Kezar Lake
WATERSHED ASSOCIATION
P.O. Box 88, Lovell, ME 04051 www.klwa.us

CLIMATE CHANGE OBSERVATORY

Sand Hill Cranes spotted at Kezar Lake in September, possibly due to climate change

2016 ANNUAL REPORT

TABLE OF CONTENTS

CONTRIBUTING AUTHORS: **LAURA DIEMER** (FB Environmental Associates), **DON GRIGGS** (KLWA/CCO), **CARRIE GREENOUGH** (KLWA Intern), **LISA DONER** (Plymouth State University), **WES HUNTRESS** (KLWA/CCO)

Design by Laura Diemer (FB Environmental Associates)

EXECUTIVE SUMMARY

Climate change is threatening the current balance of ecological systems across the globe. In New England, we can expect warmer air temperatures, more intense and frequent precipitation events, increased flooding, reduced snow cover duration, enhanced species migration and extirpation, and earlier lake ice-out. Lakes can provide early indications of climate change effects, and have been identified as "sentinels of climate change" by the scientific community.

The Kezar Lake Watershed Association (KLWA) recognized the critical need to protect and monitor its valuable natural resources in the face of climate change. As a result, KLWA established a Climate Change Observatory (CCO), whose objective is to analyze the long-term effects of climate change on atmospheric, aquatic, and terrestrial ecosystems in the Kezar Lake watershed. The CCO is led by a six-member steering committee and is funded through a grant, generous donations, and the KLWA General Fund. The formulation of the CCO was made possible through the expert guidance of collaborating partners, including the Greater Lovell Land Trust, the U.S. Forest Service, the University of Maine Climate Change Institute, the Maine Department of Inland Fisheries & Wildlife, Manomet Center for Conservation Sciences, Plymouth State University Center for the Environment, and FB Environmental Associates.

> **The mission of the Climate Change Observatory is to observe, measure, and analyze long-term climate change trends and to address their impact on the waters, lands, and wildlife of the Kezar Lake watershed.**

This document is the second CCO Annual Report, which is published in early fall following the busy summer when climate change-related activities are at their peak. The purpose of this report is to summarize CCO activities for the past year and to make recommendations based on the analysis of climate change-induced annual trends for available data. These data are presented by major ecological zone: water, atmosphere, and land.

The CCO has accomplished the following climate change activities in the watershed:

- **Developed climate change webpages** for the KLWA website (klwa.us) to showcase observed trends in several indicator categories, but most especially water quality.
- **Deployed data loggers** to monitor water temperature and water level in several tributaries draining to Kezar Lake, as well as in the lower bay and in the outlet stream to the lake.
- **Analyzed sediment core samples** for historical water quality by Dr. Lisa Doner from Plymouth State University.
- **Hosted a graduate summer intern** that helped research and compile key climate change data for the CCO webpages and report.
- **Attended major regional or national conferences** that enhanced CCO member knowledge of climate change and promoted CCO activities to the public.
- **Attended multiple meetings with project partners**, including the Town of Lovell and Plymouth State University.
- **Obtained grant funding** to continue climate change tracking efforts in the watershed.
- **Participated in multiple education and community outreach events** to promote CCO activities.

ANNUAL REPORT ON OBSERVED THREATS & RECOMMENDATIONS

CLIMATE CHANGE THREAT	ADAPTATION RECOMMENDATIONS
CLIMATE	
⊗ Increased air temperatures. ⊗ Fewer extreme cold days.	⊕ Incorporate climate change guidance language (based on the following recommendations) in updated municipal comprehensive plan. ⊕ Prepare municipal climate change adaptation plan. ⊕ Adopt a citizen pledge to reduce carbon footprint. ⊕ Provide incentives (e.g., tax breaks) for homeowners that reduce carbon footprint. ⊕ Review and improve energy usage of municipal buildings.
⊗ More days with 1-inch or more rain.	⊕ Improve infrastructure to accommodate higher and more frequent flow volumes. ⊕ Replace the remaining high priority culverts identified by the 2015 culvert study. ⊕ Expand culvert study to include private roads. ⊕ Create a funding and assessment plan to re-assess and replace culverts in the watershed on an ongoing basis. ⊕ Develop emergency management plans based on climate projections. Include current and projected flood risk maps for residents with homes in low-lying areas. Consider requiring septic system evaluations for all homes within the watershed (esp. homes within the projected flood zone) to assess potential for failure. Consider rezoning the projected flood zone for non-development.
⊗ Earlier ice-out since 1972. ⊗ Decreased annual snowfall.	⊕ Encourage establishment of a "Climate Change Adaptation" webpage on the town website that links residents to important climate change information and the CCO webpages. ⊕ Assess vulnerability of area to changes in the amount and timing of water supplies for plants, animals, and humans.
WATER	
⊗ Potential degradation of stable or improving trends in total phosphorus, chlorophyll-a, color, and pH.	⊕ Review and update local ordinances to include the following: 1) add Low Impact Development (LID) description to ordinance and require LID in site design, especially for lots with >20% imperviousness; 2) increase setback distances to at least 100 ft. around vernal pools, streams, and wetlands and restrict development to <25% within 750-ft. radius of resource to account for wildlife (e.g., pool-breeding amphibians); and 3) encourage conservation subdivisions with common open space and require land trusts or conservation organizations (not

CLIMATE CHANGE THREAT	ADAPTATION RECOMMENDATIONS
	homeowner's associations) to undertake stewardship of common open space in conservation subdivisions.
⊗ Degrading trends in alkalinity in multiple waterbodies.	⊕ Develop an alkalinity and pH study to assess the vulnerability of waterbodies to acid rain and watershed activities.
⊗ Impacted water quality at Farrington and Heald Ponds.	⊕ Target stormwater management and septic system maintenance outreach to these pond residents.
⊗ Impacted water quality from stormwater runoff at shoreline properties.	⊕ Conduct a shoreline survey of properties on Kezar Lake and ponds to identify conduits of stormwater runoff (e.g., driveways, boat ramps) and develop specific recommendations for mitigation of erosion. ⊕ Provide incentives (e.g., tax breaks) for homes that achieve LakeSmart certification through the State of Maine.
⊗ Decrease in bottom oxygen levels at the upper bay and Bradley and Horseshoe Ponds.	⊕ Ensure that development occurs in a sustainable and low-impact way to increase watershed resiliency to extreme weather events and prevent potential polluted runoff.
⊗ Increased threat from invasive aquatic plants.	⊕ Continue progressive watch programs that help prevent and control invasive plants.
⊗ Reduction in coldwater fish populations	⊕ Continue monitoring stream conditions for supporting coldwater fish species (e.g., temperature, flow, and population size). This will help target streams in need of restoration. Restoration techniques include increasing overhead vegetative cover to help cool stream water temperatures.
⊗ Reduction in aquatic bird species, esp. loons	⊕ Encourage anglers to use non-lead sinkers and to retrieve fishing line caught in shoreline vegetation.
⊗ Increased threat from aquatic pathogens, including bacteria, protozoa, and parasites.	⊕ Create a public notification system for swimming advisories following any instances of significant algal blooms when waters may be harmful to human health.
LAND	
⊗ Shifts in the habitat ranges of native plant, bird, and mammal species.	⊕ Conduct habitat and species-level vulnerability assessments. ⊕ Protect and restore riparian habitats by enhancing buffers that limit heat stress on species. ⊕ Conserve and protect land areas that serve as wildlife corridors. ⊕ Complete a habitat analysis that prioritizes high value habitat for species most vulnerable to climate change, such as the Black-capped Chickadee and Evening Grosbeak.
⊗ Increased threat from insects and pathogens.	⊕ Disseminate public notices during peak tick and mosquito season to warn residents of potential diseases, including Lyme. ⊕ Ensure state and local regulations prohibit outside firewood and other materials that potentially harbor invasive insects.

INTRODUCTION

In 2013, the Kezar Lake Watershed Association (KLWA) established a Climate Change Observatory (CCO) to observe, measure, and analyze long-term climate change trends and to address their impact on the waters, lands, and wildlife of the Kezar Lake watershed. The CCO is building upon decades of limited local data by expanding data collection activities in the Kezar Lake watershed. These data collection activities target current community interests that were identified during a Community Values Form hosted by the CCO in July 2014. The purpose of this work is to provide the public, local government, and other stakeholder organizations with 1) ongoing information related to the effects of climate change on community interests and 2) recommendations for mitigating or adapting to these potential effects.

This document is the second CCO Annual Report, which is published in early fall following the busy summer when climate change-related activities are at their peak. The purpose of this report is to summarize CCO activities for the past year and to make recommendations based on the analysis of climate change-induced annual trends for available data. These data are presented by major ecological zone: atmosphere, water, and land.

CLIMATE CHANGE OBSERVATORY MANAGEMENT AND DIRECTION

The CCO is funded by a combination of grant, donations, and the KLWA General Fund. CCO activities are guided by a Steering Committee that reports to the KLWA President and supervises the activities of the CCO, by providing direction, setting goals, establishing priorities, and allocating funds.

Current Steering Committee Members

Don Griggs, Director
Heinrich Wurm
Lucy LaCasse
Bob Winship
Ray Senecal
Wes Huntress

PARTNERS AND COLLABORATING ORGANIZATIONS

The CCO collaborates with federal and state government agencies, universities, and private organizations that are involved in climate change activities. CCO members meet and exchange ideas and data with these partners on a regular basis. The recommendations and guidance the CCO has received from these collaborating partners have been immensely helpful in formulating climate change monitoring plans and activities.

Our Partners Include:

- **Greater Lovell Land Trust** – shares our vital interest in the future of our watershed;
- **U.S. Forest Service** – established a water quality data exchange plan for streams within the watershed in the White Mountain National Forest (24% of our watershed);
- **University of Maine Climate Change Institute** – provides access to internationally-acclaimed experts studying climate science;

- **Maine Department of Inland Fisheries & Wildlife** – conducts research on the effects of climate change on fisheries and wildlife;
- **Manomet Center for Conservation Sciences** – provides technical experts on climate change effects on land and water;
- **Plymouth State University Center for the Environment** – providing historical climate data from sediment core sampling, and proving to be a source of highly-qualified graduate interns;
- **FB Environmental Associates** – provides technical advice, planning, and monitoring support for CCO activities.

CURRENT CCO ACTIVITIES (2015-2016)

The CCO has been very active during the past year from September 2015 to September 2016. These activities have bolstered community involvement and awareness of climate change in the Kezar Lake watershed. Our work has received support and commendations from several regional environmental organizations in Maine.

WEB SITE DEVELOPMENT

A major effort over the past year has been the continued development of webpages for the KLWA website (klwa.us) that tell the story of climate change trends for a variety of data collected within or near the Kezar Lake watershed. This website successfully summarizes the voluminous data collected over several decades in a format that is readily accessible and understandable to the public. Because of the extensive and local data available on water quality for Kezar Lake and six ponds within the watershed, most of the initial effort was placed on water quality. However, the CCO was also able to collect and summarize general climate information for the area, as well as the effects of climate change on many key wildlife and plant species. Website development will be an ongoing effort by the CCO and one of the primary methods of data communication with the public.

DATA COLLECTION

The CCO deployed data loggers that continuously collect water temperature and water level data in two streams draining to Kezar Lake, as well as in the lower bay and in the outlet stream of the lake. Five other streams draining to Kezar Lake are continuously monitored for water temperature. The CCO and its partners are currently working to establish a stage-discharge relationship for three sites so that water level can be converted to flow data. Climate change is likely to impact water temperature and stream flow greatly; thus, establishing a monitoring program that evaluates these parameters annually will provide insight to how the watershed responds to climate change.

SEDIMENT CORES

Under the guidance of Dr. Lisa Doner from Plymouth State University, the CCO analyzed and dated sediment core samples taken from Kezar Lake in February and June 2015 to establish a 1,000-year history of climate conditions in the lake. A summary description and preliminary results are presented later in this report.

SUMMER INTERN

The CCO was very fortunate, once again, to have a paid intern for six weeks this summer. Carrie Greenough, a graduate student from Plymouth State University, was instrumental in researching and compiling climate change data for the KLWA webpages, leading the KLWA Old Home Days booth, and participating in water quality data collection. Depending on available funding, the CCO wishes to host an intern every summer to help with climate change research.

CONFERENCES

Members of the KLWA/CCO attended several climate change conferences throughout the year to enhance their knowledge of climate change and to promote CCO activities to the public. These conferences include:

09/28/15	Attended the Lakes Environmental Association Conference in Bridgton, ME.
06/16/16	Attended a Maine VLMP workshop in Auburn, ME for training and certification in the operation and maintenance of a dissolved oxygen meter.
06/25/16	Attended the Annual Maine Lakes Conference in Unity, ME.
09/09/16	Attended a Maine VLMP Watershed Survey Workshop in Auburn, ME for training on "*How to Identify, Monitor and Mitigate Ways in Which Watershed Land Use Influences Lake Water Quality*".

MEETINGS

Members of the CCO met with Lovell officials as follows:

10/01/15	Met with Larry Fox (Lovell Road Commissioner) to discuss culvert replacements.
10/20/15	Met with Lovell Selectmen to present 2015 Annual Report.
11/04/15	Met with Lovell Planning Board to present 2015 Annual Report.

Members of the CCO met with Plymouth State University staff as follows:

11/11/15	Met with Dr. Lisa Doner in Plymouth, NH to discuss core sampling and dating.
06/30/16	Met with Dr. Lisa Doner in Plymouth, NH to discuss core sampling results and meet the 2016 summer intern.

CCO Steering Committee meetings were held on **01/04/16**, and **08/17/16**.

GRANT APPLICATION AND REPORTING

The CCO submitted a required status report on our 2015 grant in February 2016. The report detailed CCO use of the 2015 grant funds. The CCO then applied for a 2016-17 grant and was awarded $15,000 to continue our climate change tracking efforts.

EDUCATION/COMMUNITY PROGRAMS

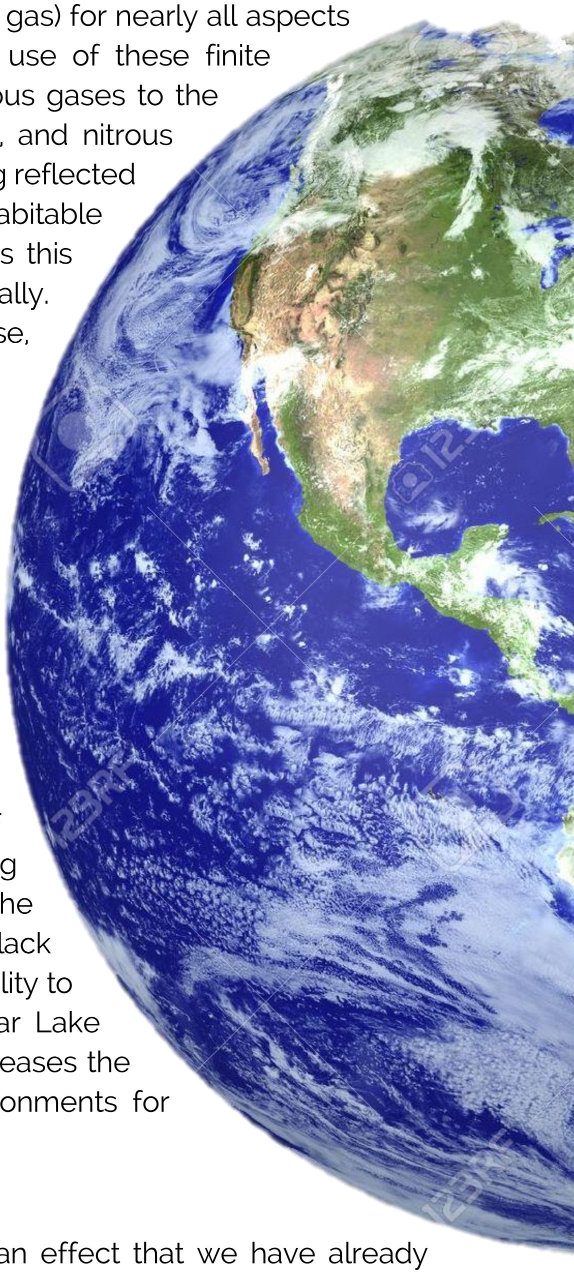
07/09/16	Presented CCO activities update at the KLWA Annual Meeting.
07/16/16	Established a climate change booth for Lovell Old Home Days with displays, informative hand-outs, and a water clarity participation event for children.
08/16/16	Sponsored a climate change movie presentation, "The Messenger," in collaboration with the Greater Lovell Land Trust.

Kezar Lake - Lower Bay. Photo Credit: Heinrich Wurm.

ANNUAL REPORT ON OBSERVED TRENDS

CLIMATE

Air Pollutants



We rely on the burning of fossil fuels (i.e., gasoline, coal, and natural gas) for nearly all aspects of our everyday lives. This heightened energy demand for and use of these finite resources over the last century has introduced an excess of noxious gases to the atmosphere. Some of these gases (e.g., carbon dioxide, methane, and nitrous oxide), also known as greenhouse gases, are responsible for trapping reflected heat from the earth's surface. This process is vital to maintaining a habitable planet, but excess greenhouse gases in the atmosphere enhances this effect by trapping more heat and increasing air temperatures globally. Warmer air temperatures impact rain and snow patterns, sea level rise, and species migrations.

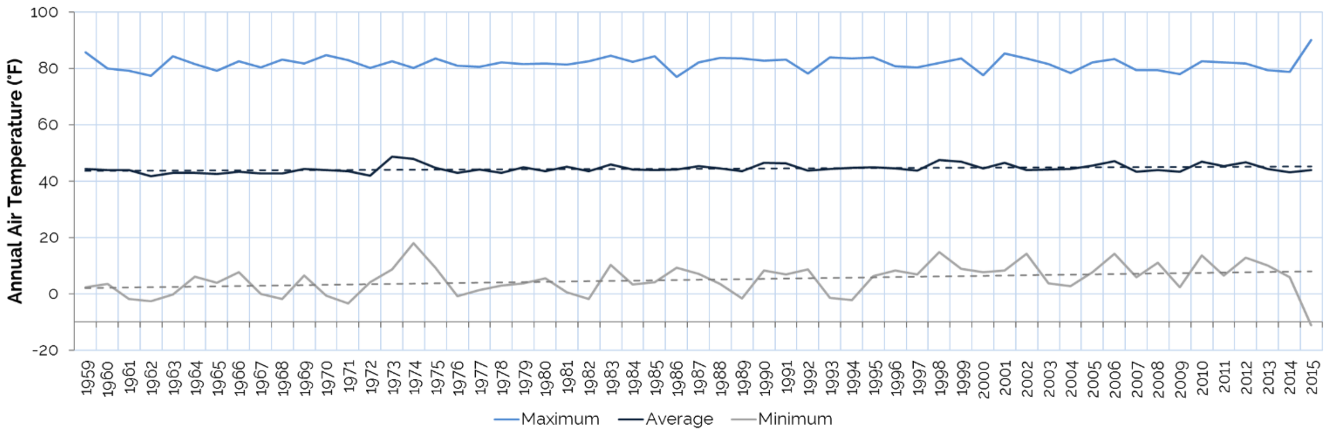
Fossil fuel combustion also emits sulfur dioxide and nitrogen oxides to the atmosphere. These gases react with water vapor, oxygen, and other gases in the atmosphere to form sulfuric and nitric acids, which fall on water and land surfaces as acid rain. Acid rain lowers the pH of aquatic and terrestrial systems, causing reduced reproductive capacity of sensitive aquatic organisms, lower body weight of fish, decreased species diversity, and forest mortality. Substantial effort was made to reduce acid rain deposition through the 1970 Clean Air Act, which established national ambient air quality standards for controlling these noxious emissions. While emissions have decreased and the damaging short-term effects of acid rain have been minimized, many waterbodies are still recovering from the long-term effects of acidification. In particular, the northeastern United States has thin soils with granite geology that lack carbonates, a key component of a system's buffering capacity or ability to neutralize acidic compounds. We see this in streams of the Kezar Lake watershed where low-pH rain (5.0) temporarily, but drastically, decreases the pH of surface waters. These swings in pH create stressful environments for sensitive aquatic organisms.

Air Temperature

Climate change is expected to increase global air temperatures, an effect that we have already observed in the last century. An important point to understand about climate change is the difference between "climate" and "weather." Climate change observations and predications are based on "climate," which is long-term averages of weather observations across regional or global space. For example, the State of Maine has seen a 3 °F increase in annual air temperatures in the last century and we expect an additional 1.4 to 3.0 °F increase in annual air temperatures by 2040. Local weather observations may deviate from this general trend from season to season or year to year, depending on a suite of local variables. For the Kezar Lake watershed, we used CONWAY 1 N, NH US (ID# GHCND:USC00271732) and NORTH CONWAY, NH US (ID#GHCND:USC00275995) weather stations from the NOAA National Climatic Data Center to track changes in air temperature since 1959[1].

> **"AVERAGE ANNUAL TEMPERATURE ACROSS MAINE WARMED BY ABOUT 3.0 °F (1.7 °C) BETWEEN 1895 AND 2014." - MAINE'S CLIMATE FUTURE, 2015 UPDATE**

ANNUAL AIR TEMPERATURES



Average and minimum annual air temperatures have warmed by about 1 °F and 8 °F, respectively, near Conway-North Conway, NH. Maximum annual air temperatures have remained fairly stable. In 1960, the minimum, average, and maximum annual air temperatures were 4 °F, 44 °F, and 80°F, respectively. This compares with higher minimum, average, and maximum annual air temperatures observed in 2012: 13 °F, 47 °F, and 82°F.

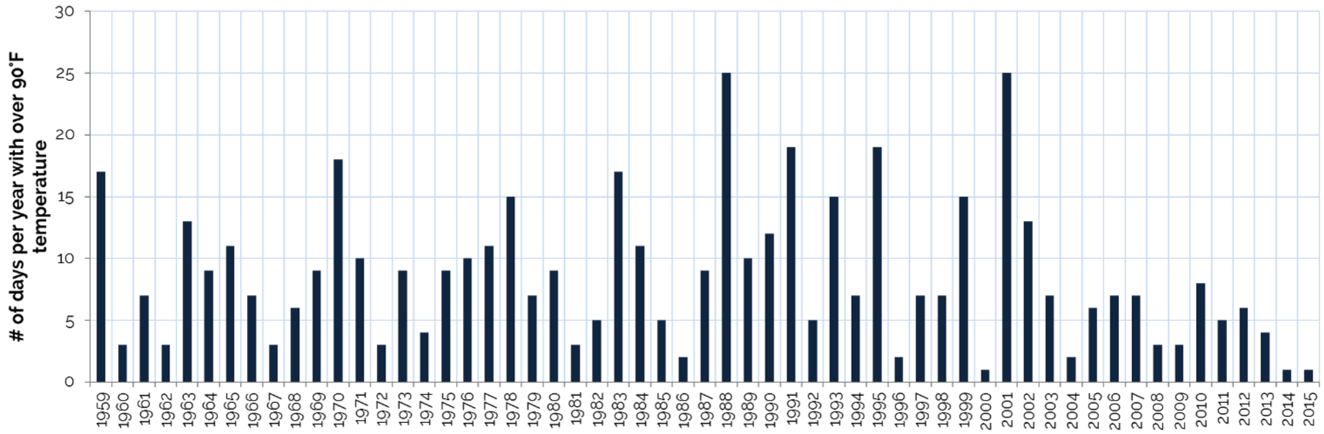
EXTREME HEAT DAYS

As air temperature rises, we can expect to see more extreme heat days. However, the Conway-North Conway weather data since 1959 show no trend in the number of days per year with air temperatures over 90 °F. In fact, the number of extreme heat days seems to have declined in the last decade. Several climate models show that the northeast will not experience as dramatic an increase in extreme heat days as the southern and middle portions of the United States.

