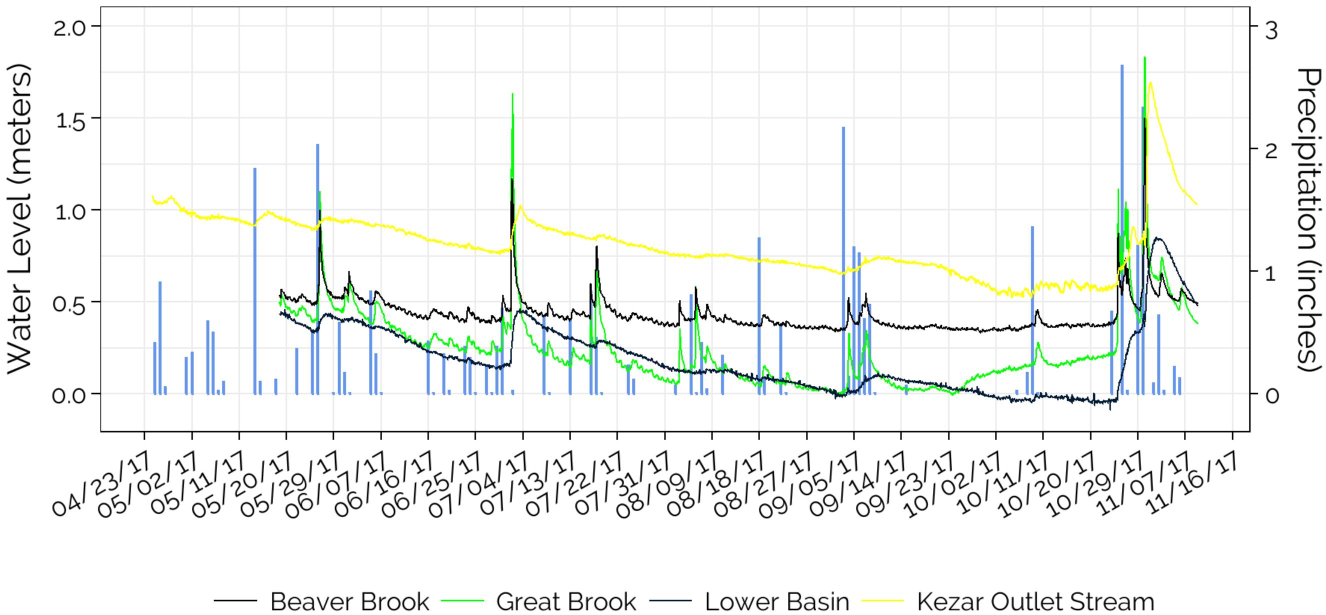


FIGURE 10. Water level data for Great Brook, Beaver Brook, the lower basin, and the Kezar outlet stream from 4/24/17 to 11/9/17. Daily precipitation data were obtained from Weather Underground Creeper Hill, NW Cove, Kezar Lake (KMEFRYEB2).