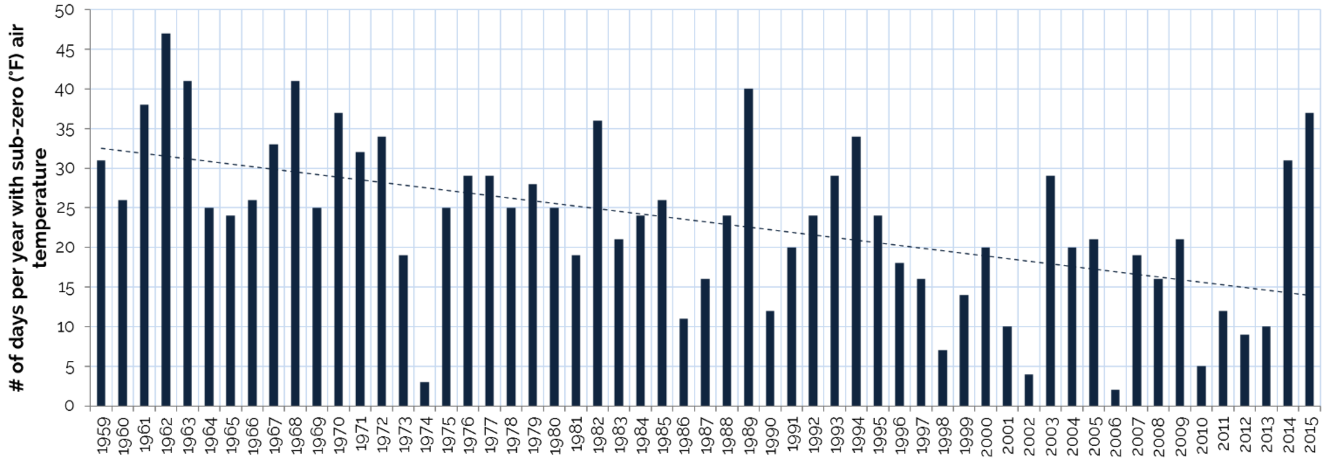
See figure on the following page.

---

[1] These stations have collected significantly more data than more local stations, including Creeper Hill (2008-present), and therefore, were determined to be a more appropriate dataset for the assessment of long-term climate change in the area. In 2016, KLWA analyzed other long-term weather data from Auburn and Bridgton, ME weather stations (1955-present) and found similar trends in weather compared to the Conway-North Conway stations, further confirming the Conway-North Conway stations as likely representative of the area.



EXTREME COLD DAYS

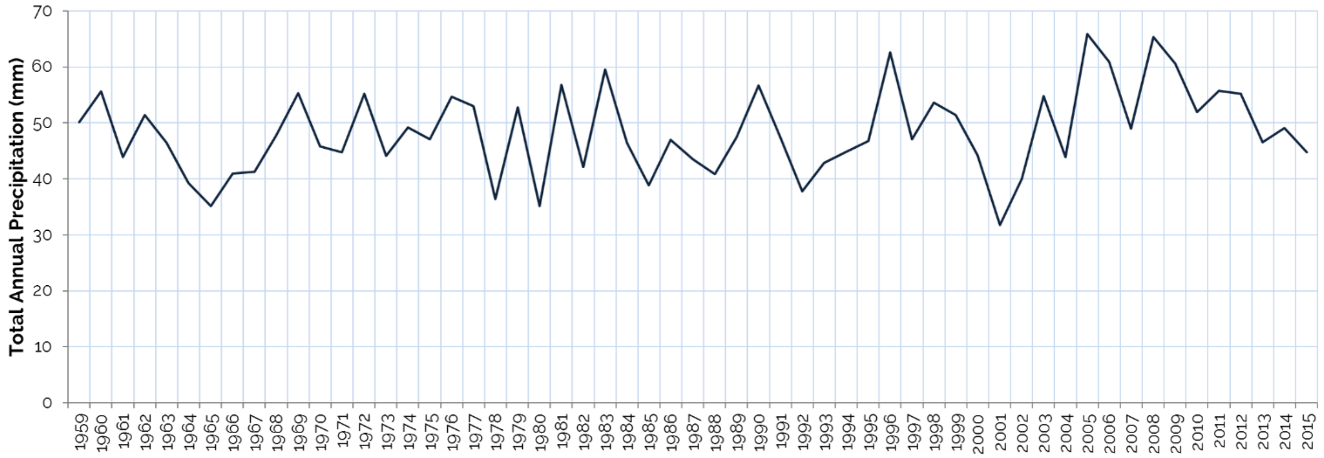


As air temperature rises, we can expect to see less extreme cold days. As expected, the Conway-North Conway weather data since 1959 show a statistically significant decrease in the number of days per year with air temperatures below 0 °F. The first half of the record shows the number of extreme cold days around 25, but the latter half shows the number of extreme cold days declining to 15.

Precipitation

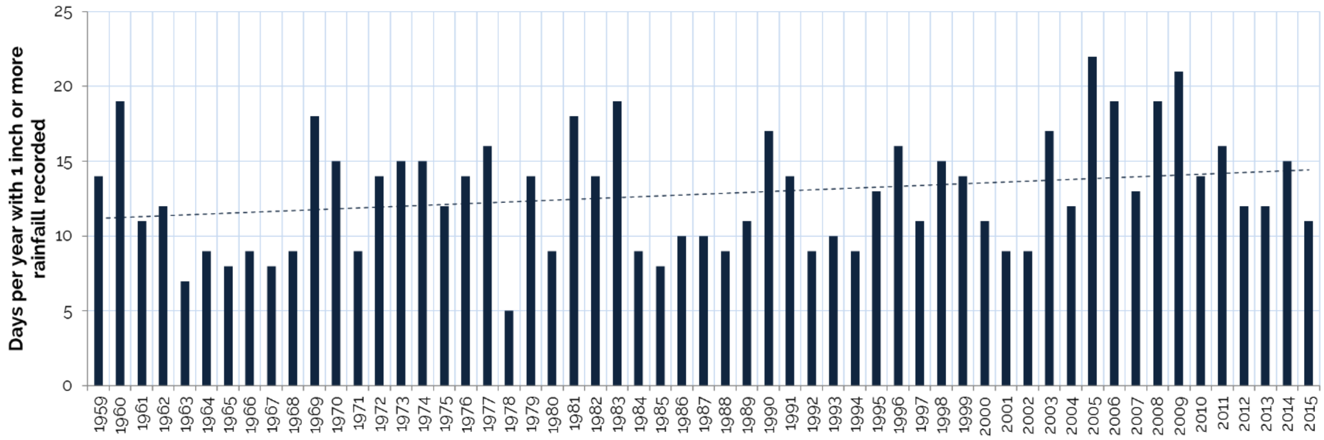
Warming air temperatures have impacted rain and snow patterns across the globe. In Maine, total annual precipitation has increased by 6 inches (13%) since 1895 and is predicted to increase an additional 5-10% by 2050. The distribution of this precipitation is highly variable; some models predict more rain in interior Maine, while historic observations show more rain along the coast. Extreme precipitation events will also likely increase in frequency and duration, particularly along the coast and in the western mountains. Maine has seen a decrease in snowfall accumulations by 1 inch and a decrease in snowpack duration by two weeks since 1895. More frequent and intense rain events will flush excess nutrients from the landscape to receiving waterbodies, including Kezar Lake, which can fuel algal production. Larger flow volumes will also threaten infrastructure, including road crossings and culverts. For the Kezar Lake watershed, we used the North Conway weather station to track changes in precipitation since 1959.

ANNUAL PRECIPITATION



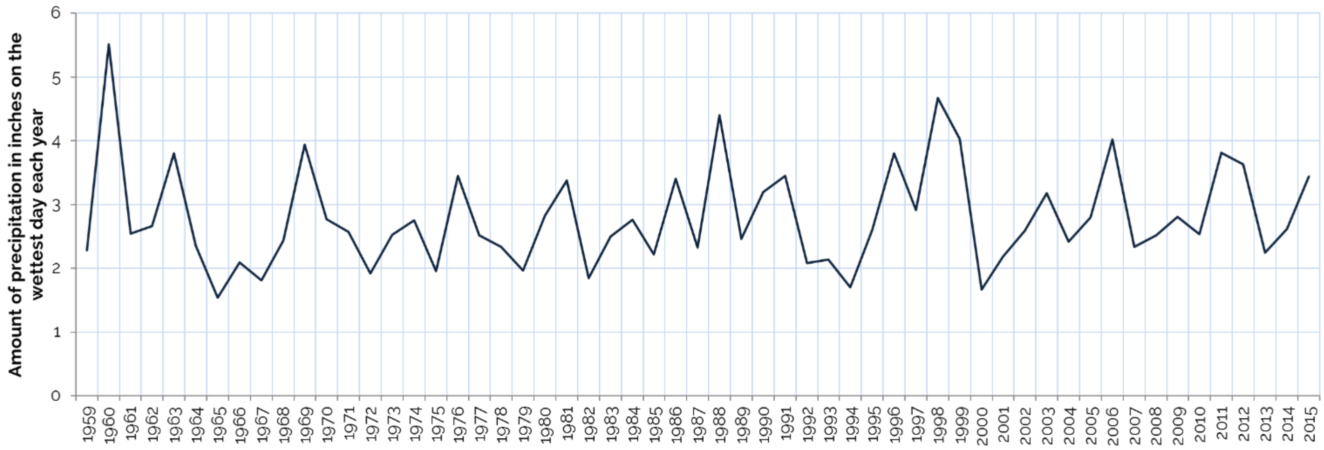
In North Conway, total annual precipitation has fluctuated greatly, but without any trend since 1959. However, three years (1996, 2005, and 2008) saw total annual precipitation above 60 inches. These were extremely wet years impacted by major storms. Total annual precipitation seems to be decreasing in the last decade.

ONE INCH RAIN EVENTS



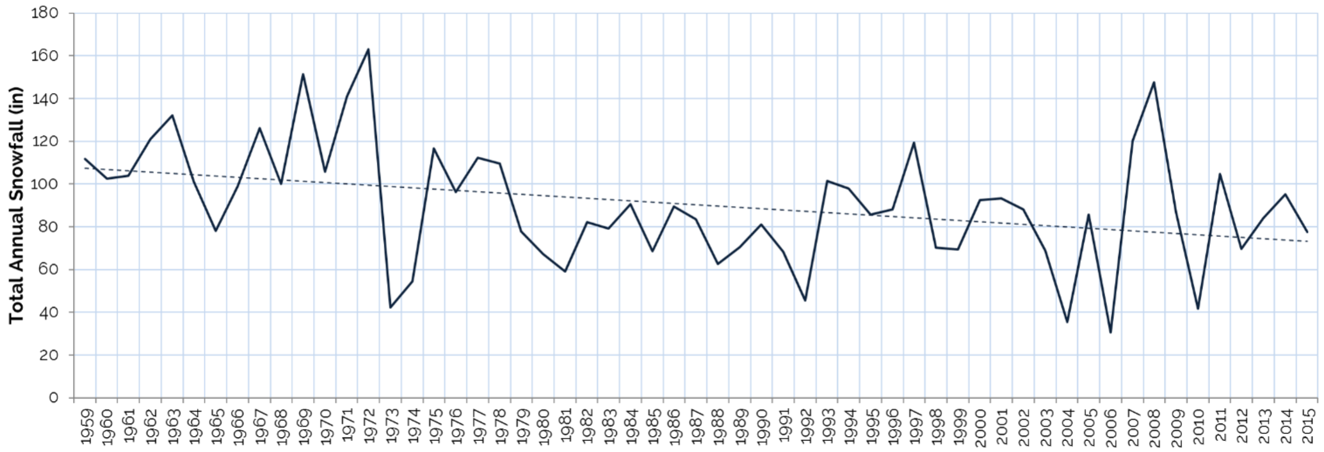
Climate change will likely cause more frequent precipitation events. For North Conway, the number of days per year receiving greater than 1 inch of rain has increased from about 11 to 15 days. The last decade shows multiple years with greater than 15 days per year with 1 inch or more of rain recorded.

WETTEST DAY OF YEAR



The intensity of extreme rain events is illustrated by finding the day from each year with the largest amount of precipitation. Since Maine has an extensive coastline, extreme precipitation events are often related to Atlantic storms. For instance, the extreme precipitation day for 1960 (5.5 inches) coincides with Hurricane Donna. The wettest day of the year precipitation amounts varied considerably throughout the record for North Conway, and no trend was observed.

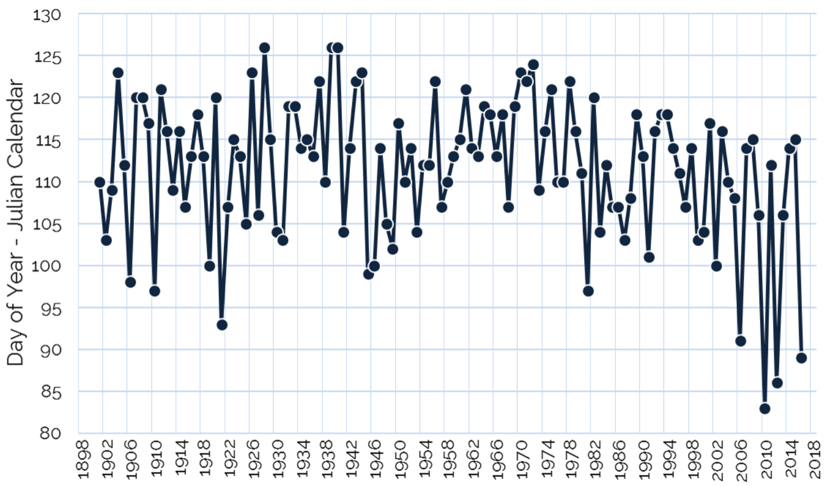
SNOWFALL ACCUMULATION



As air temperatures increase, climate change models predict less snowfall and reduced snowpack duration. Maine has already shown a statistically significant trend of decreased annual snowfall between 1950 and 2000. For North Conway, total annual snowfall has declined from an average of 110 inches to less than 80 inches of snowfall per year since 1959.

Ice-Out

Ice-out data has been collected for Kezar Lake since 1901, providing over a century of information about changes in the seasonal duration of winter snowpack and ice. Ice-out refers to the day when all ice covering Kezar Lake has broken up and melted. This marks the beginning of spring when the entire lake is exposed to direct sunlight, which stimulates lake productivity and drives the critical process of spring turnover.



Although some years within the last decade showed abnormally early ice-out dates, no statistically significant trend was found for all data since 1901. The increasing variability and abnormally early ice-out dates within the last few decades should be monitored closely in the future to confirm the trend. Early ice-out is directly linked to warming air temperatures and changes in seasonality.

Kezar Lake watershed in winter. Photo Credit: KLWA (left); Don Griggs (right).

WATER

Water Quality

Water quality data has been collected in the Kezar Lake watershed since 1970. These data provide a wealth of long-term information from which we can judge the health of the lake, ponds, and streams in the watershed. Because water quality can fluctuate significantly from year-to-year depending on local conditions and activities within the watershed, analyzing data over a longer time period can reveal subtle, yet steady directional changes in water quality. It is important to identify waterbodies at risk for degrading water quality as a result of climate change or development, so we can take action to combat the effects.

Statistical trend analyses (Mann-Kendall[2]) were performed on annual water quality data for all available water quality parameters at all monitored waterbodies in the Kezar Lake watershed. A summary of current conditions and trends are as follows:

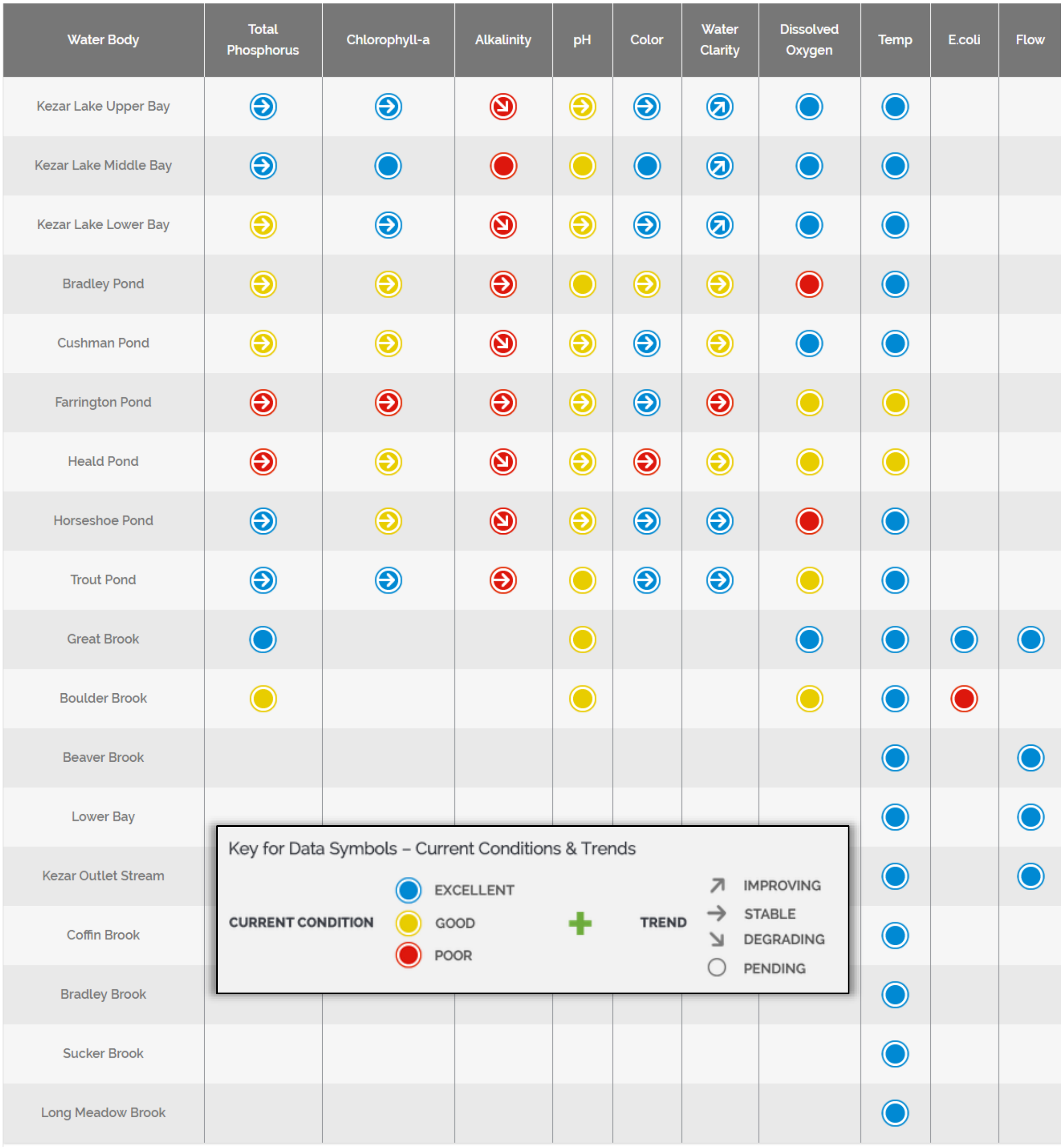
- **Total phosphorus** shows stable trends, but is elevated at Farrington and Heald Ponds.
- **Chlorophyll-a** shows stable trends, but is elevated at Farrington Pond.
- **Alkalinity** shows degrading trends at the upper bay, lower bay, and Cushman, Heald, and Horseshoe Ponds, and is critically, but naturally, low in all waterbodies.
- **pH** shows stable trends, and is low (acidic) in all waterbodies.
- **Color** shows stable trends, and is elevated at Heald Pond.
- **Water clarity** shows improving trends at Kezar Lake, and is poor (but stable) at Farrington Pond.
- **Dissolved oxygen** is regularly anoxic near the bottom in late summer at Bradley and Horseshoe Ponds.
- **Temperature** is generally good or excellent in all waterbodies.
- **Anoxic Factor** shows a degrading trend at the upper bay. In the 2015 report, Cushman Pond had a degrading trend, however the addition of the 2015 data showed improvement in the anoxic conditions. The anoxic factor is highest at Horseshoe Pond.

A list of water quality definitions is provided in Appendix A. The following section showcases annual historical and continuous data for Kezar Lake, six ponds, seven tributaries, and the outlet stream.

---

[2] Mann-Kendall trend tests were performed on annual water quality data to determine trends over time. Dotted trend lines were added where statistically significant. Sample stations with less than 10 years of data cannot be analyzed for statistically significant trends (too few data points). Data obtained from Maine DEP and FB Environmental Associates.

Summary of Current Conditions & Trends



Water Body	Total Phosphorus	Chlorophyll-a	Alkalinity	pH	Color	Water Clarity	Dissolved Oxygen	Temp	E.coli	Flow
Kezar Lake Upper Bay	🔵→	🔵→	🔴↘	🟡→	🔵→	🔵↗	🔵	🔵		
Kezar Lake Middle Bay	🔵→	🔵	🔴	🟡	🔵	🔵↗	🔵	🔵		
Kezar Lake Lower Bay	🟡→	🔵→	🔴↘	🟡→	🔵→	🔵↗	🔵	🔵		
Bradley Pond	🟡→	🟡→	🔴→	🟡	🟡→	🟡→	🔴	🔵		
Cushman Pond	🟡→	🟡→	🔴↘	🟡→	🔵→	🟡→	🔵	🔵		
Farrington Pond	🔴→	🔴→	🔴→	🟡→	🔵→	🔴→	🟡	🟡		
Heald Pond	🔴→	🟡→	🔴↘	🟡→	🔴→	🟡→	🟡	🟡		
Horseshoe Pond	🔵→	🟡→	🔴↘	🟡→	🔵→	🔵→	🔴	🔵		
Trout Pond	🔵→	🔵→	🔴→	🟡	🔵→	🔵→	🟡	🔵		
Great Brook	🔵			🟡			🔵	🔵	🔵	🔵
Boulder Brook	🟡			🟡			🟡	🔵	🔴	
Beaver Brook								🔵		🔵
Lower Bay								🔵		🔵
Kezar Outlet Stream								🔵		🔵
Coffin Brook								🔵		
Bradley Brook								🔵		
Sucker Brook								🔵		
Long Meadow Brook								🔵		

Key for Data Symbols – Current Conditions & Trends

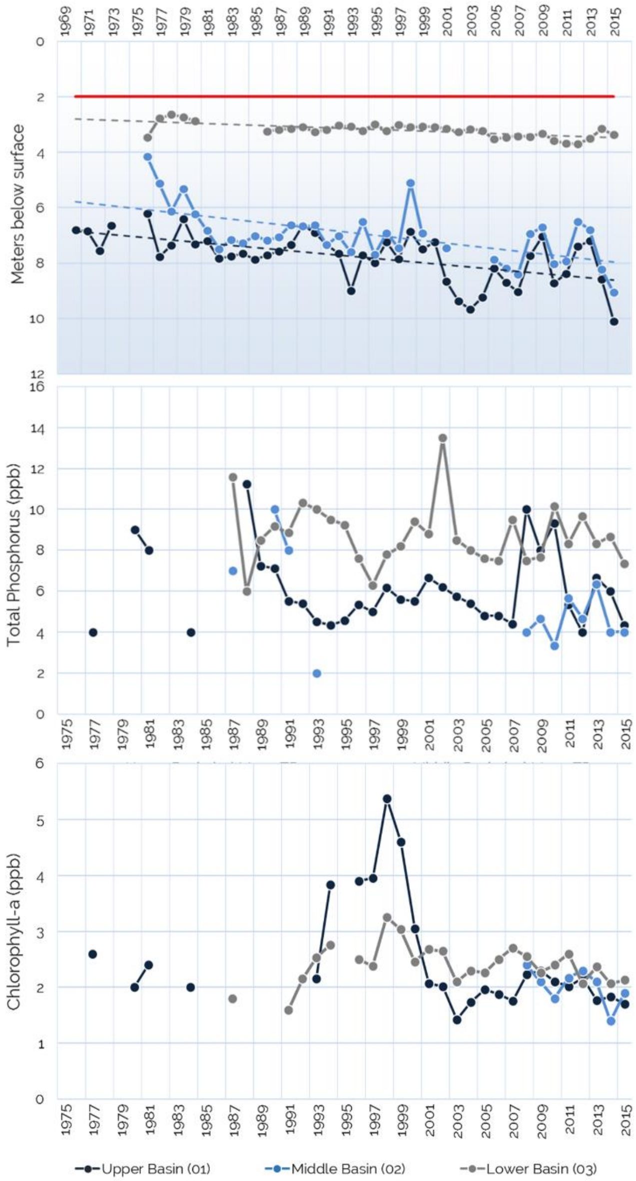
CURRENT CONDITION		+	TREND	
	🔵 EXCELLENT			↗ IMPROVING
	🟡 GOOD			→ STABLE
	🔴 POOR			↘ DEGRADING
				○ PENDING

The **"Current Condition"** for each parameter is based on the data collected during the most recent sampling year compared to state or federal water quality standards. The current condition may also factor in monitoring results with respect to the state-wide average for Maine lakes.

The **"Trend"** indicates whether water quality is improving (up arrow), degrading (down arrow), or remaining stable (horizontal arrow) over time based on statistical analysis of the long-term data set for each parameter by waterbody. Stop lights provide a simple visual assessment of these trends.

KEZAR LAKE
WATER QUALITY TRENDS

Kezar Lake (Midas #0097) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. The lake stretches 9 miles from north to south, covering 2,665 acres (4.16 square miles) and has a maximum depth of 155 feet (47 meters; FBE recorded 162 feet (49 meters) on 9/19/2011 at the upper basin) and a mean depth of 34 feet (10 meters). Water quality monitoring data have been collected since 1970 at Station 1 (upper), 1976 at Station 2 (middle), and 1976 at Station 3 (lower).



WATER CLARITY

Since the early 1970's, water clarity at all three basins of Kezar Lake has improved with the upper and middle basins improving by nearly 1 meter. The slight, but statistically significant, improvement at the lower basin is an artifact of changing lake depth since nearly all readings hit bottom.

↗ ↗ ↗

TOTAL PHOSPHORUS

Since the late 1970's, total phosphorus at all three basins of Kezar Lake has revealed no statistically significant trend over time. The generally higher median annual total phosphorus observed at the lower basin is an artifact of its shallow depth, where wave action can disturb bottom sediments that release phosphorus into the water column.

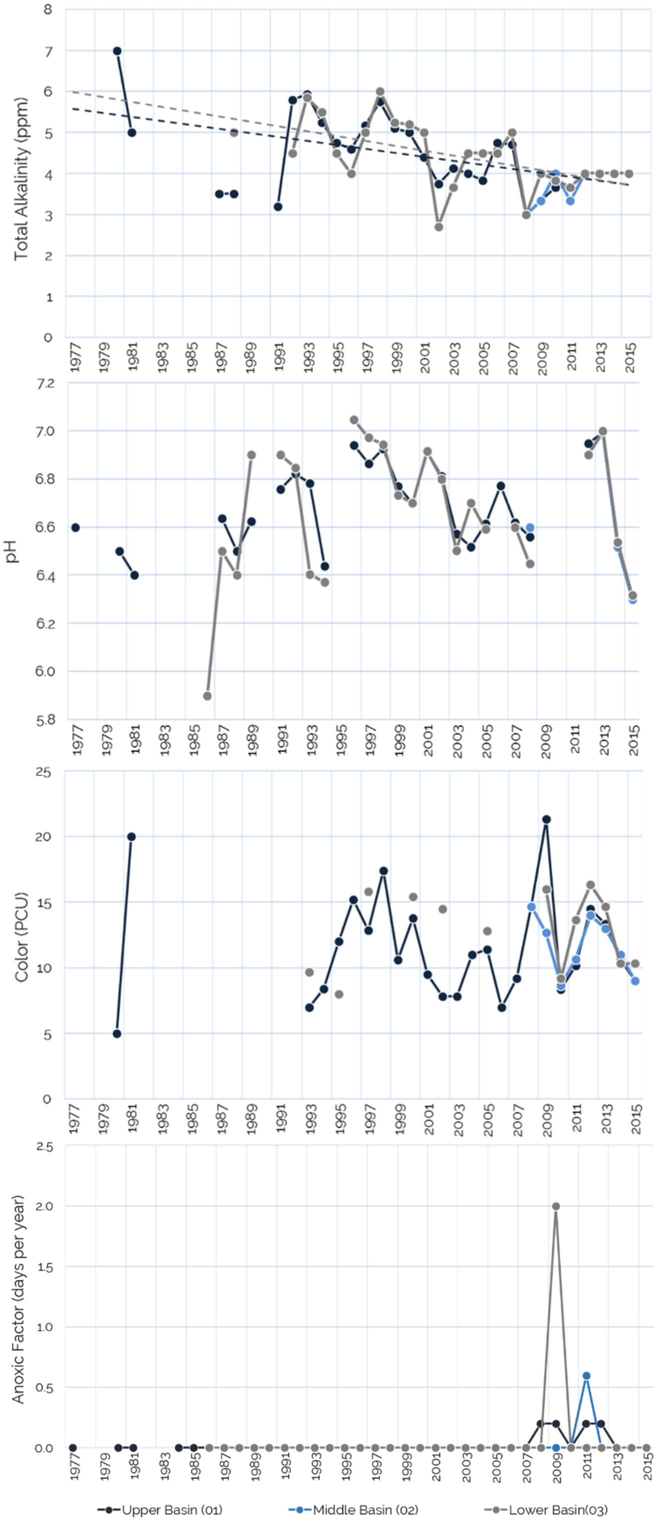
→ → →

CHLOROPHYLL-A

Since the late 1970's, chlorophyll-a at all three basins of Kezar Lake has revealed no statistically significant trend over time. The period from 1994 to 1999 saw a marked rise in chlorophyll-a at the upper basin, but chlorophyll-a has remained below 3 ppb since then. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth.

→ ● →

KEZAR LAKE
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since the early 1980's, total alkalinity at the upper and lower basins of Kezar Lake has degraded by nearly 3 ppm. Total alkalinity fluctuates naturally from year-to-year in response to rain. Dry years generally show lower total alkalinity; wet years generally show higher total alkalinity. The degrading trend in alkalinity is despite the increase in precipitation observed in the last century, suggesting other processes are impacting the natural level of alkalinity in the lake.

↘ ● ↘

pH

Since the early 1980's, pH at all three basins of Kezar Lake has revealed no statistically significant trend over time. Generally, pH becomes more acidic as total alkalinity in the epilimnion declines. Low alkalinity makes Kezar Lake susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

→ ● →

COLOR

Since the early 1980's, color at all three basins of Kezar Lake has revealed no statistically significant trend over time. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake. The stable trend in color is despite the increase in precipitation observed in the last century, suggesting that more data are needed to confirm the trend.

→ ● →

ANOXIC FACTOR

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, which is typical of unproductive, oligotrophic lakes. While the extent and duration of anoxia (anoxic factor) is excellent at all three basins, the upper basin shows a statistically-significant (but very slight) increase in anoxia within a meter of the bottom. This should continue to be monitored closely in the future.

↘ → →

LOWER BAY
WATER QUALITY TRENDS

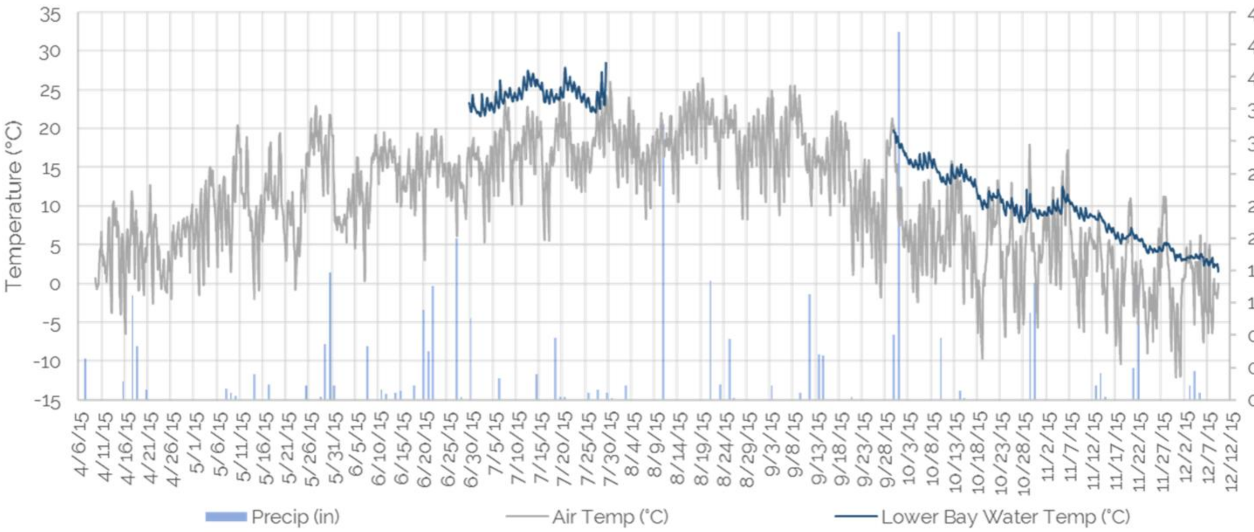
The lower bay is the southernmost basin of Kezar Lake. The stilling well was deployed on Heinrich Wurm's property along the western rocky shoreline of the lake. Water quality monitoring data have been collected since 2015.

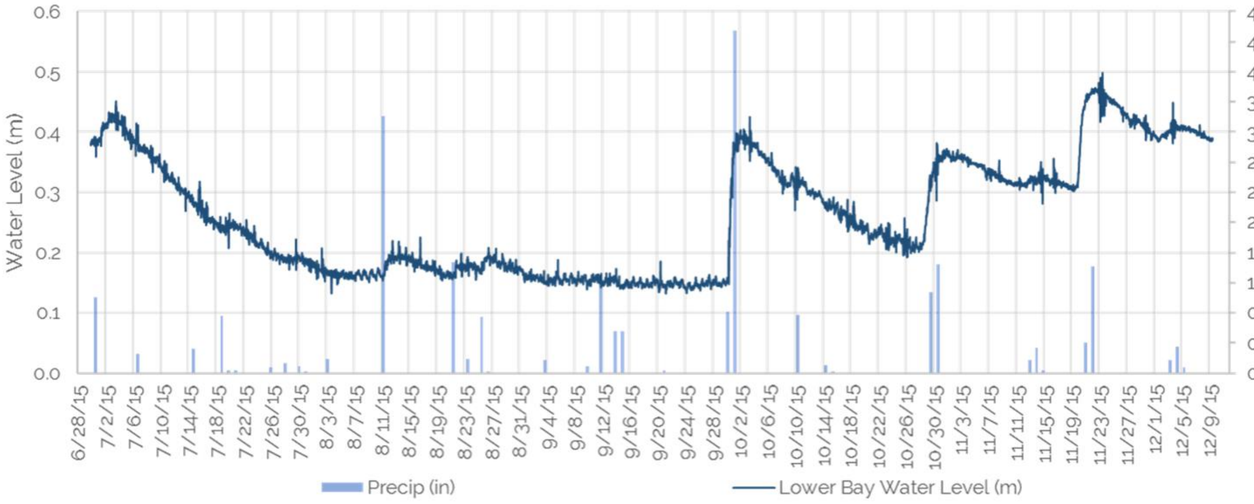
WATER TEMPERATURE

Water temperature steadily declined at the lower bay until retrieval in December, following closely with observed air temperature.

LAKE SURFACE WATER HEIGHT

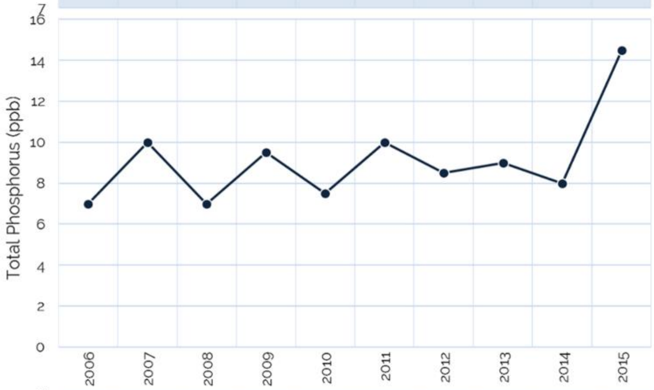
Water level data collected at the lower bay showed that lake level steadily declines from June to September due to evaporation and then responds quickly (by rising) to large precipitation events in the fall.





BRADLEY POND
WATER QUALITY TRENDS

Bradley Pond (Midas #3220) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 35 acres (0.05 square miles) with a maximum and mean depth of 29 and 10 feet (9 and 3 meters), respectively, the pond drains to Heald Pond, which in turn drains to a tributary to Boulder Brook and eventually Kezar Lake. Water quality monitoring data have been collected since 2006 at Station 1 (deep spot).



WATER CLARITY

Since 2006, water clarity at Bradley Pond has generally remained stable.

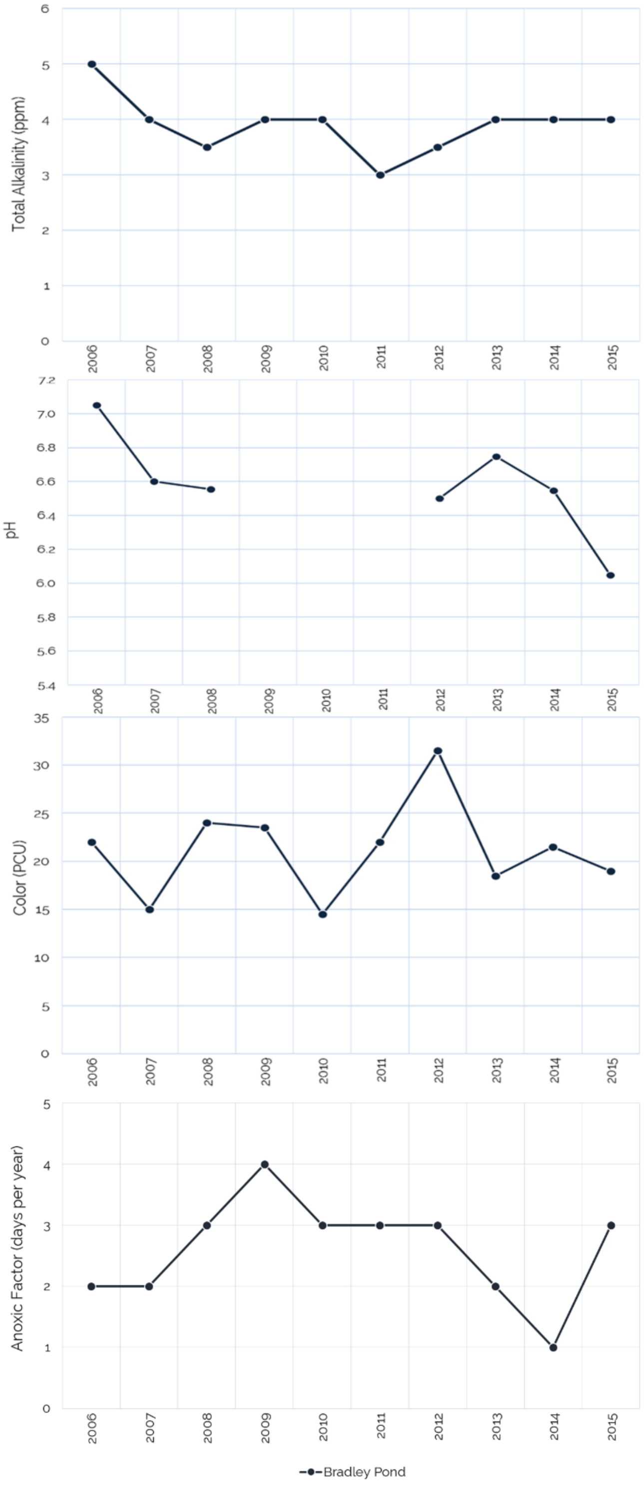
TOTAL PHOSPHORUS

Since 2006, total phosphorus at Bradley Pond has generally remained stable with the exception of 2015, which had an unusually high median of 14.5 ppb. Cause is unknown, but it is possible that the sample may have mixed with disturbed bottom sediments during the spring sampling.

CHLOROPHYLL-A

Since 2006, chlorophyll-a at Bradley Pond has ranged from about 2 to 6 ppb. The period from 2011 to 2012 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth.

BRADLEY POND
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since 2006, total alkalinity at Bradley Pond has generally remained stable. Bradley Pond has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e. granite) that lacks carbonates, bicarbonates, and carbonic acid. These low concentrations make Bradley Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

➔

pH

Minimal pH data are available for Bradley Pond to make any conclusions about long-term trends, but mean annual pH falls within acceptable ranges for aquatic life. 2015 shows a significant drop in pH to 6.0.

●

COLOR

Since 2006, color at Bradley Pond has generally remained stable. High color was observed for 2012, likely due to the wet summer conditions. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape and into the lake.

➔

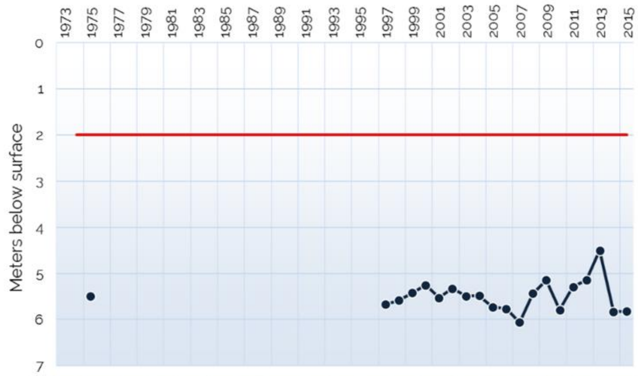
ANOXIC FACTOR

Dissolved oxygen profiles show oxygen depletion beginning 5-6 meters below the water surface, which is typical of more productive ponds. The extent and duration of anoxia (anoxic factor) is overall good at Bradley Pond. Dissolved oxygen at depth should continue to be monitored closely in the future.

➔

CUSHMAN POND
WATER QUALITY TRENDS

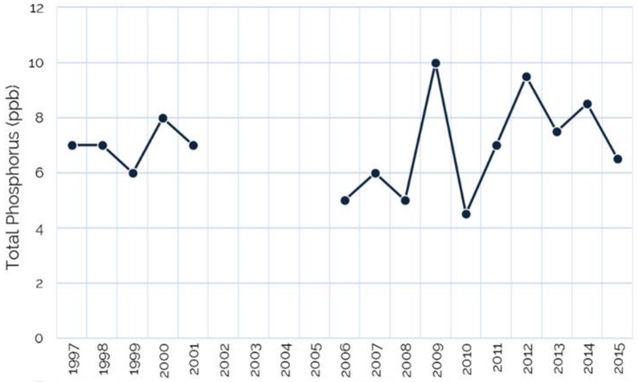
Cushman Pond (Midas #3224) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 37 acres (0.06 square miles) with a maximum and mean depth of 21 and 15 feet (6 and 5 meters), respectively, the pond drains to Heald Pond, which in turn drains to a tributary to Boulder Brook and eventually Kezar Lake. Cushman Pond is impacted by Variable Milfoil, which poses a threat to fish habitat. Water quality monitoring data have been collected since 1997 at Station 1 (deep spot).



WATER CLARITY

Water clarity at Cushman Pond has remained stable with no statistically significant trend.

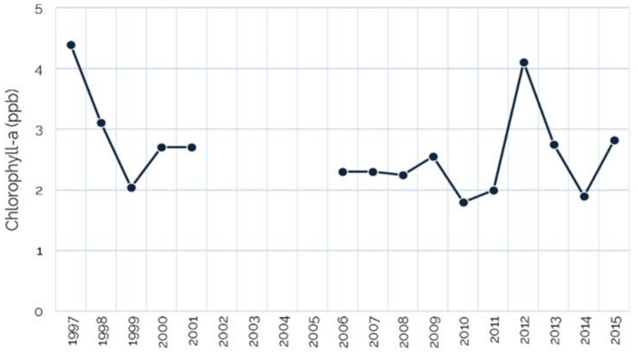
➡



TOTAL PHOSPHORUS

Since 1997, total phosphorus at Cushman Pond has remained stable with no statistically significant trend. Year-to-year variation in total phosphorus (4 to 10 ppb) is fairly large at Cushman Pond.

➡

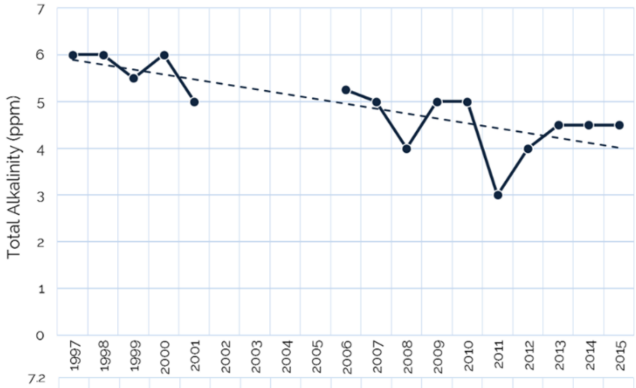


CHLOROPHYLL-A

Since 1997, chlorophyll-a at Cushman Pond has remained stable with no statistically significant trend. Sampling years 1997 and 2012 saw a rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth.

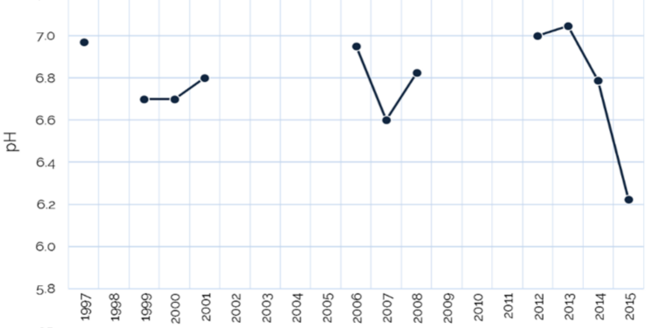
➡

CUSHMAN POND
WATER QUALITY TRENDS



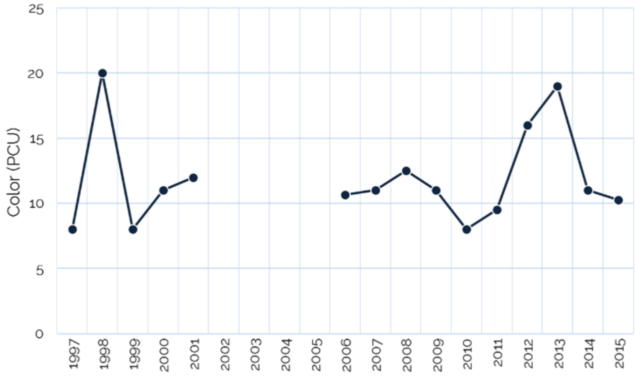
TOTAL ALKALINITY

Since 1997, total alkalinity at Cushman Pond has degraded by about 2 ppm. The degrading trend in alkalinity is despite the increase in precipitation observed in the last century, suggesting other processes are impacting the natural level of alkalinity in the pond.



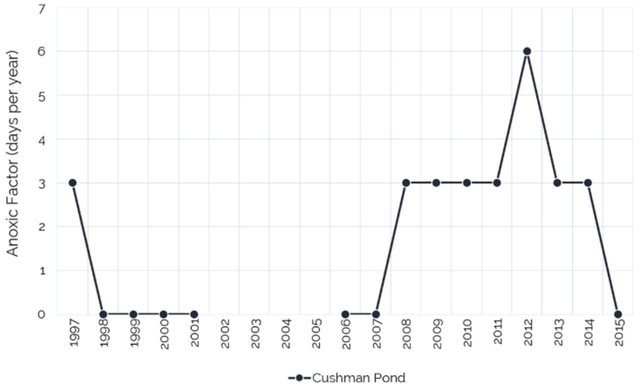
pH

Since 1997, pH at Cushman Pond has revealed no statistically significant trend over time. Mean annual pH falls within acceptable ranges for aquatic life. More consistent data are needed to confirm long-term trends. Low alkalinity makes Cushman Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since 1997, color at Cushman Pond has remained stable with no statistically significant trend. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake.

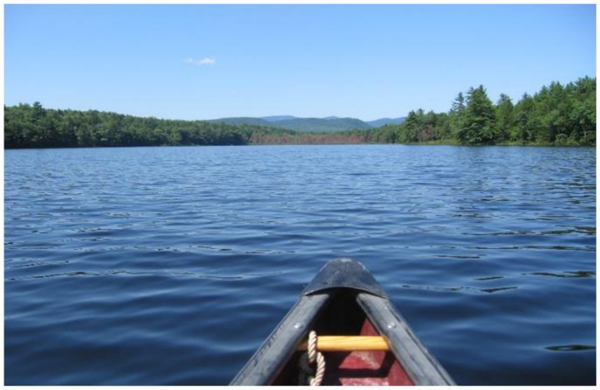


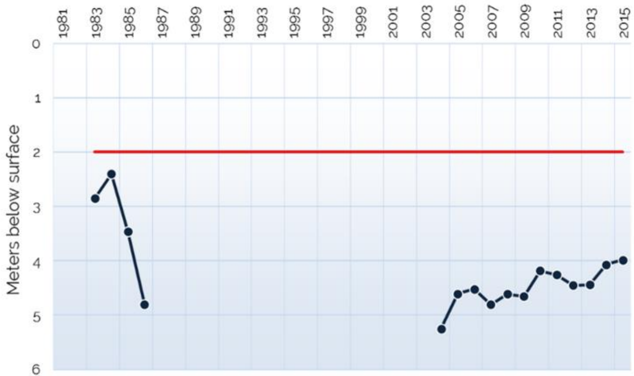
ANOXIC FACTOR

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent and duration of anoxia (anoxic factor) is overall good. Cushman Pond showed a statistically-significant increase in anoxia through 2014, but the addition of the 2015 data shows an improvement in the pond's anoxic factor. The pond now has a stable anoxic factor over the entire record. Dissolved oxygen at depth should continue to be monitored closely in the future.