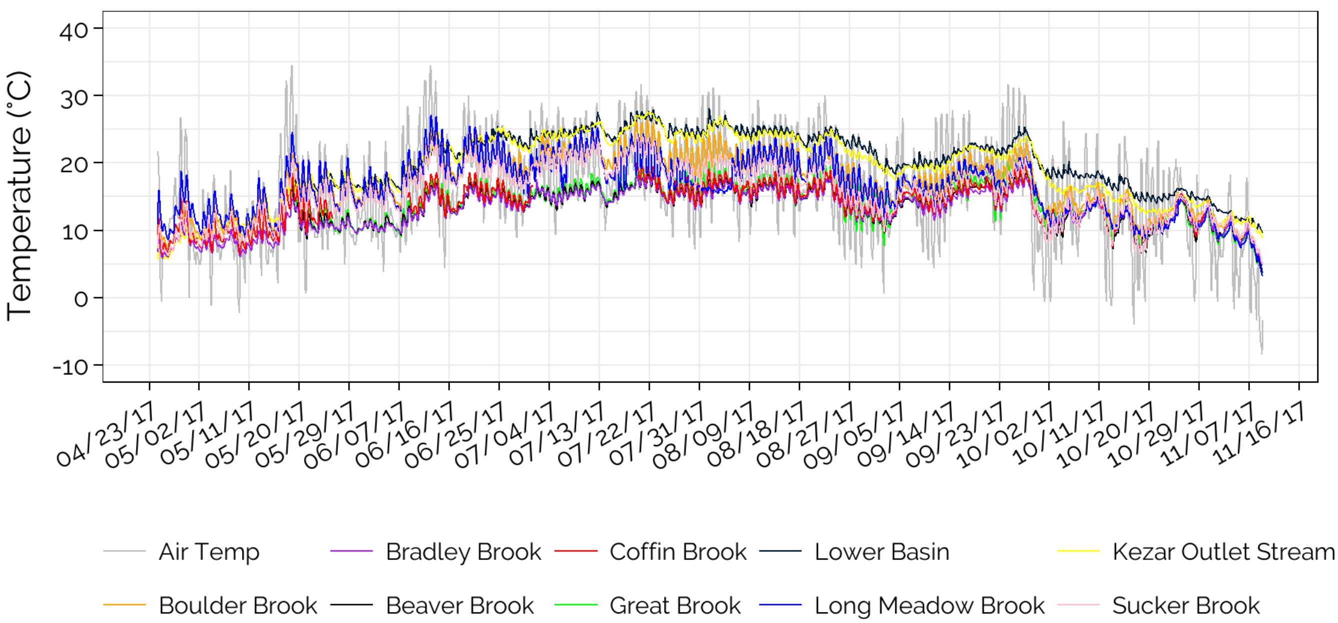


FIGURE 11. Water temperature data for all nine KLWA CCO sites from 4/24/17 to 11/9/17. Daily precipitation data were obtained from Weather Underground Creeper Hill, NW Cove, Kezar Lake (KMEFRYEB2). Hourly air temperature data were obtained from NOAA NCEI QCLCD Fryeburg Eastern Slopes Regional Airport (54772/IZG).

SUMMARY


Heinrich Wurm (KLWA) on Kezar Lake in 2017. 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 historic averages. Water clarity is statistically 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 cold-water fish species survive the warmest months of the year. However, pH hit a near-record low for the fourth year in a row. All three basins are experiencing a statistically-significant degradation in total alkalinity, which would otherwise help to buffer against dramatic changes in pH. Color in 2017 was also above historic medians for all three basins, despite the relatively dry summer and fall. This could be due to excess materials washing in from the watershed during larger storm events, wind/wave action stirring up bottom sediments, and/or biological growth within the water column.

As observed in 2016, 2017 experienced generally worse water quality compared to historic medians in most ponds, despite the dry summer and fall conditions. Exceptions included water clarity at Horseshoe and Trout Ponds and chlorophyll-a in Cushman, Farrington, and Horseshoe Pond (despite higher (worse) total phosphorus, which may not have been the limiting factor for algae and plant growth). Heald and Bradley Ponds continue to show oxygen depletion for a significant portion of the water column, despite shallower depths as compared to Horseshoe and Trout Ponds, which are deeper and have stronger thermal stratification in summer. pH hit record or near-record lows in all the ponds for the fourth year in a row. Heald and Horseshoe Ponds are experiencing a statistically-significant degradation in pH. Total alkalinity, which is naturally-low for the area, makes these waterbodies more susceptible to changes in pH and has shown a statistically-significant degradation in all but Bradley Pond.

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, 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 the pH-alkalinity tributary study that includes samples for aluminum and calcium, and determine the potential impact of these parameters on aquatic organisms.
- Deploy a string of continuous dissolved oxygen loggers on a buoy line at the upper and lower basins of Kezar Lake (currently funded for 2017-18).
- Expand in-lake monitoring to include spring and fall profiles during turnover when these systems are most vulnerable to external and internal material loading.
- 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.
- 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).
- Develop a watershed management plan for the lake that summarizes water quality conditions, sets a water quality goal, and details next steps for improvements.
- Ensure a sustainable funding program is in place to continue water level and temperature monitoring at existing stream sites.
- Consider upgrading all existing stream sites to water level and temperature monitoring (pending a sustainable funding source).
- Consider deploying other continuous loggers (e.g., specific conductivity, turbidity, etc.) at existing stream sites (pending a sustainable funding source).
- 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.

- Supplement monitoring efforts by adding a July sampling event for Kezar Lake and ponds to better assess seasonal (summer) water quality during the most productive time of the year.

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