FARRINGTON POND
WATER QUALITY TRENDS

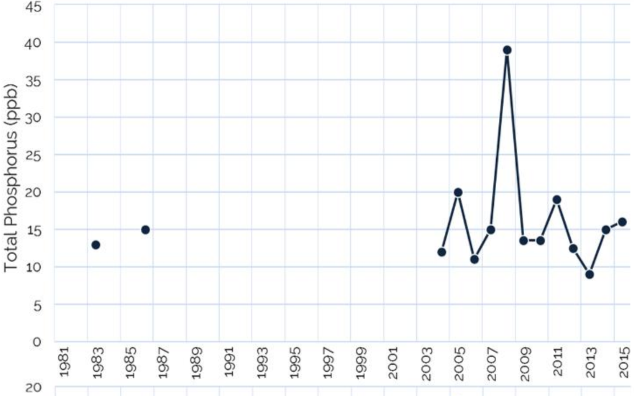
Farrington Pond (Midas #3200) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 57 acres (0.09 square miles) with a maximum and mean depth of 15 and 5 feet (5 and 2 meters), respectively, the pond drains directly to Kezar Lake. Water quality monitoring data have been collected since 1983 at Station 1 (deep spot).





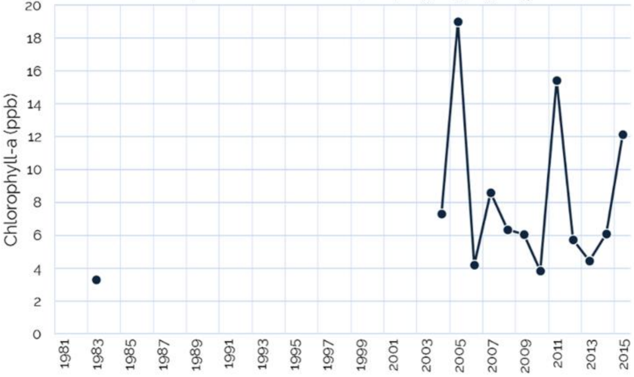
WATER CLARITY

Since 1983, water clarity at Farrington Pond has revealed no statistically significant trend, but data collected since 2004 show a steady degradation in water clarity by more than 1 meter.



TOTAL PHOSPHORUS

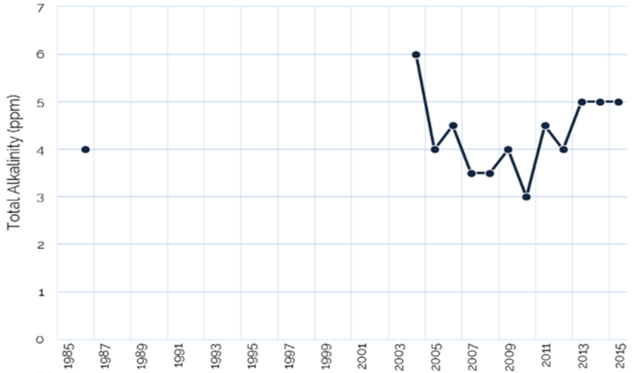
Since 1983, total phosphorus at Farrington Pond has remained stable with no statistically significant trend. Year-to-year variation in total phosphorus (10 to 40 ppb) is large at Farrington Pond, which also has the highest mean annual total phosphorus of all the ponds. The marked rise in total phosphorus observed in 2008 reflects nutrient-laden sediment in runoff entering the lake during this very wet year. Farrington Pond is highly susceptible to internal loading of phosphorus due to its shallow depth, where disturbance of bottom sediments can release phosphorus into the water column.



CHLOROPHYLL-A

Since 1983, chlorophyll-a at Farrington Pond has remained stable with no statistically significant trend, but experienced the highest concentration of chlorophyll-a of the other ponds. Sampling years 2005 and 2011 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth. Chlorophyll-a generally increased with increasing total phosphorus.

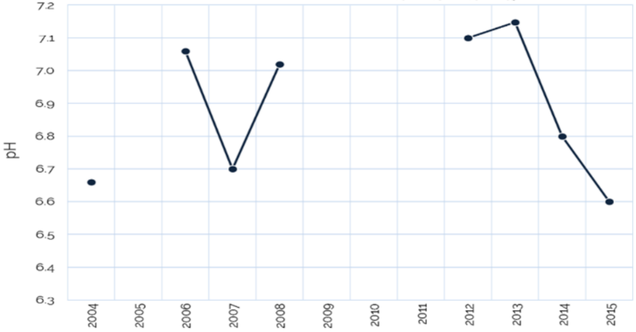
FARRINGTON POND
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since 1986, total alkalinity at Farrington Pond has remained stable with no statistically significant trend, unlike the other ponds that largely show degrading trends. Farrington Pond has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid.

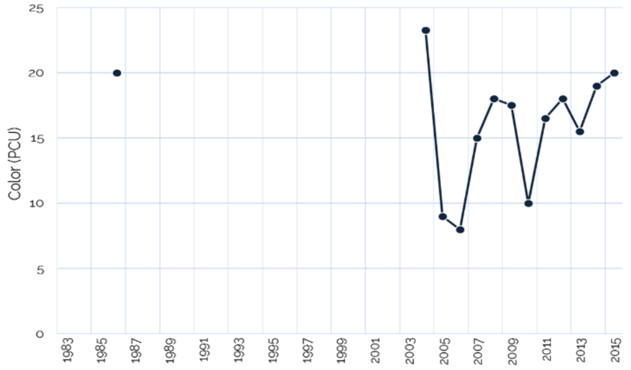
➔



pH

Minimal pH data are available for Farrington Pond to make any conclusions about long-term trends, but mean annual pH falls within acceptable ranges for aquatic life. Low alkalinity makes Farrington Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

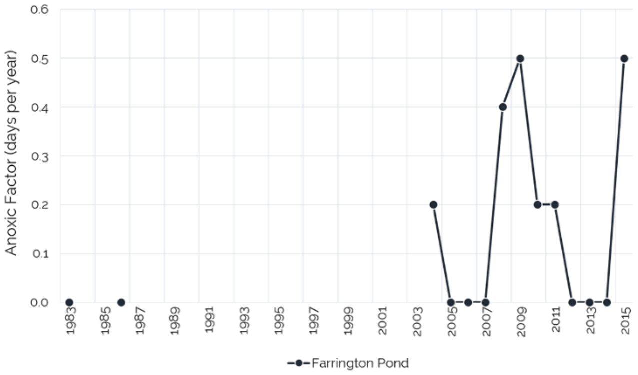
●



COLOR

Since 1983, color at Farrington Pond has revealed no statistically significant trend, though year-to-year variation is large (8 to 23 PCU). Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake.

➔



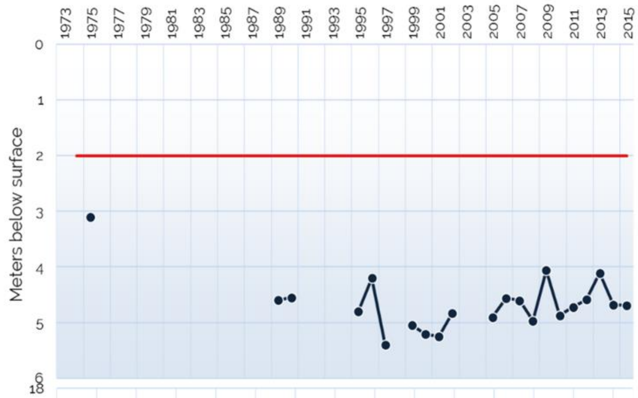
ANOXIC FACTOR

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent and duration of anoxia (anoxic factor) is overall excellent at Farrington Pond and shows no statistically-significant trend. However, dissolved oxygen at depth should continue to be monitored closely in the future.

➔

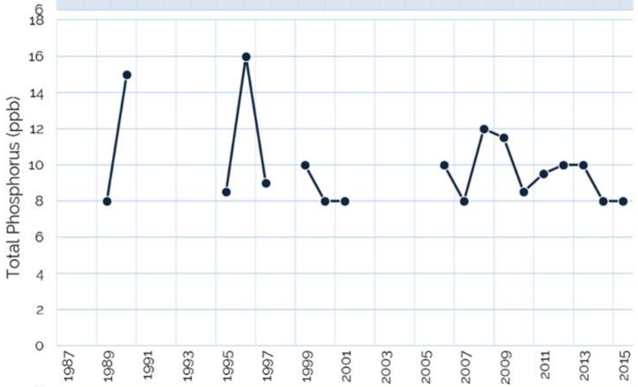
HEALD POND
WATER QUALITY TRENDS

Heald Pond (Midas #3222) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 106 acres (0.17 square miles) with a maximum depth of 17 feet (5 meters), the pond drains directly to Kezar Lake through a tributary to Boulder Brook. Water quality monitoring data have been collected since 1975 at Station 1 (deep spot).



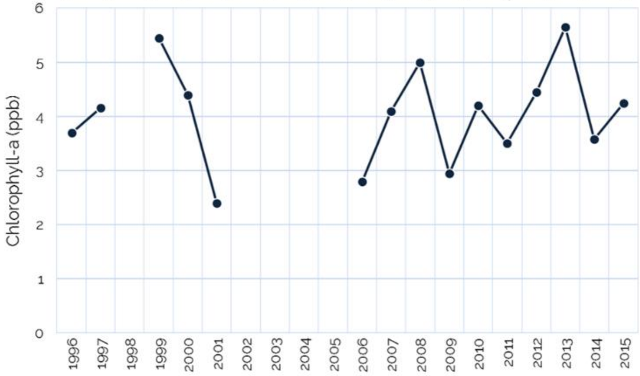
WATER CLARITY

Since 1975, water clarity at Heald Pond has remained stable with no statistically significant trend, but data collected since 2000 show a steady degradation in water clarity by nearly 1 meter.



TOTAL PHOSPHORUS

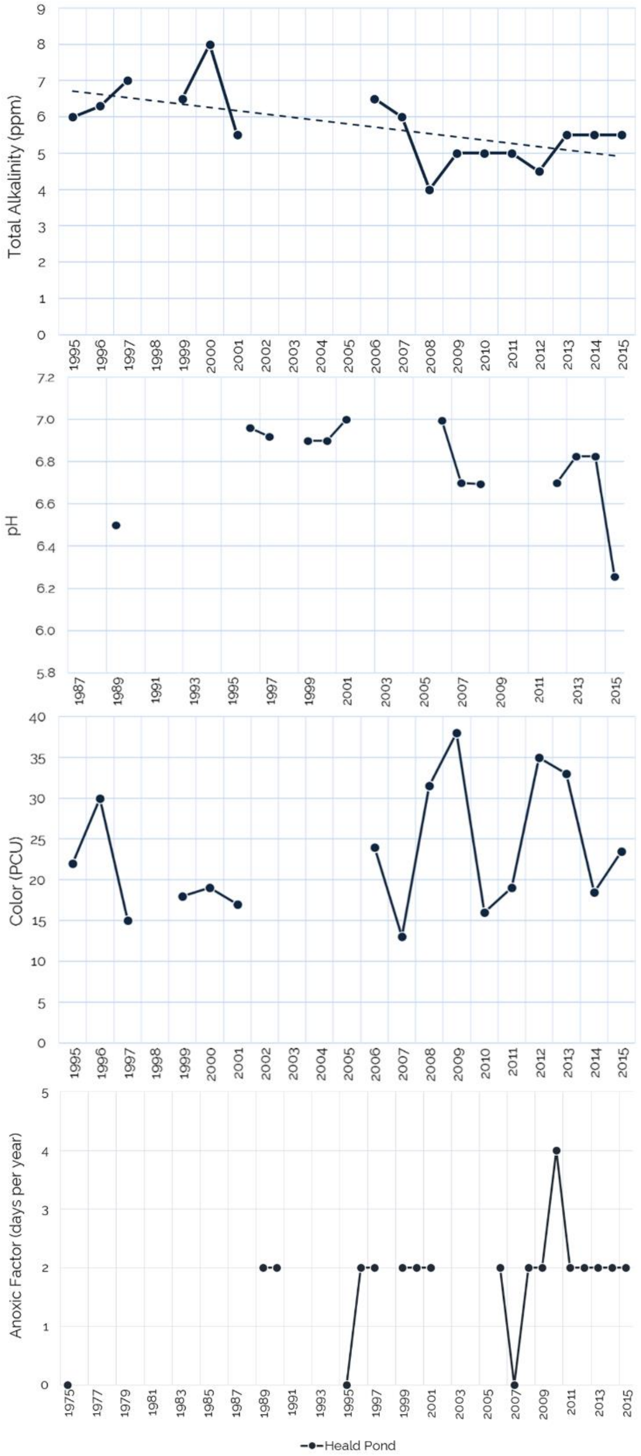
Since 1989, total phosphorus at Heald Pond has remained stable with no statistically significant trend. Higher phosphorus generally corresponds to wetter years at Heald Pond. Sediment in runoff entering the pond during rain events carries limiting nutrients. Heald Pond is highly susceptible to internal loading of phosphorus due to its shallow depth, where disturbance of bottom sediments can release phosphorus into the water column.



CHLOROPHYLL-A

Since 1996, chlorophyll-a at Heald Pond has remained stable with no statistically significant trend. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth.

HEALD POND
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since 1995, total alkalinity at Heald Pond has degraded by nearly 2 ppm. Total alkalinity fluctuates naturally from year-to-year in response to rain. Dry years generally show lower total alkalinity; wet years generally show higher total alkalinity. The degrading trend in alkalinity is despite the increase in precipitation observed in the last century, suggesting other processes are impacting the natural level of alkalinity in the pond.

pH

Since 1989, pH at Heald Pond has revealed no statistically significant trend over time. Mean annual pH falls within acceptable ranges for aquatic life. More consistent data are needed to confirm long-term trends. Low alkalinity make Heald Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

COLOR

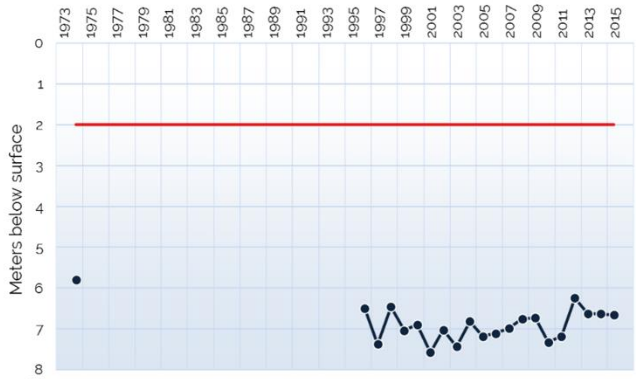
Since 1995, color at Heald Pond has remained stable with no statistically significant trend, but consistently experienced the highest color compared to the other ponds. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake.

ANOXIC FACTOR

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent and duration of anoxia (anoxic factor) is overall good at Heald Pond and shows no statistically-significant trend. However, dissolved oxygen at depth should continue to be monitored closely in the future.

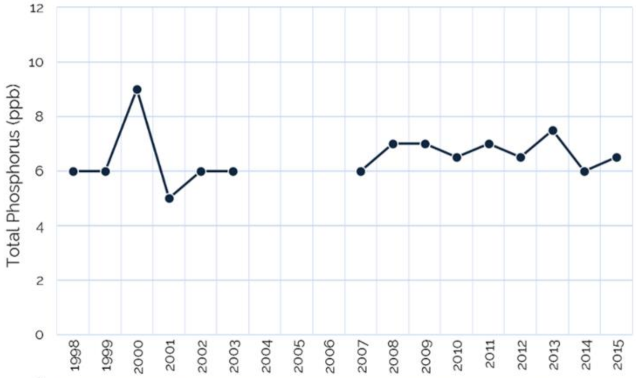
HORSESHOE POND
WATER QUALITY TRENDS

Horseshoe Pond (Midas #3196) is a non-colored waterbody located in the Town of Lovell and Stoneham, Oxford County, Maine. Covering 136 acres (0.20 square miles) with a maximum and mean depth of 40 and 12 feet (12 and 4 meters), the pond drains to Moose Pond, which in turn drains directly to Kezar Lake. Water quality monitoring data have been collected since 1974 at Station 1 (deep spot).



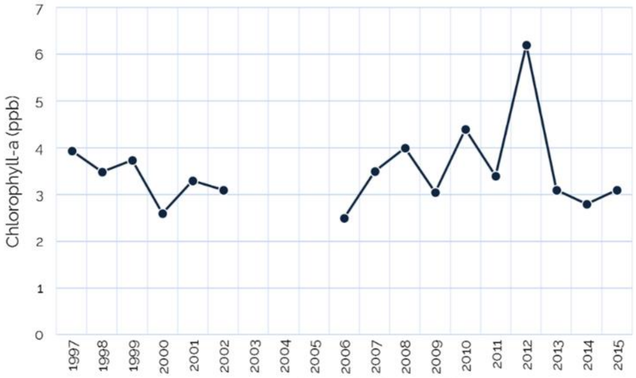
WATER CLARITY

Since 1974, water clarity at Horseshoe Pond has remained stable with no statistically significant trend.



TOTAL PHOSPHORUS

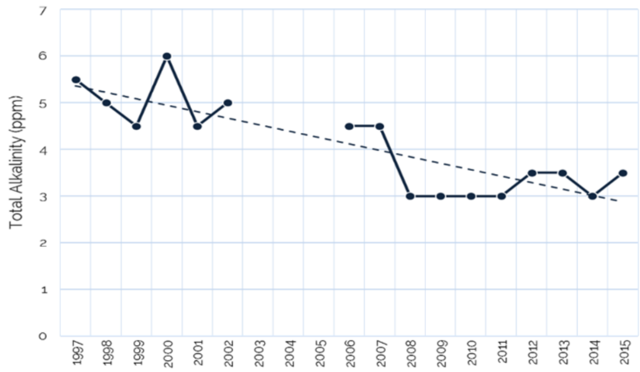
Since 1998, total phosphorus at Horseshoe Pond has remained stable with no statistically significant trend. Horseshoe Pond experiences consistently low phosphorus compared to the other ponds.



CHLOROPHYLL-A

Since 1997, chlorophyll-a at Horseshoe Pond has remained stable with no statistically significant trend. Sampling year 2012 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algal growth.

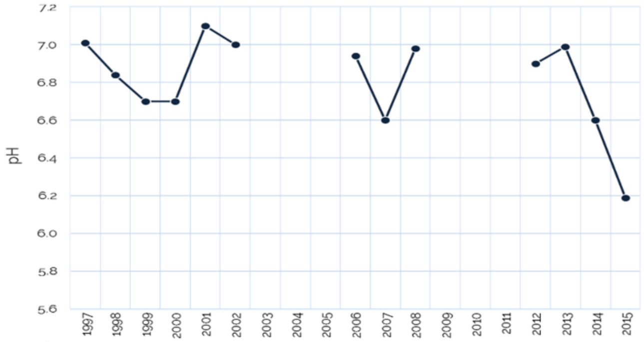
HORSESHOE POND
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since 1997, total alkalinity at Horseshoe Pond has degraded by more than 2 ppm. Total alkalinity fluctuates naturally from year-to-year in response to rain. Dry years generally show lower total alkalinity; wet years generally show higher total alkalinity. The degrading trend in alkalinity is despite the increase in precipitation observed in the last century, suggesting other processes are impacting the natural level of alkalinity in the pond.

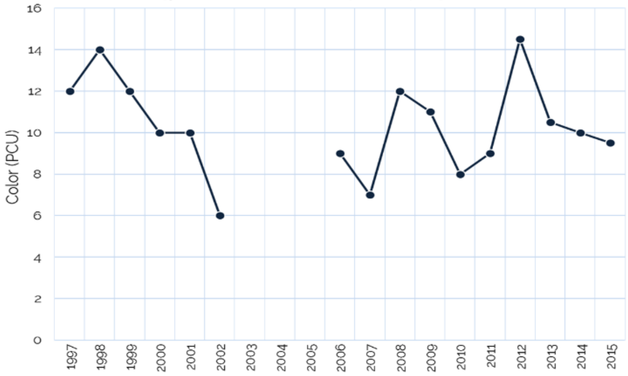
↘



pH

Since 1997, pH at Horseshoe Pond has revealed no statistically significant trend over time. Mean annual pH falls within acceptable ranges for aquatic life. Low alkalinity makes Horseshoe Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

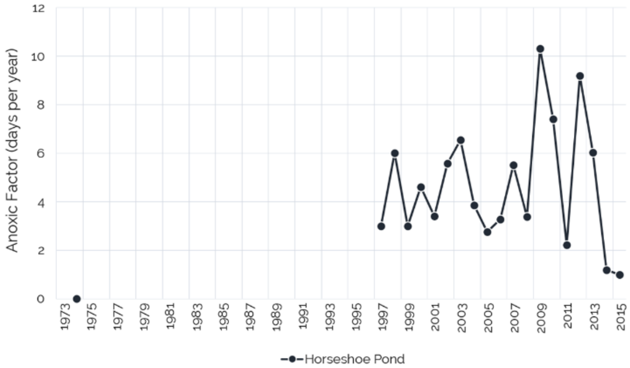
→



COLOR

Since 1997, color at Horseshoe Pond has remained stable with no statistically significant trend. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the pond.

→



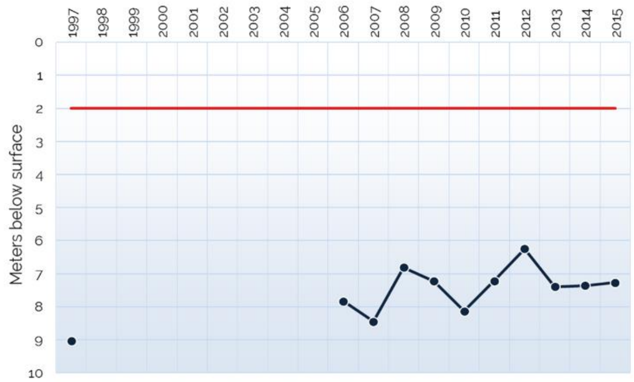
ANOXIC FACTOR

Dissolved oxygen profiles show oxygen depletion from 8 to 12 meters below the water surface in late summer. The extent and duration of anoxia (anoxic factor) is overall poor at Horseshoe Pond and shows no statistically-significant trend. Dissolved oxygen at depth should continue to be monitored closely in the future.

→

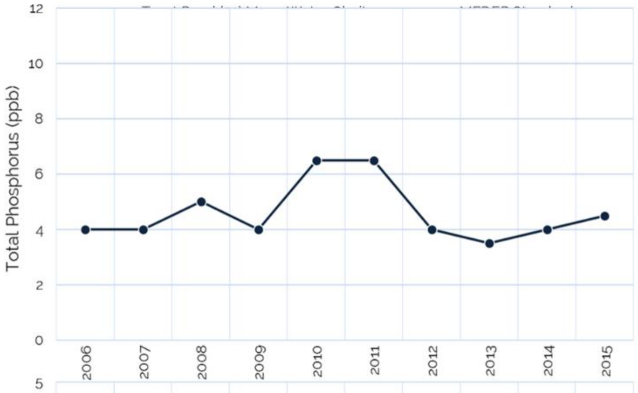
TROUT POND
WATER QUALITY TRENDS

Trout Pond (Midas #3212) is a non-colored waterbody located in the Town of Stoneham, Oxford County, Maine. Covering 64 acres (0.10 square miles) with a maximum and mean depth of 68 and 27 feet (21 and 8 meters), respectively, the pond drains to Cushman Pond, which in turn drains to Heald Pond, then to a tributary to Boulder Brook and eventually Kezar Lake. Water quality monitoring data have been collected since 1997 at Station 1 (deep spot).



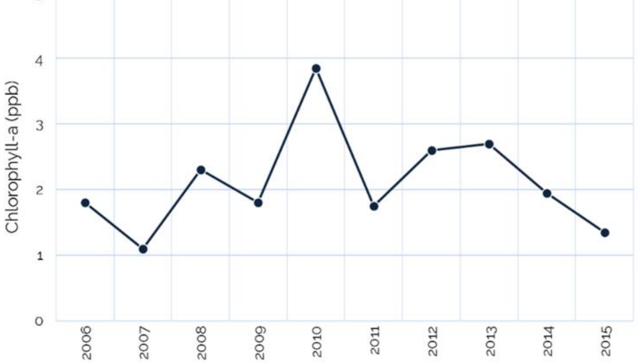
WATER CLARITY

Since 1997, water clarity at Trout Pond has remained stable with no statistically significant trend, though there appears to be a steady degradation in water clarity of nearly 1 meter.



TOTAL PHOSPHORUS

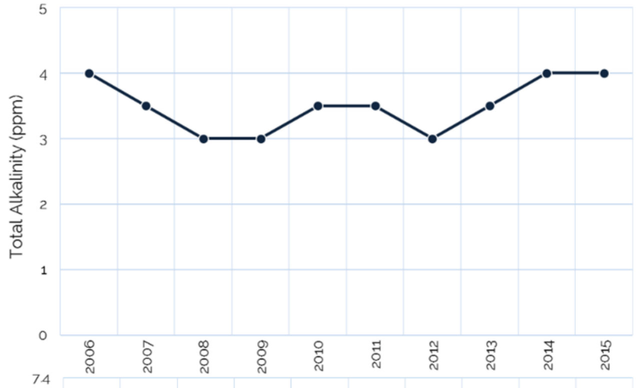
Since 2006, total phosphorus at Trout Pond has generally remained stable.



CHLOROPHYLL-A

Since 2006, chlorophyll-a at Trout Pond has ranged from about 1 to 4 ppb. Trout Pond experiences the lowest concentration of chlorophyll-a compared to the other ponds.

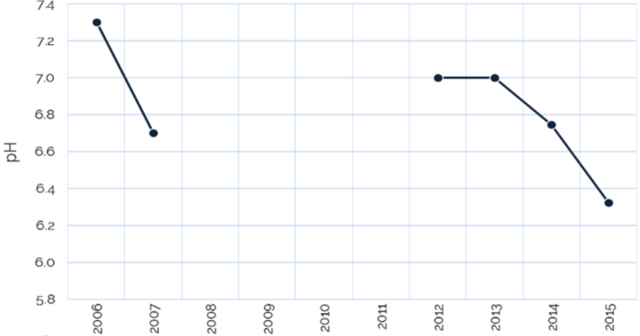
TROUT POND
WATER QUALITY TRENDS



TOTAL ALKALINITY

Since 2006, total alkalinity at Trout Pond has generally remained stable. Trout Pond has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid.

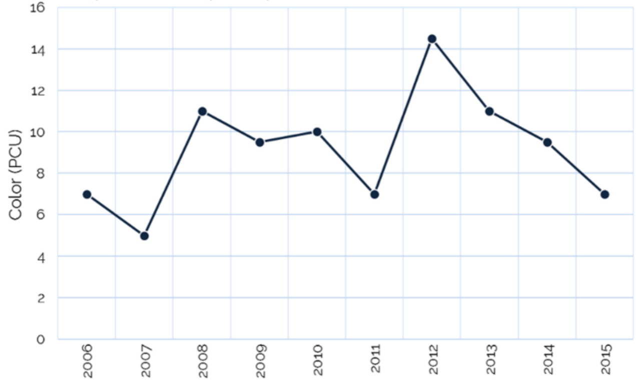
➡



pH

Minimal pH data are available for Trout Pond to make any conclusions about long-term trends, but mean annual pH falls within acceptable ranges for aquatic life. Low alkalinity makes Trout Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.

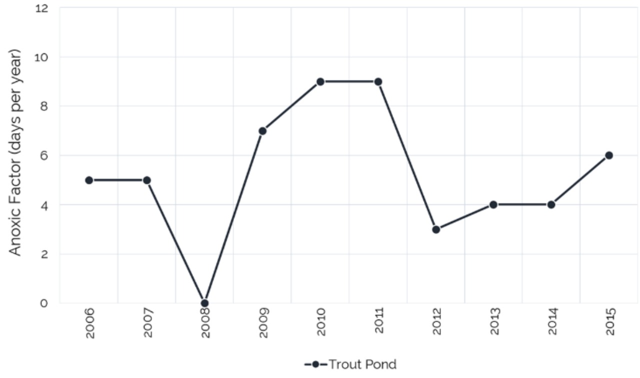
●



COLOR

Since 2006, color at Trout Pond has generally remained stable. High color was observed for 2012, likely due to the wet summer conditions. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the pond.

➡



ANOXIC FACTOR

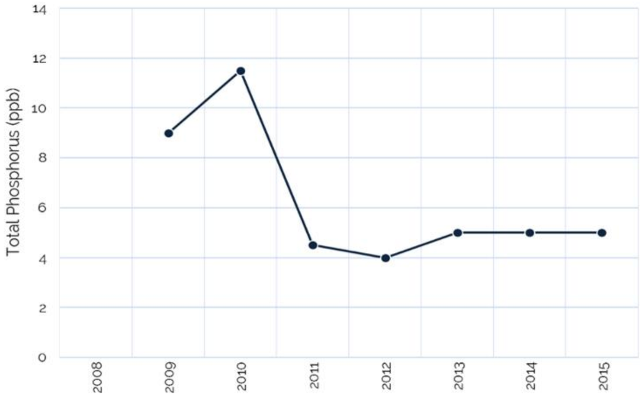
Dissolved oxygen profiles show oxygen depletion beginning 15 meters below the water surface. The extent and duration of anoxia (anoxic factor) is overall good at Trout Pond. Dissolved oxygen at depth should continue to be monitored closely in the future.

➡

GREAT BROOK

WATER QUALITY TRENDS

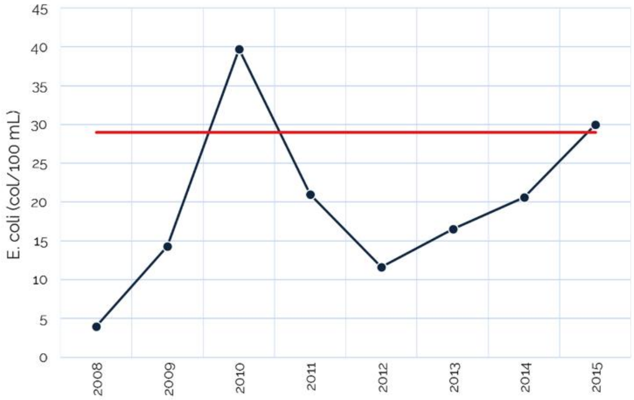
Great Brook is located on the northwest end of Kezar Lake off West Stoneham Road. Great Brook drains a large portion of the White Mountain National Forest. Water quality monitoring data have been collected since 2008.



TOTAL PHOSPHORUS

Since 2009, total phosphorus at Great Brook has remained below 12 ppb.

●



E. COLI

Since 2008, E. coli at Great Brook has been less than the Class A stream geometric mean of 29 col/100mL, with the exception of 2010 (39.7 col/100mL) and 2015 (30 col/100mL).

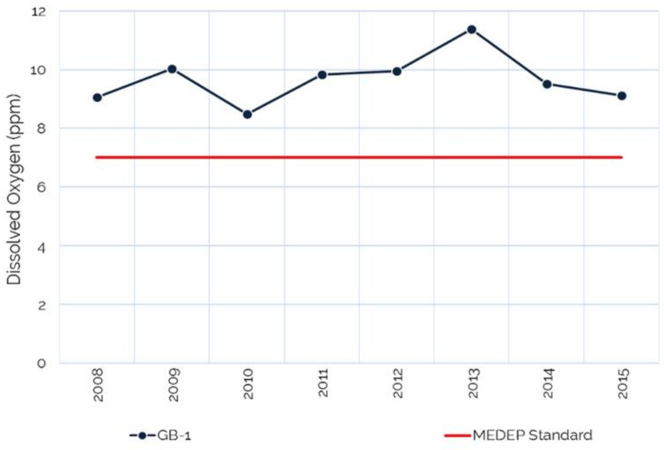
●

pH

Minimal pH data are available for Great Brook, but pH generally falls within the range suitable for aquatic life. In 2014 and 2015, Great Brook experienced pH below 6.5, the recommended lower limit for pH.

●

GREAT BROOK
WATER QUALITY TRENDS



DISSOLVED OXYGEN

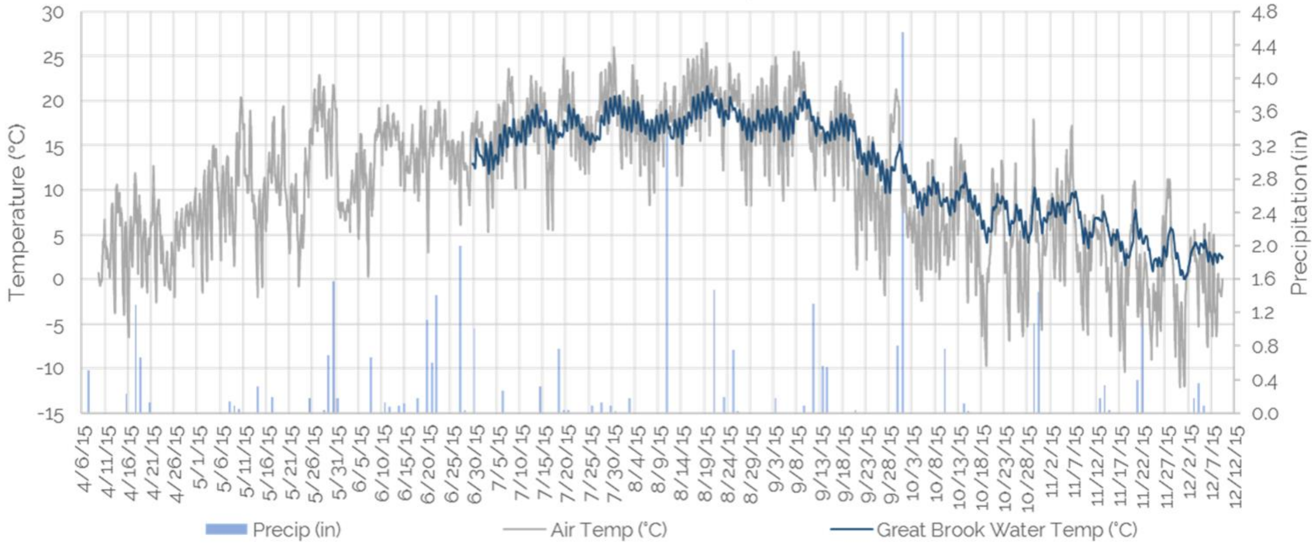
Dissolved oxygen at Great Brook remains above the Maine DEP standard of 7 ppm for Class A streams.

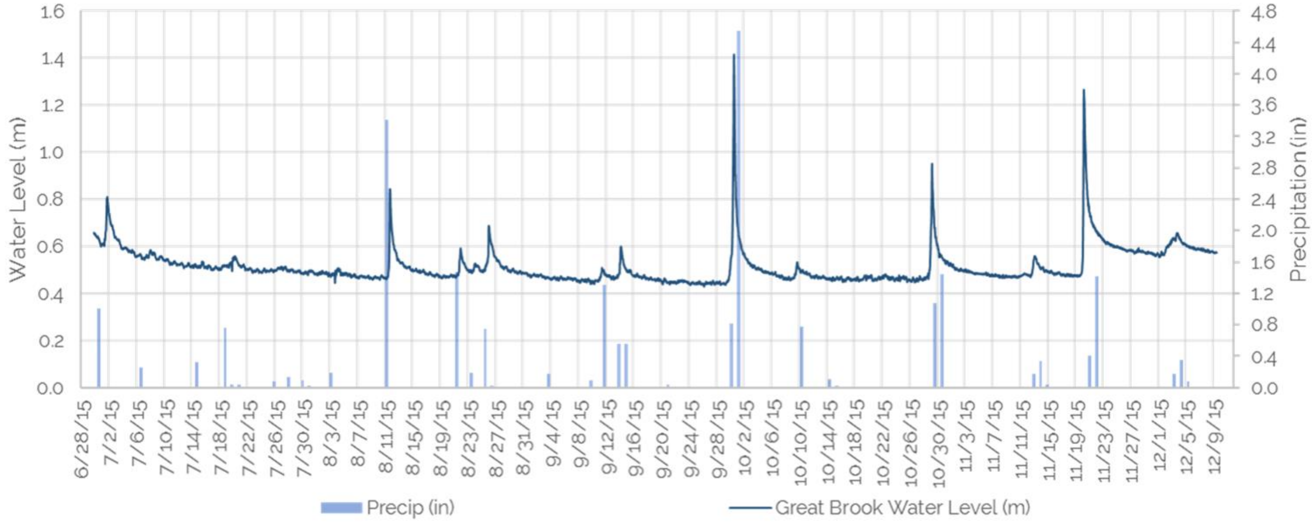
WATER TEMPERATURE

Water temperature increased at Great Brook from May to August and then steadily declined until retrieval in December, following closely with observed air temperature.

STREAM FLOW

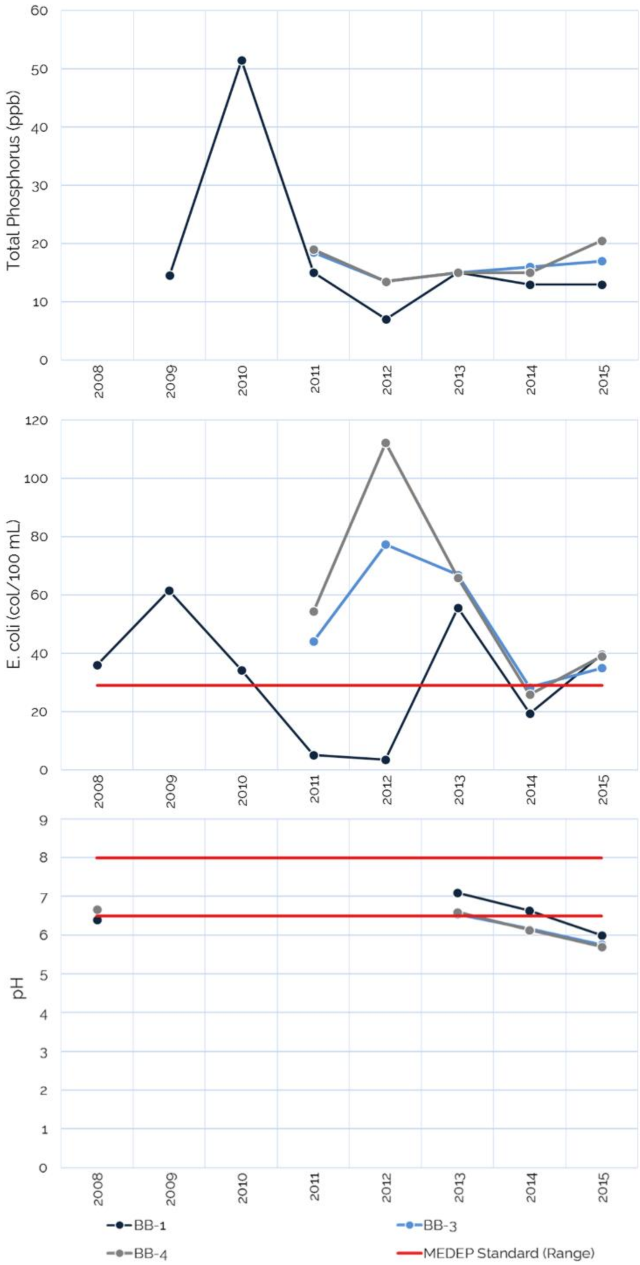
Water level data collected at Great Brook shows that the stream responds quickly to precipitation.





BOULDER BROOK
WATER QUALITY TRENDS

Boulder Brook drains an area that includes Bradley, Trout, Cushman, and Heald Ponds. Boulder Brook crosses under Route 5 north of Center Lovell, and flows past the Boulder Brook Club before entering the east side of Boulder Brook at the swimming area. Water quality monitoring data have been collected since 2008 at multiple stations (BB-1, BB-2, BB-3, and BB-4) along Boulder Brook.



TOTAL PHOSPHORUS

Since 2009, total phosphorus at Boulder Brook has generally remained below 20 ppb, with the exception of 2010 (51 ppb). Heavy rains may have washed excess phosphorus-laden sediment from the landscape into the stream.

E. COLI

Since 2008, E. coli at Boulder Brook has largely exceeded the Class A stream geometric mean of 29 col/100mL.

pH

Minimal pH data are available for Boulder Brook, but generally pH falls within the range suitable for aquatic life up until 2015 when both BB-3 and BB-4 experienced a pH of 5.7. Low pH (acidic) waters can threaten fish and other aquatic life. Optimal pH of 6.5-8.0 supports proper metabolic and reproductive functions.

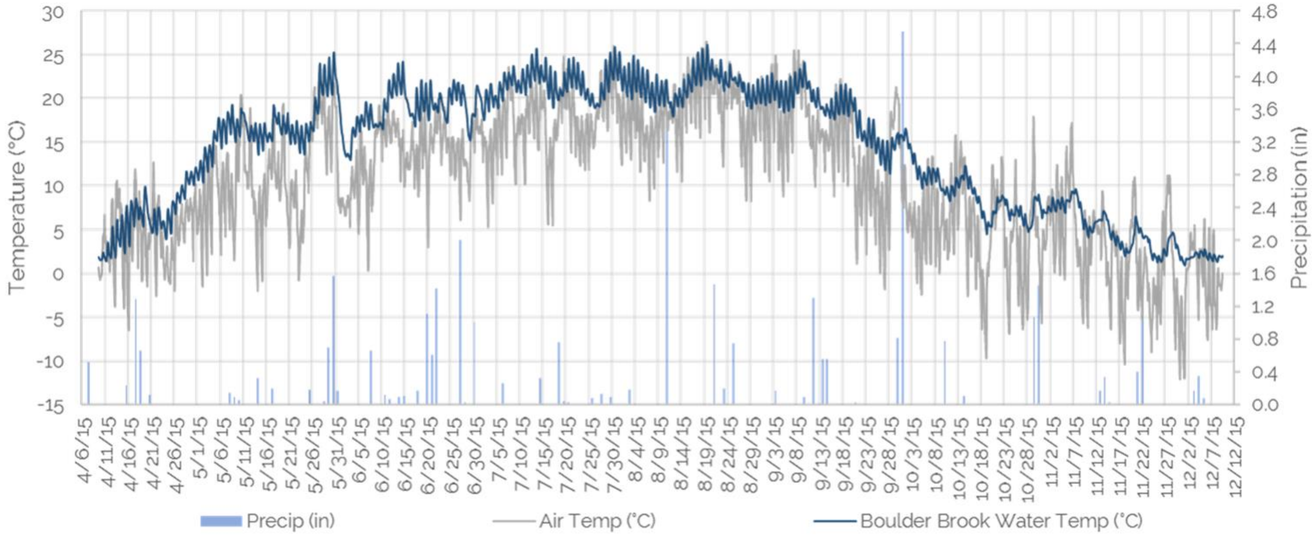
BOULDER BROOK
WATER QUALITY TRENDS

DISSOLVED OXYGEN

Dissolved oxygen at Boulder Brook generally remains above the Maine DEP standard of 7 ppm for Class A streams, with the exception of BB-4 (upstream of Rt. 5) in 2014 and BB-3 (downstream of Rt. 5) in 2015.

WATER TEMPERATURE

Water temperature increased at Boulder Brook from May to August and then steadily declined until retrieval in December, following closely with observed air temperature. Boulder Brook experienced some of the highest water temperatures compared to the other streams. July to August 2015 showed water temperatures above 24 °C, which may threaten coldwater fish species.



BEAVER BROOK
WATER QUALITY TRENDS

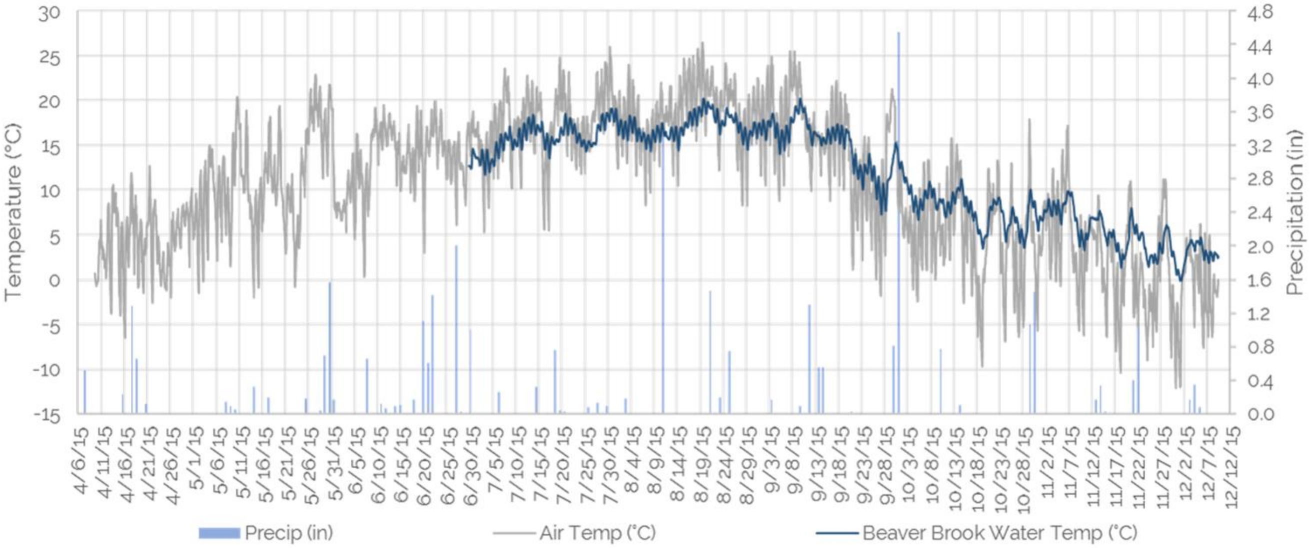
Beaver Brook is a major tributary to Great Brook, located on the northwest end of Kezar Lake off West Stoneham Road. Beaver Brook drains a portion of the White Mountain National Forest. Water quality monitoring data have been collected since 2014.

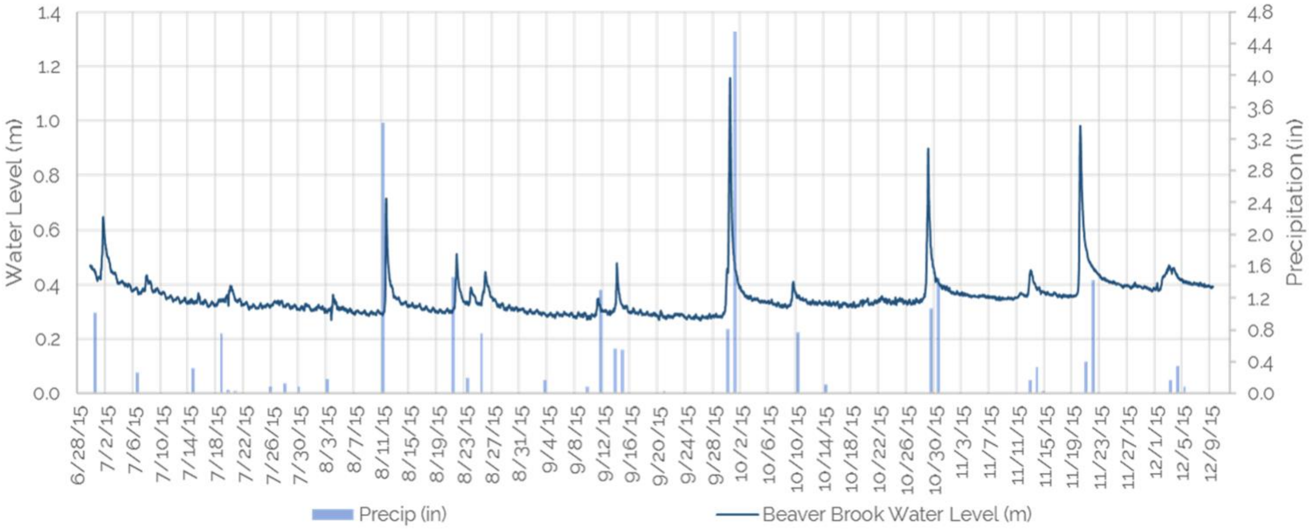
WATER TEMPERATURE

Water temperature increased at Beaver Brook from May to August and then steadily declined until retrieval in December, following closely with observed air temperature.

STREAM FLOW

Water level data collected at Beaver Brook shows that the stream responds quickly to precipitation.





KEZAR OUTLET STREAM
WATER QUALITY TRENDS

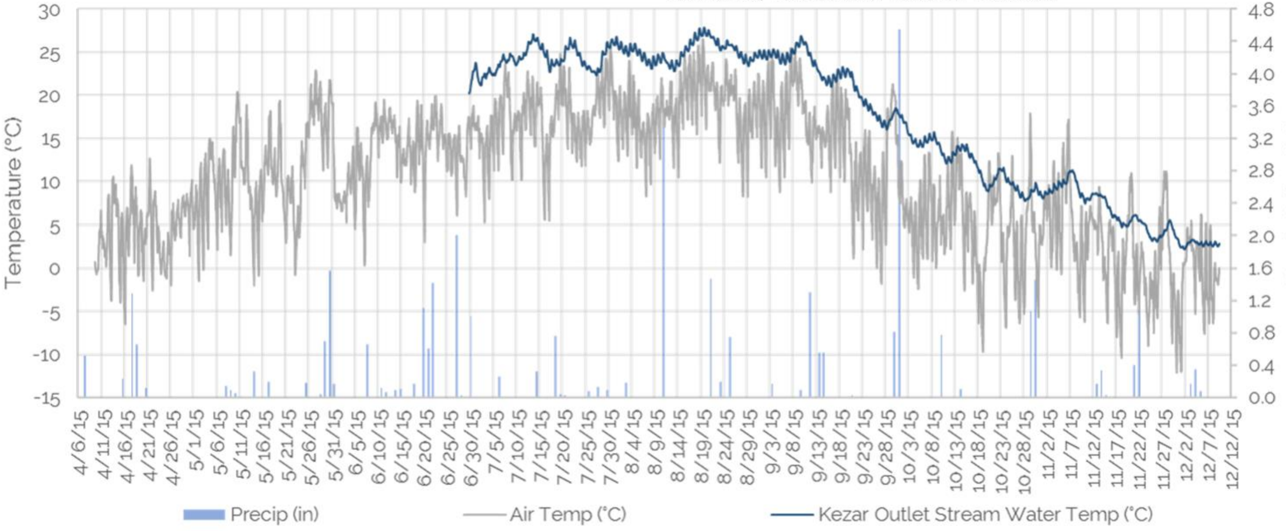
The Kezar Outlet Stream flows south from the lower bay of Kezar Lake. The stilling well was attached to an old fish dam structure just upstream of Harbor Road. Water quality monitoring data have been collected since 2015.

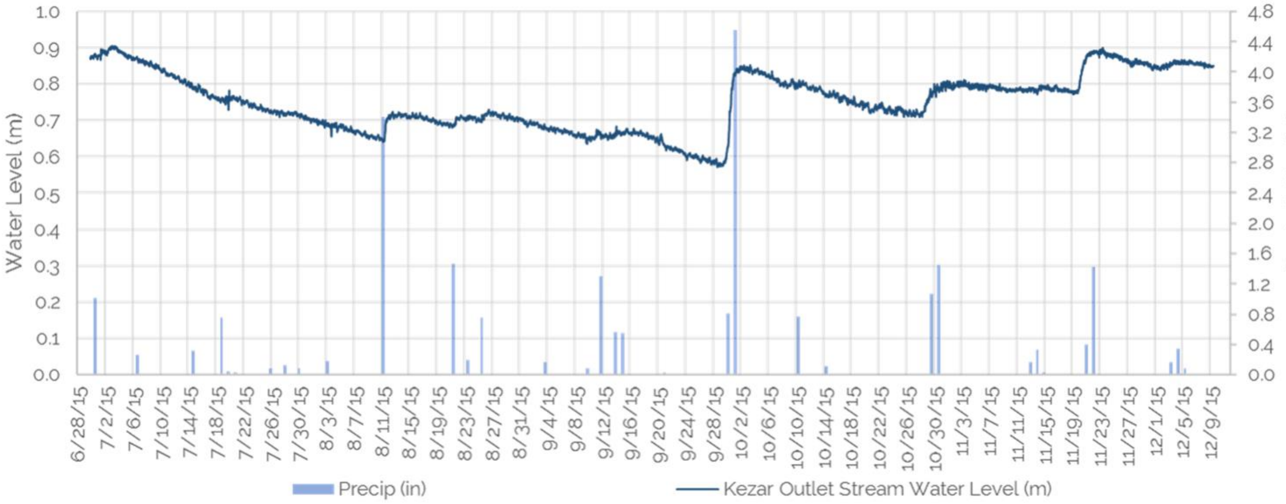
WATER TEMPERATURE

Water temperature increased at the Kezar Outlet Stream from June to September and then steadily declined until retrieval in December, following closely with observed air temperature.

STREAM FLOW

Water level data remained fairly consistent throughout the deployment. The large, but delayed volume of water flowing from the lake through the Kezar Outlet Stream allowed water level to increase and decrease much more gradually compared to the smaller headwater streams, Great and Beaver Brooks.



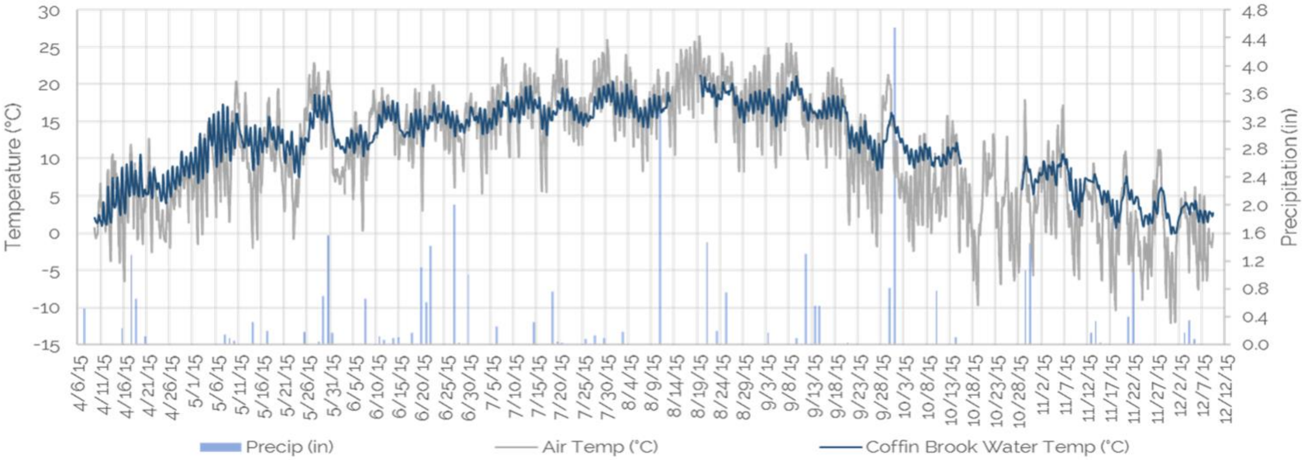


COFFIN BROOK
WATER QUALITY TRENDS

Coffin Brook drains to the eastern side of the upper basin of Kezar Lake, crossing Rt. 5 just south of West Stoneham Road. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature increased at Coffin Brook from May to August and then steadily declined until retrieval in December, tracking observed air temperatures closely.

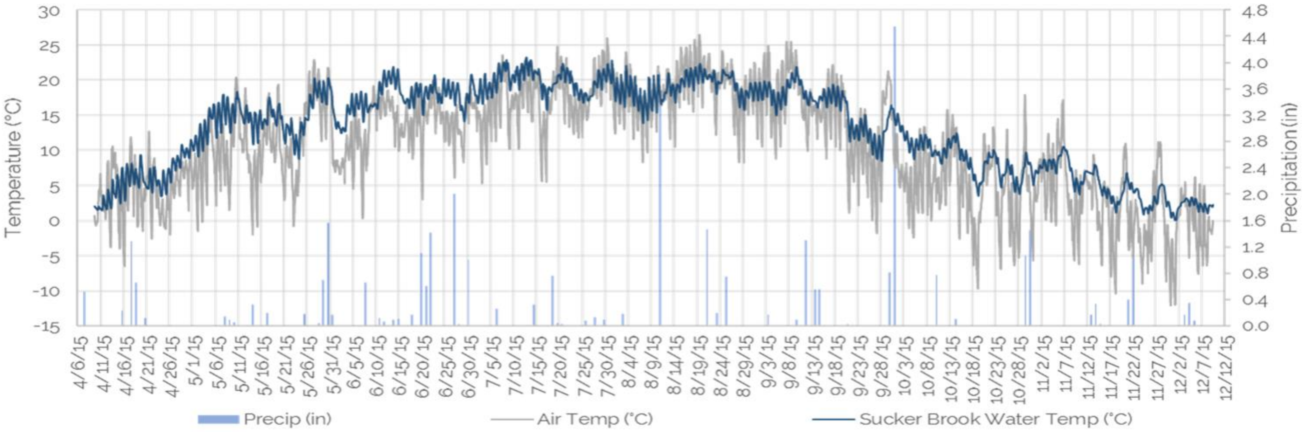


SUCKER BROOK
WATER QUALITY TRENDS

Sucker Brook begins is a tributary that begins at the outlet to Horseshoe Pond and drains to the western side of the lower basin of Kezar Lake after converging with Bradley Brook. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature increased at Sucker Brook from May to August and then steadily declined until retrieval in December, closely following observed air temperatures.



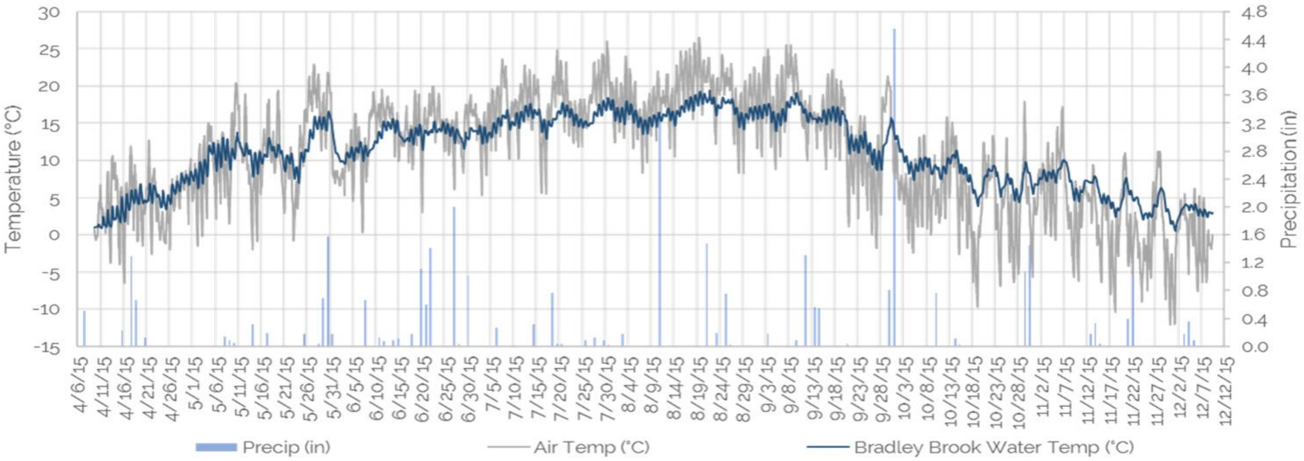
BRADLEY BROOK

WATER QUALITY TRENDS

Bradley Brook is a tributary that drains to the western side of the lower basin of Kezar Lake. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature increased at Bradley Brook from May to August and then steadily declined until retrieval in December, closely following observed air temperatures.



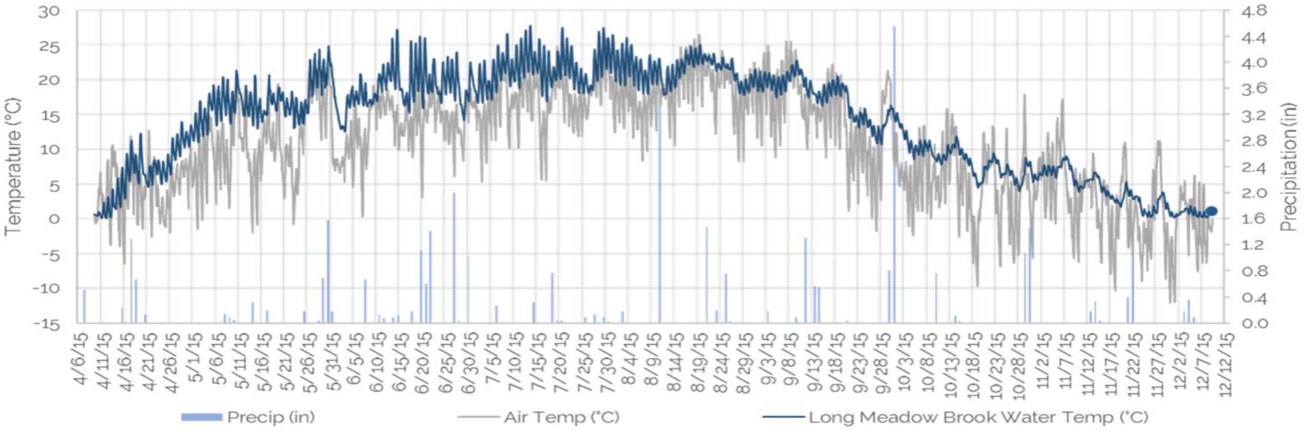
LONG MEADOW BROOK

WATER QUALITY TRENDS

Long Meadow Brook is a tributary that drains through a large wetland complex to the southwestern side of the lower basin of Kezar Lake. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature increased at from May to August and then steadily declined until retrieval, closely following observed air temperatures. June 2014 and July 2015 showed temperatures above 24°C, which may threaten coldwater fish species.



ADDITIONAL WATER TEMPERATURE MONITORING

In partnership with Prof. Daniel Buckley from the University of Maine at Farmington, KLWA participates in a high-resolution lake temperature monitoring study that uses Onset HOBO sensors to record water temperature in over 30 Maine lakes. These automated thermometers were installed to gather data on water temperature in each of the three lake basins and Horseshoe Pond. Through this collaboration, KLWA hopes to continue collecting water temperature data through automatic sampling techniques.

OTHER AQUATIC INDICATORS

Sediment Core Study

One of the most effective ways to understand the long-term effects of climate change on lake ecosystems is to compare past conditions with current ones. Since sediments that accumulate at the bottom of a lake are the result of the biological, geological, and climatological changes within each lake's watershed, they provide a sequential record of past conditions in lake productivity, stratification, oxygenation, and material inflows from streams and watershed runoff. The sediment core study of Kezar Lake aimed to better link water quality with climate and land use and to determine which stressors have put Kezar Lake water quality at greatest risk for future impairment.

SUMMARY

- Natural processes affecting water quality within the Kezar Lake watershed were relatively stable until the Europeans arrived in the 1800's.
- The Europeans logged forests, plowed fields, raised farm animals, trapped beavers, and built roads, resulting in significant changes to the landscape.
- The Industrial Age added other stressors and pollutants, such as acid rain, heavy metals from the burning of fossil fuels, chemicals from fertilizers and other uses, and high-powered boats that create wakes and disturb bottom sediments.
- The synergistic effect of human activities and rising temperatures due to climate change is having a measurable impact on our environment.

MAJOR STUDY FINDINGS

- Between A.D. 2000-2015, the sediment accumulation rate and organic content of both the deep spot of Kezar Lake and the area near Great Brook increased dramatically, likely the result of intensified watershed runoff and erosion due to climate change effects of more frequent and more violent storms. This recent intensification of larger-scale flood and erosion events caused a notable increase in particle-size and decrease in aluminum concentrations in lake bottom sediments at both sites.
- Preliminary diatom results indicate that a marked change in algal composition accompanied the increase in sediment accumulation rates after 2008. This supports the idea that the lake is not currently as stable as it was just a decade ago.
- The particle-size record at the deep spot of Kezar Lake suggests that no large-scale events have occurred in the Kezar Lake watershed since the large hurricanes in the 1600's, despite forest clearances in the 1800's and fires in the 1930's. The Great Brook core record showed the influence of many smaller-scale events that are most likely associated with minor flood events.

- The deep spot of Kezar Lake showed a steady rise in lead and zinc from the burning of coal and gasoline since the 1800's, then a sharp decline in the 1970's after the ban of leaded gas. The Great Brook core record did not show as sharp a decline in lead and zinc as at the deep spot, which may indicate a continued source of heavy metal contamination from dredged or disturbed lake sediments with legacy contamination.

METHODS

In February and June 2015, sediment cores were collected by several KLWA volunteers, led by Dr. Lisa Doner, using an Uwitec Corer from Plymouth State University (PSU). Cores came from the deep spot of Kezar Lake at the northern end of the lake in 155 ft. (47 m) of water near Palmer Lane (N 44.22383 and W 70.8976), and from a spot southeast of Great Brook's outlet (N 44.23972 and W 70.90167) in 40 ft. (12.2 m) of water. The deep spot was selected because it contains a portion of all materials introduced to or created by the lake over time, and so represents whole lake conditions. The area near Great Brook was selected to better understand sediment flows out of Great Brook and, to a lesser degree, Cold Brook, both of which empty into northwest Kezar Lake. A total of 5 cores were taken with an average length of about 51 cm. Each core was subsampled at 1 cm intervals for a total of 246 subsamples. These subsamples were freeze-dried and then divided and analyzed at PSU, the University of Maine-Orono, Beta Analytic, Inc. in Florida, and Activation Laboratories in Canada. In all, over 2,340 analyses were performed on the Kezar Lake cores collected in 2015, 97% of which were completed by PSU.

Subsamples were labeled by depth below lake bottom or where the water meets the accumulated mud. Geology is based on the simple logic that in any accumulation of material, the bottommost material is laid down first, and thus, is oldest, and layers above are progressively younger. In the Kezar Lake cores, 0-1 cm is the uppermost and youngest subsample, while the bottom layer is oldest. While relative ages (younger versus older) provide important information on the sequence of events, for this study we also wanted to determine how the watershed and lake were affected by changes in climate and land use that occurred at particular times, such as during different phases of land development for agriculture, lumbering, residences, and boat access. We determined the absolute ages (actual dates) for one of the cores taken from the deep spot of Kezar Lake. Using the absolute ages (actual dates) from that core, we can infer the approximate timing of changes in other cores with similar records. However, sediment accumulation rates between the deep spot and Great Brook are likely very different because accumulation in the Great Brook outlet area is likely much higher due to the influence of nearby streams, which contribute inorganic sediments to the lake.

For this study, **Plymouth State University** determined:

- Organic content (an approximation for lake productivity) by burning a portion (1 gram) of the dried material for each subsample in a furnace at about 1,020˚F (550˚C) and weighing the difference before and after, a process called loss-on-ignition (LOI). These data are presented as the percent organic content in each subsample.
- Mineral grain size using a laser particle-size analyzer (the Horiba LA-920), with pretreatment in boiling hydrogen peroxide to dissolve organic components. The instrument's red and blue lasers and sensor array distinguish clay particles as small as 0.22 microns (0.88 x 10^{-5} inches) and sand particles up to 2 mm (0.079 inches) diameter. Each sample was run three times for

an average. The result included the percentages of particles in 84 different size ranges, the average (mean) size, and the variation in size for each subsample. Here, only the average particle sizes are shown for each subsample.

The University of Maine determined:

- The absolute ages (actual dates) for sediment layers in one of the cores from the deep spot of Kezar Lake (KZRDP 2015 Core 3) using the radioactive element lead-210 (^{210}Pb). Each of the subsamples was placed in front of a gamma detector, and its radioactive emission rate was measured over several days. Recent (younger) material emits higher concentrations of radioactivity, which then die off at an exponential rate in older material. The result is an age curve that mimics this exponential decay rate. The most accurate ages come from the youngest material, and uncertainty in age increases down-core until after about 150 years when there is too much error to give a reliable estimate. This occurred at just 12 cm sediment depth for the Kezar Lake cores.

Beta Analytic, Inc. determined:

- The absolute age (actual date) of the bottommost (oldest) subsample in KZRDP 2015 Core 3, at 54-55 cm, using radiocarbon analysis by mass spectrometry (AMS ^{14}C). This bottom material had no measurable lead-210 and was much deeper than any of the lead-210 dated material. The radiocarbon date range for the bottommost sample of KZRDP 2015 Core 3 was A.D. 1020-1165, giving us almost 1,000 years of water quality history for Kezar Lake.

Activation Laboratory determined:

- Sediment geochemistry, or the different mineral elements that make up the inorganic portion of sediments, by dissolving the sediments in a variety of acids. Results were the amount of each element in each subsample; more abundant elements were given in parts per hundred (percent), while less abundant ones in parts per million (ppm). Of interest are elements that accumulate in clays and deep layers of soil, like aluminum, because these elements increase in lake sediments during periods of more intense soil erosion. Also, some heavy metals, like lead, zinc, and chrome, that have accumulated in lake sediments can be re-introduced to the lake water if oxygen levels decrease at the bottom of the lake. Thus, high accumulations of heavy metals in the uppermost sediments are a potential source of contamination if the lake bottom experiences prolonged periods of low oxygen.

RESULTS

The radiocarbon date range for the bottommost sample of the longest core was A.D. 1020-1165, giving us almost 1,000 years of water quality history for Kezar Lake. This allowed us to see not only quantifiable changes in the water quality of Kezar Lake, but also when those changes occurred.

Different areas of a lake can have different sediment accumulation rates because of the influence of water depth and nearby streams or outlets. For instance, lake areas in shallow water and near land or streams will trap sediments and fill in more quickly than steep-sided, offshore basins, such as at the deep spot of Kezar Lake. The sediment accumulation rate at the deep spot of Kezar Lake was low

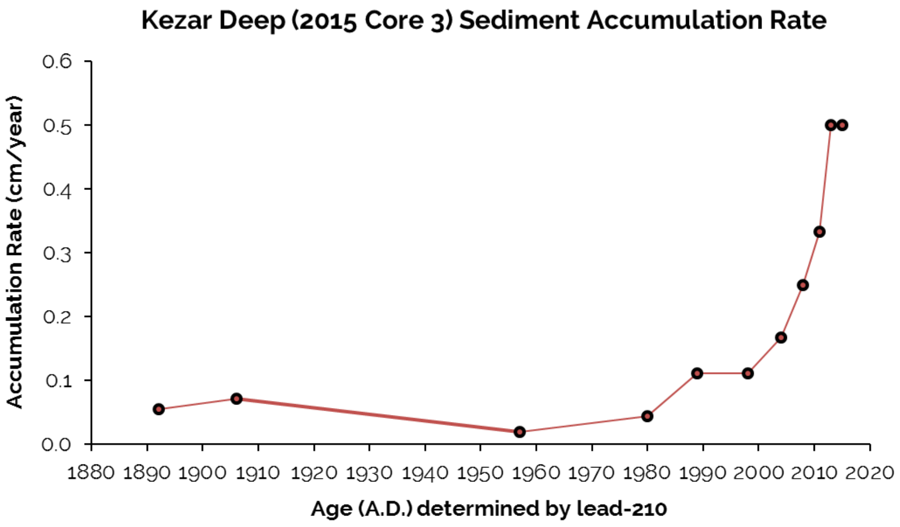


FIGURE 1. *Sediment accumulation rate (cm/year) from A.D. 1892-2015 (lead-210 dated) for the Kezar Lake Deep 2015 Core 3.*

prior to 1980, averaging 0.5 to 1 mm per year (less than 1/32 of an inch per year; **FIGURE 1**). Because lake algae are often major contributors of material to lake bottoms, and Kezar Lake is oligotrophic (meaning low lake productivity) with low algae concentrations, the low sediment accumulation rate in the deep spot of Kezar Lake was not surprising. However, sediment accumulation rates in Kezar Lake began to increase after 1980 and became exponential after 2000. Since the deep spot does not have any large drainages near it, possible explanations for the exponential increase in sedimentation rate are that algae concentrations in lake water and/or watershed runoff/erosion have increased. Note: sediment accumulation rates for the Great Brook site are not available because the core has not yet been dated.

Preliminary diatom results indicate that a marked change in algal composition accompanied the increase in sediment accumulation rates after 2008. This supports the idea that the lake is not currently as stable as it was just a decade ago.

Organic content is considered an approximation of algae concentration and thus, lake productivity. Most organic material in a lake comes from a combination of algal growth and material influx from land sources. However, even in oligotrophic lakes, such as Kezar Lake, most organic material in sediments is derived from algal production. Between A.D. 2000-2015, the organic content of both the deep spot of Kezar Lake and the area near Great Brook increased sharply from a long-term average of 25% (dotted lines) prior to 2000 to about 30% after 2000, as shown in **FIGURE 2**. Note: the difference in peak organic content between the two sites is not significant and is approximated at 30%; focus should be placed more broadly on the significant step increase from the long-term average of 25% organic content to about 30% in recent years at both sites.

There are two lines of evidence that help explain the recent increase in both sediment accumulation rates and percent organic content at Kezar Lake:

SCENARIO 1: Increased algal production (by eutrophication or process by which lake productivity increases). This scenario supports the idea that recent increases in sediment accumulation rate and percent organic content were due to increases in lake productivity. If true, then the similarity in percent organic content in all cores at both sites points to a change affecting most of the lake, not just a few areas that may be influenced by other factors like stream inflows. A problem with this explanation is

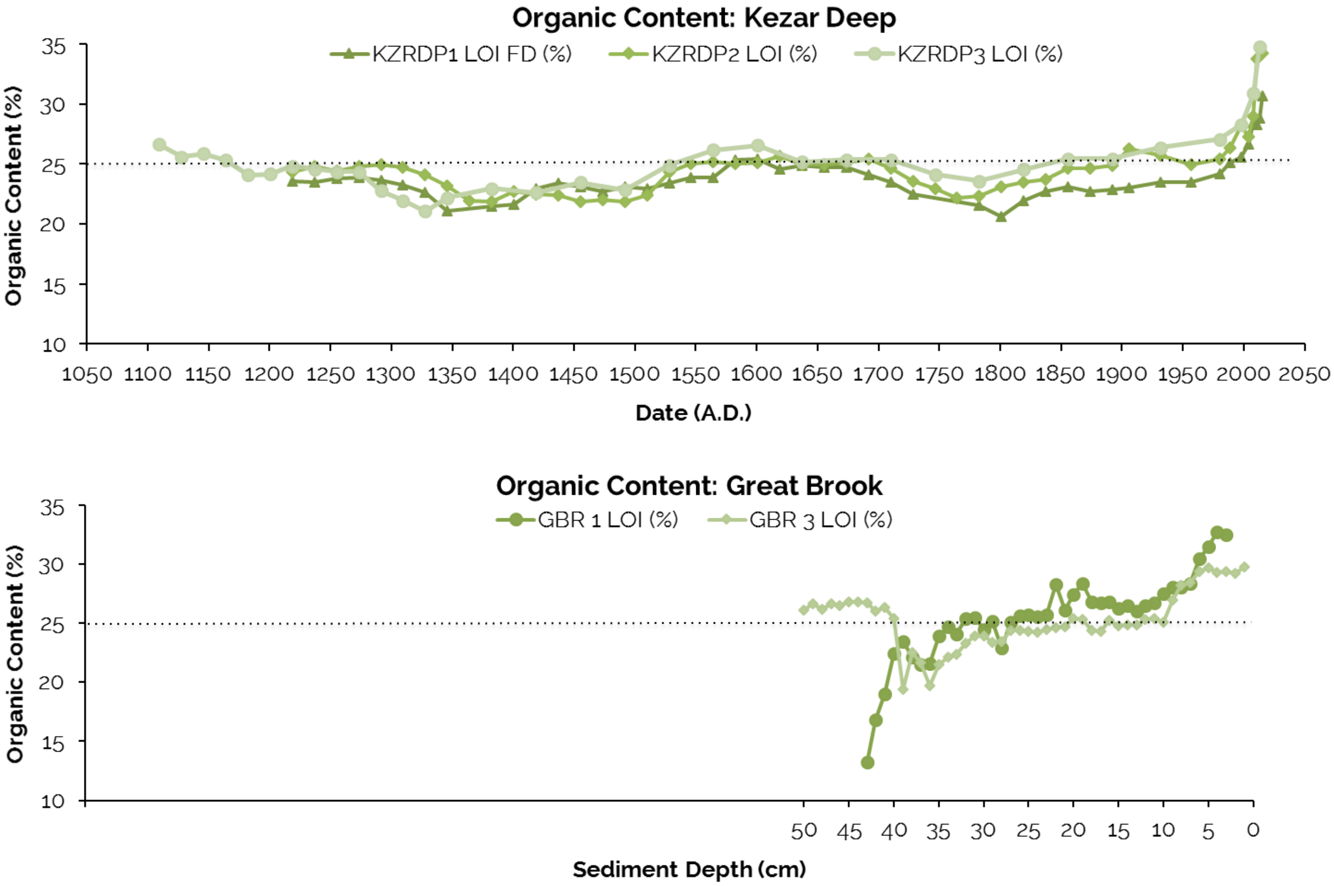


FIGURE 2. *Percent organic content from A.D. 1109-2013 (lead-210 and radiocarbon dated) for the Kezar Lake Deep 2015 Cores 1, 2, and 3 (top) and from 49-0 cm of sediment depth below lake bottom (roughly A.D. 1640-2013) for Great Brook 2015 Cores 1 and 3 (bottom). LOI = loss-on-ignition.*

that sediment accumulation rates at the Great Brook site were about 2.36 times higher than at the deep spot (note: neither of the Great Brook cores were independently dated, but correlation of sediment accumulation rates at the two core sites were approximated by matching peaks in particle size (Figure 3) and lead concentrations (Figure 4); though this process showed some troubling inconsistencies and should be interpreted with caution). The difference of 2.36 in sediment accumulation rate between the two sites is not unreasonable given the influence of two streams feeding into the Great Brook site. However, since percentages of organic content were very similar in all cores (around 25%), if the streams contributed 2.36 times more material to the Great Brook site than the deep spot receives, then the organic content of the streams must also have been 25% (otherwise the inorganic material coming from the streams would dilute the organic signal). For the lake and streams to contribute the same percentage of organic material requires an unlikely coincidence.

SCENARIO 2. Increased inputs from stream and land sources. In this scenario, recent increases in percent organic content may be due to intensified contributions of organic material from land or riverine sources, such as from intensified stream flows and runoff. This scenario accounts for the similarity in the percent organic content in all cores at both sites, but it runs counter to published work from many other sites that point to algal production as the dominant contributor of organic material in lakes. The validity of this scenario can be tested by obtaining absolute ages (actual dates) for one of the Great Brook cores, which could verify timing of sediment accumulation rates, and thus, stream inputs to that site. This scenario could also be verified by conducting carbon:nitrogen (C:N) analyses to reveal whether organic carbon in the sediments was derived primarily from land plants or from algae. The C:N approach is the less expensive solution, but it would not resolve uncertainty about dates of events in the Great Brook cores.

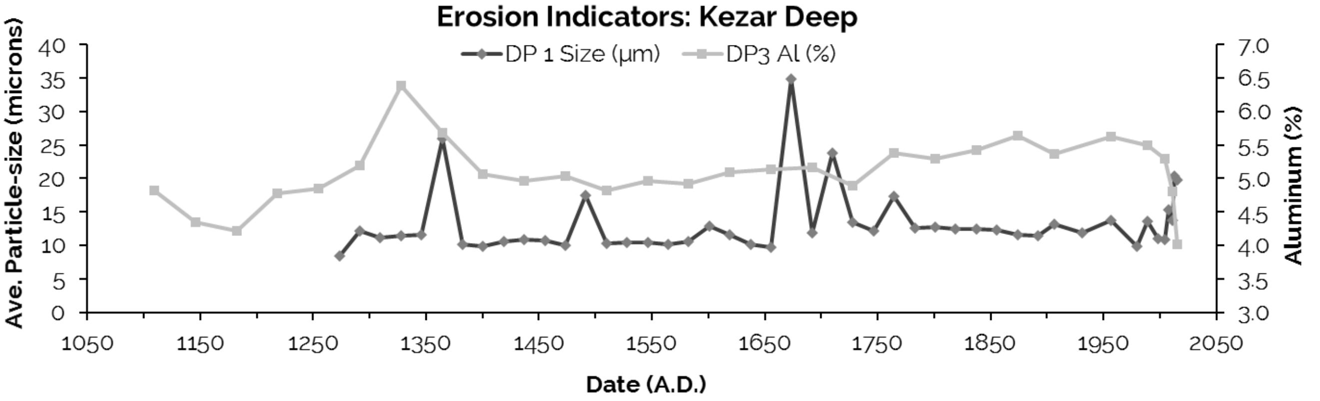
Although contrary to other regional lake studies, the marked increase from A.D. 2000-2015 in sediment accumulation rates and percent organic content at the deep spot of Kezar Lake and the area near Great Brook was likely due to increased inputs from stream flows and runoff sources from the watershed (given the similarity in the long-term percent organic content between the two sites).

A few other findings from these core studies were also notable. The average particle-size at the deep spot of Kezar Lake was about 10 microns (fine silt) with a few distinct pulses of coarser material (medium to coarse silt), while the average particle-size at the outlet area of Great Brook was much more variable, but was most often in the 20-25-micron range (medium silt) with pulses of coarse silt and fine sand (over 63 microns), as shown in **FIGURE 3**. The most significant change in average particle-size occurred around A.D. 1674 at both sites. A slightly smaller event occurred a few decades later at about A.D. 1710. These dates are estimates only because part of the deep spot core was outside the lead-210 dating range and well above the level with the radiocarbon date, and Great Brook cores were not independently dated. Nevertheless, two major hurricanes hit New England in A.D. 1635 and 1675 and could have affected particle-sizes in the lake.

The particle-size data are shown alongside aluminum concentrations in Figure 3. Aluminum is a weathering product that tends to accumulate in the deeper (B horizon) of soils, especially in clay minerals. The deep spot core record showed a relatively steady background concentration of aluminum, irrespective of particle-size, except in the most recent deposits (which may reflect changes in aluminum-sediment export from coarser to finer material from the streams in recent years). The unchanging aluminum concentration despite peaks in particle-size suggests that large events that caused peaks in particle-size in the 1600's (e.g., the hurricanes mentioned previously) were large enough to also flush aluminum bound to fine sediments out of the lake before settling on lake bottom. In the Great Brook core record, however, aluminum and particle-size seem to have opposite signals; when one goes up, the other goes down. This pattern is due to the influence of streams contributing sediment to the Great Brook site. High stream flow events (during extreme rain events) move larger particles and flush aluminum and fine-grained sediments out of soils and into the lake. During these high flows, fine silts and clays that are bound to aluminum remain suspended in water and exit the lake through the outlet. Smaller flow events (during minor rain events) transport aluminum-bound silts and clays into the lake where they can settle on lake bottom.

There also may be an increasing trend in particle-sizes and decreasing trend in aluminum concentration for the Great Brook core record, which suggests a change in sediment transport processes from the streams to the lake. Without more historical evidence, it is difficult to determine the cause of changes in sediment transport. The Great Brook delta may have shifted further away from the core site or the streams may have been impacted by flow restrictions from natural or man-made damming or stream flow may have increased from increasing precipitation.

In summary, the particle-size record for the deep spot of Kezar Lake suggests that no large-scale flood and erosion events have occurred in the Kezar Lake watershed since the large hurricanes in the 1600's, despite forest clearances in the 1800's and large fires in the 1930's. The Great Brook core record showed many smaller-scale events that are most likely associated with minor flood events.



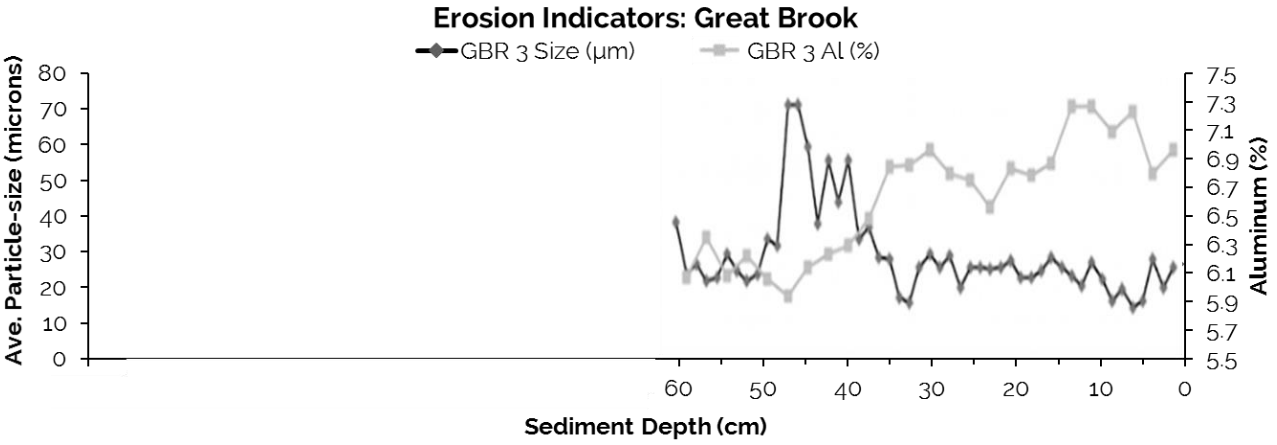


FIGURE 3. *Average particle size (microns) from A.D. 1109-2015 (lead-210 and radiocarbon dated) for the Kezar Lake Deep 2015 Core 1 (top); percent aluminum from A.D. 1273-2015 for the Kezar Lake Deep 2015 Core 3 (top); average particle size (microns) and percent aluminum for Great Brook 2015 Core 3 from 60-0 cm of sediment depth below lake bottom (roughly A.D. 1575-2015) (bottom).*

Another indicator for concern from this study is heavy metal concentrations. **FIGURE 4** shows lead and zinc concentrations, but other elements, like cadmium, copper, and nickel also increased in the upper (younger) sediment subsamples. The significant and steady rise in lead and zinc since the 1800's were likely associated with the burning of coal on an industrial scale, and later, with gasoline and diesel fuel use. The tell-tale peak in the 1970's and sharp decline afterwards at the deep spot follows a trend seen across North America after leaded gas was phased out in 1975. The Great Brook site did not show as significant as sharp a decline in lead and zinc as at the deep spot, which may indicate a continued source of contamination from the watershed or from lake sediments.

> **The Great Brook core record did not show as sharp a decline in lead and zinc as at the deep spot in the 1970's after the ban of leaded gas, which may indicate a continued source of heavy metal contamination from the watershed or from lake sediments. Dredging and anchoring, which disturb lake sediments deeply enough to mix pre-1970's material back to the surface, is the likely cause of continued high heavy metal concentrations at the Great Brook site, particularly given the dredging history and prior existence of a marina in this area of the lake.**

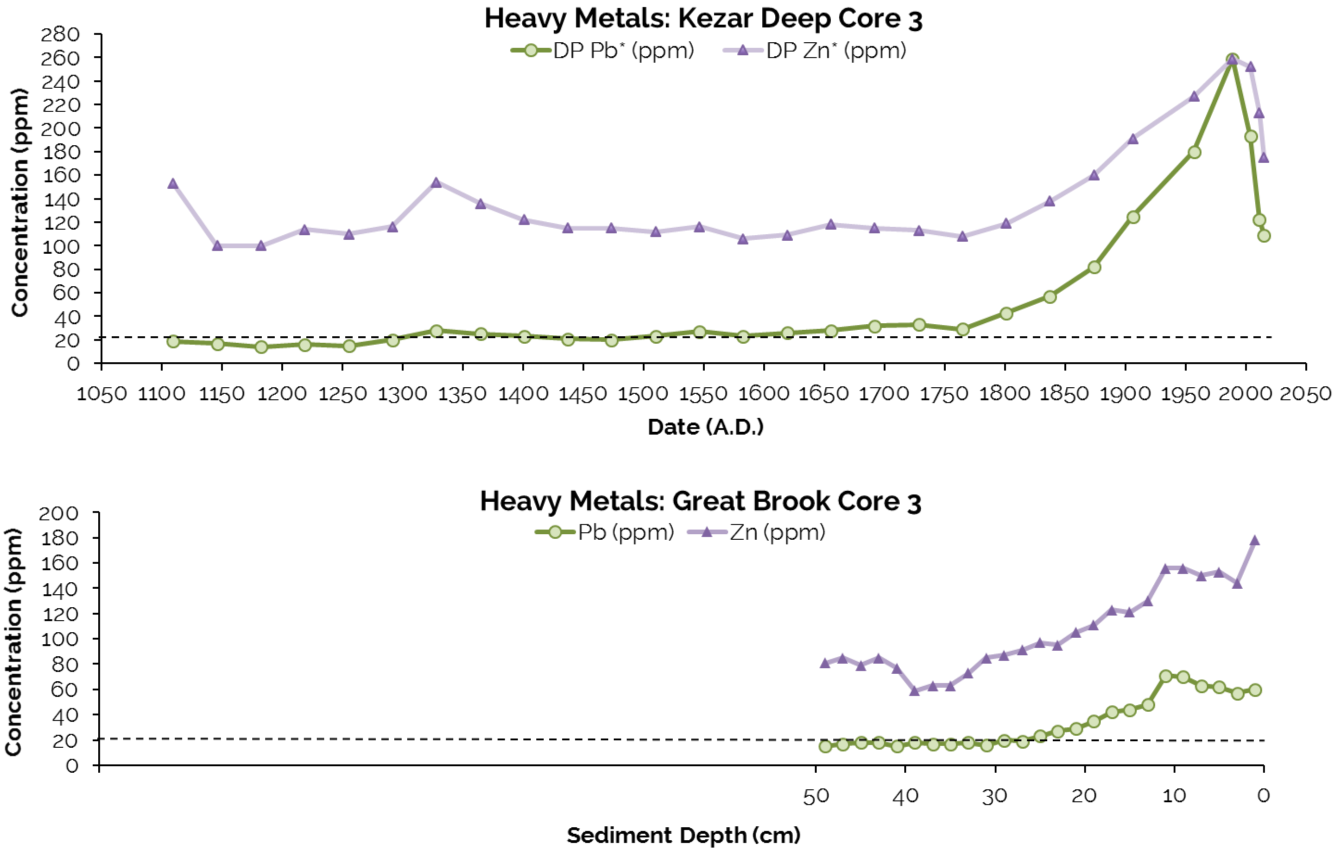


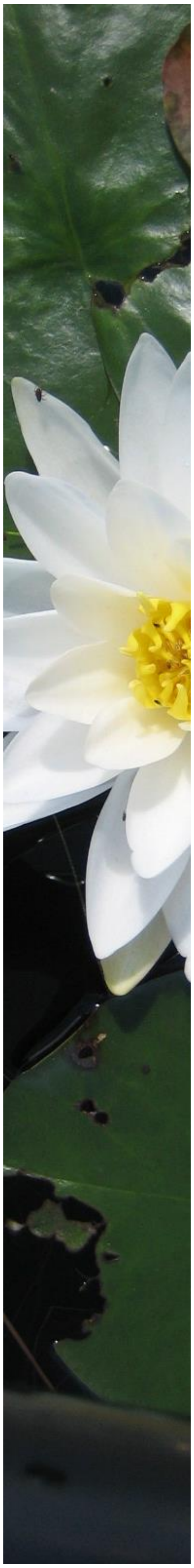
FIGURE 4. *Heavy metal concentrations (parts per million) from A.D. 1109-2015 (lead-210 and radiocarbon dated) for the Kezar Lake Deep 2015 Core 3 (top) and from 49-0 cm of sediment depth below lake bottom (roughly A.D. 1575-2015) for the Great Brook 2015 Core 3 (bottom).*

FUTURE CORE STUDIES

- In 2017, we expect to complete the diatom analysis and integrate those results with the existing data sets. Diatom (microscopic algae) assemblages provide information on how aquatic plant species changed over time. Depending on the aquatic species that changed, it is possible to estimate historic air and water temperature, as well as historic water quality conditions, like pH, alkalinity, clarity, and nutrient availability.

- In 2017, we also plan to obtain a lead-210 (^{210}Pb) dating of one of the Great Brook cores to more accurately correlate the data sets from the Kezar Lake deep spot and the Great Brook cores. Radiocarbon dating of a subsample (around A.D. 1600) of the Kezar deep spot core would also be helpful in validating the timeline for the rate of sediment accumulation.

Sediment core collection in June 2015 (left) and February 2015 (right). Photo Credit: KLWA.



Aquatic Plants

Warming water temperatures, longer growing seasons, and changing precipitation patterns will cause shifts in the extent and abundance of native aquatic plant species. Many aquatic plant species that thrive under cooler conditions will die out, giving opportunity for southern plant species to take root. This will cause a gradual change in aquatic plant species composition and distribution within the lake and ponds. Different aquatic plant species have varying levels of nutrient and water needs, a change in which will alter cycling dynamics within the lake and ponds. An immediate threat to Kezar Lake is the invasion of non-native plants that can outcompete native plants. This threat is being addressed by the Lovell Invasive Plant Prevention Committee (LIPPC). A list of aquatic plants native to waterbodies within the Kezar Lake watershed is being compiled using data collected by the Lake and Watershed Management Association from 2011-2015, as well as published survey reports funded by the LIPPC. Cushman Pond has already been invaded by variable-leaf milfoil and efforts to eradicate this invasive have taken place over the last 20 years.

Fish

Fish are a keystone species for the Kezar Lake fishing community, who have relied on abundant populations of coldwater fish for their recreational enjoyment. These coldwater fish species are extremely sensitive to changes in water temperature and chemistry. Coldwater fish will seek cold, deep areas of lakes, ponds, and streams to avoid warm surface waters in late summer. This can be problematic in productive lakes that have depleted oxygen in bottom waters, leaving little habitat for these fish species to survive. pH is particularly critical to fish species and other aquatic life as it affects their metabolic functioning and reproductive capacity. This is a concern for Kezar Lake and its ponds given the naturally-low buffering capacity of the soil and water in the watershed. Low-pH rain (4.3) will temporarily decrease the pH of surface waters, placing significant stress on aquatic organisms residing in those waters. If climate change enhances the frequency and duration of precipitation events, then sensitive fish populations may face high disturbance, low pH environments that may be fatal. Because of this, fish can be a good indicator of climate change and should be monitored.

Aquatic Birds

Warmer air temperatures, variable precipitation patterns, and changes in vegetation will very likely reduce the abundance and diversity of aquatic bird species, including the iconic common loon. Earlier snowmelt means changes in seasonal duration and timing, which greatly impacts life cycles, including growth and survival rates of loons and other bird species. Monitoring these populations will help assess the effects of climate change on native species in the watershed.

Maine Audubon is partnering with the University of Maine to increase loon observations

Water Lily. Photo Credit: Don Griggs.

and track changes in hatching and maturation times. Since it is possible that observations may underestimate the true number of loons, a pilot detectability study will also be conducted to determine if the results represent actual number of loons in the survey area. Loon counts are done on a specific day, and the observers record the adults and chicks seen in their count area for a half hour period in the morning, which may miss the count of known loons in the area.

Overall, the adult loon population at Kezar Lake has been constant with some annual changes in the last 30 years (Fig. 1). The chick population shows a statistically-significant, but slight decline (based on Mann Kendall Trend Test) over the observation period. This could be an artificial decline because the chicks were not visible during the count period or an actual decline because chicks are being killed by eagles. Over 29 years of observations show an increase in eagle nesting population at Kezar Lake. Several eagle attacks on chicks have been observed over the last few years; most attacks were unsuccessful, but at least two did capture a chick.

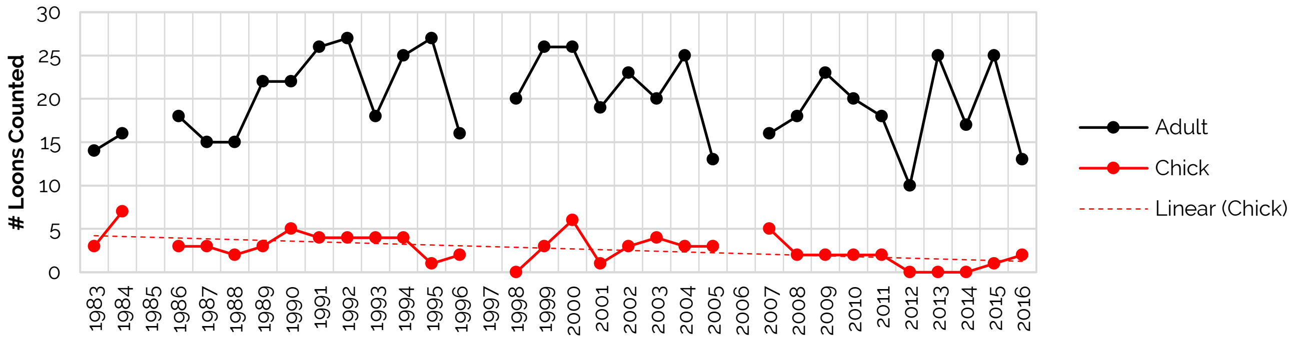


Fig. 1. Annual loon counts for adult and chick populations observed at Kezar Lake from 1983-2016.

The ponds have a much sparser data set:

- Based on 14 non-consecutive years of observations, Horseshoe Pond hosts an annual chick population varying from zero to three, and Farrington Pond hosts a few adult loons with only two chicks seen in 2016.

Loon on Kezar Lake. Photo Credit: Conary.

- Based on 18 non-consecutive years of observations, Heald Pond hosts an annual adult population varying from zero to three. The first and only chick was documented in 2015.
- Based on 29 years of non-consecutive observations, Cushman Pond hosts an annual adult population varying from zero to three. The first and only two chicks were documented in 2011.
- Based on 10 non-consecutive years of observations, Trout Pond hosts an annual adult population varying from zero to two. No chicks have been documented.
- No surveys have been done on Bradley Pond.

Estimation of loon population in southern Maine conducted by the Maine Audubon show an increase in loon population despite climate change impacts. The study suggests that as long as lakes are clear, the food supply is abundant, and any adverse human impacts are avoided, the loon population will remain stable and/or increase.

Zooplankton

Zooplankton play an important role in a lake's ecosystem and are useful indicators of food web stability. As microscopic animals that consume phytoplankton, zooplankton serve as a valuable food source for fish. KLWA supported a study of zooplankton in Kezar Lake from 2004-2007, the results of which were published in a 2008 article titled, "Cladoceran and copepod zooplankton abundance and body size in Kezar Lake, Maine (MIDAS 0097)" by Nichole M. Cousins and Katherine E. Webster from the School of Biology and Ecology at the University of Maine, Orono. The results of the study show that the zooplankton population in Kezar Lake was consistent during the sampling period and can be used as a baseline for future studies. The CCO supports future zooplankton studies to assess long-term trends in zooplankton population as a result of climate change or other environmental stressors.

Crayfish

KLWA supported a brief study of crayfish in Kezar Lake in August-September 2008. The study was conducted by Dr. Karen Wilson at the University of Southern Maine. The study found three native species and caught a total of 29 crayfish, which were mostly found around rocky islands. The spatial and temporal sample size were too small to gain any significant conclusions on population size, species composition, or size trends. No evidence of invasive crayfish was found. Anecdotal evidence suggests that the crayfish population has declined in Kezar Lake. The CCO supports a new, more comprehensive, crayfish study in the future.

Pathogens

Warmer water temperatures, along with increased population growth, will increase the risk of aquatic pathogens, including bacteria, protozoa, and parasites. While it is difficult to control the spread of these pathogens due to climate change, we can make sure proper waste disposal techniques are used for all existing and future development in the watershed and along the shoreline of Kezar Lake and its ponds.

LAND

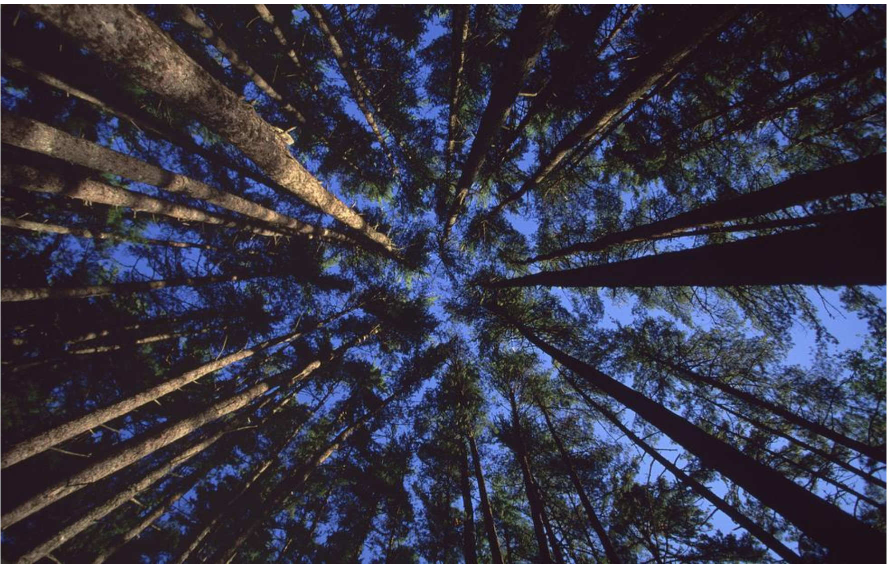
Climate affects the abundance, extent, and diversity of all life on the planet – plants and trees, birds, mammals, and insects and pathogens. As the climate changes, terrestrial species will need to adapt to or move from these changing environments. Two-thirds of Maine's animal and plant species are predicted to be at risk from climate stress. We can watch for change in these populations as indicators of climate change. The CCO intends to collaborate with existing phenology networks across the country to better understand the periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors.

An outstanding, detailed climate change vulnerability assessment of Maine's wildlife species of greatest conservation need has been published by the Manomet Center for Conservation Sciences, titled *Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species*[3]. This will serve as an excellent resource for the CCO as they formulate adaptation strategies.

Plants & Trees

Earlier and warmer summers will lengthen the growing season, but potentially more days above 90 degrees and variable precipitation patterns may mitigate any benefits for farming in the region. Watermelon, tomatoes, peppers, peaches, and others will benefit from higher air temperatures, but corn, wheat, and oats will have lower yields. Cabbage, potato, apples, blueberries, and winter wheat that need cool weather and cold winters will also decline. Flowering, fruit set, and seed production will decline in many species due to loss of pollinators.

Warming air temperatures and changing precipitation patterns will cause shifts in the geographic extent of native plant and tree species in the area. Many plant and tree species that thrive under cooler, drier conditions will die out, giving opportunity for southern plant and tree species to take root. This will cause a gradual change in plant and tree species composition and distribution within the watershed. For example, spruce and fir will move farther north and to higher elevations. The sap season for maples will come earlier and sugar maples may be restricted to northern Maine. Different plant and tree species have varying levels of nutrient and water needs, a change in which will alter ecosystem cycling dynamics.



Tree canopy. Photo Credit: Jose Azel.

Joshua Halman, a Forest Health Specialist with the Vermont Department of Forest, Parks and Recreation, has been monitoring trees in Underhill State Park for 25 years by recording color change and leaf drop. These data show that the timing of peak color and leaf drop have come later in the season by about eight days in the last 25 years. Comparable data are not available for Lovell; however, Underhill State Park is at approximately the same latitude, and therefore, can be extrapolated as relevant to the White Mountain National Forest and the Kezar Lake watershed.

---

[3] https://www.manomet.org/sites/default/files/publications_and_tools/2013%20BwH%20Vulnerability%20Report%20CS5v7_0.pdf

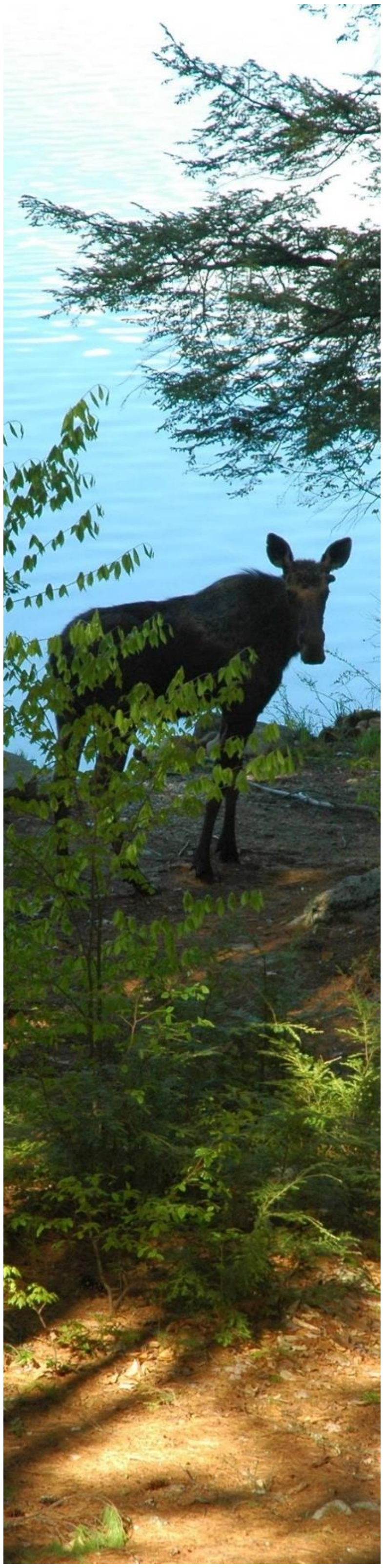
In 2004, a survey was undertaken to document non-native and invasive species on all GLLT-owned properties. Surveys documented the presence of non-native species sheep sorrel (*Rumex acetosella*) and coltsfoot (*Tussilago farfara*). While some might consider these plants to be invasive, they are not often targeted for management efforts. Later that year, GLLT conducted surveys in the town targeting areas where invasive plants would most likely occur, such as power lines, roadsides, logging roads, informal camping spots, playing fields, and disturbed areas. Japanese knotweed (*Fallopia japonica*), sheep sorrel, coltsfoot, black locust (*Robinia pseudoacacia*), and non-native honeysuckle (*Lonicera sp.*) were detected during these surveys. Of all observed non-native plants, Japanese knotweed was observed to be the most pervasive. GLLT also surveyed 12 private properties, which revealed the presence of additional non-native invasive plants, including Japanese barberry (*Berberis thunbergii*), non-native honeysuckle, autumn olive (*Elaeagnus umbellata*), asiatic bittersweet (*Celastrus orbiculatus*), and purple loosestrife (*Lythrum salicaria*). Anecdotally, Tom Henderson of GLLT reports that an infestation of purple loosestrife was also found on a member's property, but was eradicated. Other non-native, invasive plant species known to occur in neighboring towns include glossy false buckthorn (*Frangula alnus*) and yellow iris (*Iris pseudacorus*).

Birds

Bird counts and movements can be monitored easily and can serve as an indicator of climate change. Changes in air temperatures and precipitation amounts can shift habitat ranges and limit mating and nesting seasons. Late spring storms can kill migrating birds and cause behavioral shifts. Available food sources can change, forcing birds to find new suitable habitat. Birds in the Kezar Lake watershed that are most likely to decline due to climate change include the Black-capped Chickadee (Maine State Bird), Evening Grosbeak, Ruffed Grouse, Wood Thrush, and all high-elevation species. Birds that may increase or move into Maine include the Tufted Titmouse, Canada Goose, House Finch, Brown-headed Nuthatch, and Loggerhead Shrike.

Mammals

Moose are an iconic mammal in Maine and a local inhabitant of the Kezar Lake watershed. This iconic species is vulnerable to heat stress and ticks that proliferate following mild winters. The observed decline of moose in Maine from disease or migration north is a clear signal of climate change.



Moose in Kezar Lake watershed. Photo Credit: KLWA.

Attempts by the KLWA to find detailed information on historical moose populations in Lovell were not successful (this included an evaluation of the Statewide permit and harvest data). The last estimate of moose population was in 2012 when the State of Maine reported a population of 76,000. While hunting permit numbers are not linearly related to the total population, Maine Inland Fisheries and Wildlife (MIFW) reports moose harvests by individual towns. Very few moose harvests have been recorded in Lovell with the maximum in 2009 at only two individuals. Moose are also unevenly distributed throughout the State and primarily occupy the commercial forestlands in northern Maine. The State division that includes Lovell (Division 15) receives 25 permits per year and reports approximately a 50% success rate (ranging from 24% - 60% historically).

Detailed Statewide information is needed to make assessments of the moose population in Lovell. Unfortunately, data on other mammals, such as bear, deer, and wild turkey are also limited. MIFW has more information regarding these mammals on their website.

Insects & Pathogens

The movement of warmer and wet weather pests into New England are a signal of climate change. Migratory insects will arrive earlier with earlier snowmelt and rising air temperatures, and insects only marginally-adapted to the region will begin to invade as the climate warms. Increases in balsam woolly adelgid, spruce budworm, Beech bark disease, and winter moth will adversely affect tree populations. Inadequate winter chill will adversely affect agriculture by increasing populations of insects and disease, including flea beetle and Steward's wilt.

Climate change impacts human health, agriculture, and aquatic-terrestrial ecosystems through insect-borne diseases. Increasing air temperatures and more precipitation will increase mosquito and tick populations. The predicted northward expansion of insect-born pathogens, particularly tick-borne lyme disease and mosquito-borne encephalitis, will be harmful to the health of Maine residents.

The Maine Center for Disease Control and Prevention (Maine CDC) has shown that Lyme disease cases are increasing in Maine. The northern migration of ticks as a result of warming air temperatures may increase the prevalence of Lyme disease cases in Maine.

There are a number of other tick-borne diseases that threaten public health and may increase with a changing climate. These include Anaplasmosis, Babesiosis, Ehrilichiosis, Powassan, Spotted Fever Rickettsiosis, as well as other less common diseases. Each of these has shown an increase over the years, especially Anaplasmosis.

CLIMATE CHANGE REFERENCES

The following table provides references to key documents related to climate change. The subsequent table contains links to important climate change websites that are applicable to the Kezar Lake CCO.

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Maine's Climate Future	2015	Assessment of climate change and key indicators in Maine	http://cci.siteturbine.com/uploaded_files/climatechange.umaine.edu/files/MainesClimateFuture_2015_Update2.pdf
Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species	2014	Summarizes a climate change vulnerability assessment of Maine's wildlife Species of Greatest Conservation Need, state-listed Threatened or Endangered plant species, and Key Habitats of the Maine Comprehensive Wildlife Conservation Strategy.	https://www.manomet.org/sites/default/files/publications_and_tools/2013%20BwH%20Vulnerability%20Report%20CS5v7_0.pdf
Climate Change 2014 Synthesis Report	2014	Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development	https://www.ipcc.ch/report/ar5/syr/
Climate Change Profound Impacts on Lakes in Europe	2014	Coldwater fish species such as trout and whitefish are declining dramatically due to climate warming and nutrient enrichment	http://voices.nationalgeographic.com/2014/07/21/climate-change-already-having-profound-impacts-on-lakes-in-europe/
Lakes as Sentinels of Climate Change	2014	Lakes are effective sentinels for climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2854826/
Lakeshore & Rivershore Climate Assessment	2013	Strategies to address vulnerabilities	http://extension.unh.edu/resources/files/Resource004598_Rep6566.pdf
Lake Ice	2013	Ice formation and breakup dates are relevant indicators of climate change	http://www.epa.gov/climatechange/pdfs/lake-ice_documentation.pdf

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Evolutionary and plastic responses of freshwater invertebrates to climate change: realized patterns and future potential	2013	Temperature increase and associated ecological challenges such as changes in predation rates	http://onlinelibrary.wiley.com/doi/10.1111/eva.12108/epdf
Warming Lakes: Effects of Climate Change seen on Lake Tahoe	2012	Extended lake stratification season is a concern for water quality	http://voices.nationalgeographic.com/2012/10/17/warming-lakes-effects-of-climate-change-seen-on-lake-tahoe/
Allied attack: climate change and eutrophication	2011	Global warming and eutrophication in fresh and coastal waters may mutually reinforce the symptoms they express and thus the problems they cause	https://www.fba.org.uk/journals/index.php/IW/article/viewFile/359/263
Climate Change and Vermont's Waters	2011	Flooding, water quality, dissolved oxygen, drought; short term mitigation options	http://www.anr.state.vt.us/anr/climatechange/Pubs/AdaptationWP_ClimateChangeandWaterReources.pdf
Confronting Climate Change in the US Northeast	2007	The Northeast Climate Impacts Assessment (NECIA) is a collaborative effort between the Union of Concerned Scientists (UCS) and a team of independent experts to develop and communicate a new assessment of climate change and associated impacts on key climate-sensitive sectors in the northeastern United States	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/confronting-climate-change-in-the-u-s-northeast.pdf
Sensitivity of future ozone concentrations in the Northeast U.S. to regional climate change	2008	NE predictions: warmer/less cloudy summers, increased biogenic emissions, and increased ozone concentrations	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/kunkel_et_al.pdf
Emissions Mitigation Opportunities and Practice in Northeastern United States	2008	Emission reductions in NE, with a 3% reduction recommended with individuals choosing personal BMPS and technologies; action vs inaction debated as well	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/moomaw_and_johnston.pdf

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Adaptation to Climate Change in the Northeast United States: Opportunities, Processes, Constraint	2008	How to plan for climate change	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/moser_et_al.pdf
Potential Effects of Climate Change and Rising CO2 on Ecosystem Processes in Northeastern U.S. Forests	2008	A look into the range of possible outcomes under different warming scenarios.; factors of interest: forest growth, carbon exchange, water runoff, nitrate leaching, etc.	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/ollinger_et_al.pdf
Potential Effects of Climate Change on Birds of the Northeast	2008	Large changes in bird communities of the northeast are likely to result from climate change, and these changes will be most dramatic under a scenario of continued high emissions.	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/rodenhouse_et_al.pdf
Climate Change Vulnerability of the US Northeast Winter Recreation - Tourism Sector	2008	This study examined the vulnerability of the two largest winter recreation industries, snowmobiling and alpine skiing, to four climate change scenarios for the 21st century. Under all scenarios, natural snow became an increasingly scarce resource.	http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/pdf/miti/scott_et_al.pdf
A Shoreland Homeowner's Guide to Stormwater Management	-	Cost effective options for Best Management Practices to mitigate stormwater runoff	http://nhlakes.mylaketown.com/uploads/tinymce/nhlakes/Stormwater%20Guides/HomeownersStormwaterGuide.pdf

FUTURE PLANS

CCO plans for the 2016-2017 year include the following activities:

- Continue to develop and expand the climate change portion of the KLWA website to include more trend data, especially information on parameters for climatology, flora, and fauna. Continue to improve the easy public access to climate change data and trends for the Kezar Lake watershed.
- Continue to participate in water quality monitoring of the lake, ponds, and streams.
- Further expand the sediment core dating and analysis to include diatom analysis.
- Expand our collaboration with other organizations involved with climate change monitoring and analysis.
- Continue to research and gather data pertinent to climate change in the watershed.
- Employ a 2017 graduate summer intern to further climate change work.

SUMMARY & RECOMMENDATIONS

Climate change is a real and imminent threat to our local, regional, and global ecosystems, most especially our treasured lakes. Lakes are recognized as "sentinels of climate change" because their physical, chemical, and biological responses to climate change can provide the first signal of the effects of climate change. In New England, we can expect warmer air temperatures, more intense and frequent precipitation events, increased flooding, reduced snow cover duration, enhanced species migration and extirpation, and earlier lake ice-out. In reaction to these predications, a Climate Change Observatory (CCO) was established with the objective to analyze the long-term effects of climate change on atmospheric, aquatic, and terrestrial ecosystems in the Kezar Lake watershed.

The CCO has accomplished a great deal since its establishment in 2013. To continue this great work, the following adaptation strategies are recommended for the Kezar Lake watershed community:

ADAPTATION RECOMMENDATIONS

- Incorporate climate change guidance language (based on the following recommendations) in updated municipal comprehensive plan.
- Prepare municipal climate change adaptation plan.
- Adopt a citizen pledge to reduce carbon footprint.
- Provide incentives (e.g., tax breaks) for homeowners that reduce carbon footprint.
- Review and improve energy usage of municipal buildings.
- Improve infrastructure to accommodate higher and more frequent flow volumes.
- Replace the remaining high priority culverts identified by the 2015 culvert study.
- Expand culvert study to include private roads.

ADAPTATION RECOMMENDATIONS

- Create a funding and assessment plan to re-assess and replace culverts in the watershed on an ongoing basis.
- Develop emergency management plans based on climate projections. Include current and projected flood risk maps for residents with homes in low-lying areas. Consider requiring septic system evaluations for all homes within the watershed (esp. homes within the projected flood zone) to assess potential for failure. Consider rezoning the projected flood zone for non-development.
- Encourage establishment of a "Climate Change Adaptation" webpage on the town website that links residents to important climate change information and the CCO webpages.
- Assess vulnerability of area to changes in the amount and timing of water supplies for plants, animals, and humans.
- Review and update local ordinances to include the following: 1) add Low Impact Development (LID) description to ordinance and require LID in site design, especially for lots with >20% imperviousness; 2) increase setback distances to at least 100 ft. around vernal pools, streams, and wetlands and restrict development to <25% within 750-ft. radius of resource to account for wildlife (e.g., pool-breeding amphibians); and 3) encourage conservation subdivisions with common open space and require land trusts or conservation organizations (not homeowner's associations) to undertake stewardship of common open space in conservation subdivisions.
- Develop an alkalinity and pH study to assess the vulnerability of waterbodies to acid rain and watershed activities.
- Target stormwater management and septic system maintenance outreach to these pond residents.
- Conduct a shoreline survey of properties on Kezar Lake and ponds to identify conduits of stormwater runoff (e.g., driveways, boat ramps) and develop specific recommendations for mitigation of erosion.
- Provide incentives (e.g., tax breaks) for homes that achieve LakeSmart certification through the State of Maine.
- Ensure that development occurs in a sustainable and low-impact way to increase watershed resiliency to extreme weather events and prevent potential polluted runoff.
- Continue progressive watch programs that help prevent and control invasive plants.
- Continue monitoring stream conditions for supporting coldwater fish species (e.g., temperature, flow, and population size). This will help target streams in need of restoration. Restoration techniques include increasing overhead vegetative cover to help cool stream water temperatures.
- Encourage anglers to use non-lead sinkers and to retrieve fishing line caught in shoreline vegetation.
- Create a public notification system for swimming advisories following any instances of significant algal blooms when waters may be harmful to human health.
- Conduct habitat and species-level vulnerability assessments.
- Protect and restore riparian habitats by enhancing buffers that limit heat stress on species.

ADAPTATION RECOMMENDATIONS

- Conserve and protect land areas that serve as wildlife corridors.
- Complete a habitat analysis that prioritizes high value habitat for species most vulnerable to climate change, such as the Black-capped Chickadee and Evening Grosbeak.
- Disseminate public notices during peak tick and mosquito season to warn residents of potential diseases, including Lyme.
- Ensure state and local regulations prohibit outside firewood and other materials that potentially harbor invasive insects.

LITERATURE SOURCES FOR REPORT

Boeck, M., Jackson, R., and H. Shaftel. Global Climate Change Temperature website. NASA. July 28, 2015. http://climate.nasa.gov/interactives/climate-time-machine

Clark, Neal. Birds on the Move: A guide to New England's Avian Invaders. North Country Press: Unity, Maine. (1988).

Cousins, N.M., and K.E. Webster. "Cladoceran and Copepod Zooplankton Abundance and Body Size in Kezar Lake, Maine (MIDAS 0097)". (2008).University of Maine, School of Biology and Ecology.

Duchesne, L., and D. Houle. "Interannual and spatial variability of maple syrup yield as related to climatic factors." PeerJ 2 (2014):e428.

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. "Maine's Climate Future: 2015 Update." Orono, ME: University of Maine (2015): 24. climatechange.umaine.edu/research/publications/climate-future

Fleming, D. Winter ticks raise concerns about future of Maine's moose herd. Portland Press Herald, 14 June 2014.

Groisman, Pavel Ya, et al. "Changes in the probability of heavy precipitation: important indicators of climatic change." Climatic Change 42.1 (1999): 243-283.

Hodgkins, Glenn A., Ivan C. James, and Thomas G. Huntington. "Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000." International Journal of Climatology 22.15 (2002): 1819-1827.

Huntington, Thomas G., et al. "Changes in the proportion of precipitation occurring as snow in New England (1949-2000)." Journal of Climate 17.13 (2003): 2626-2636.

IPCC [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." IPCC, Geneva, Switzerland: (2014): 151. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

Iverson, Louis R., Mark W. Schwartz, and Anantha M. Prasad. "How fast and far might tree species migrate in the eastern United States due to climate change?" Global Ecology and Biogeography 13.3 (2004): 209-219.

Karl, Thomas R., and Richard W. Knight. "Secular trends of precipitation amount, frequency, and intensity in the United States." Bulletin of the American Meteorological society 79.2 (1998): 231-241.

Karl, Thomas R., Richard W. Knight, and Neil Plummer. "Trends in high-frequency climate variability in the twentieth century." (1995): 217-220.

Leighton, P.A., J.K. Koffi, Y. Pelcat, L.R. Lindsay, and N.H. Ogden. "Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector *Ixodes scapularis* in Canada." Journal of Applied Ecology 49 (2012):457–464

Meyer, Judy L., et al. "Impacts of climate change on aquatic ecosystem functioning and health." Journal of the American Water Resources Association 35.6 (1999): 1373-1386.

Monthly Summaries of the Global Historical Climatology Network - Daily (GHCN-D). COOP:275995 & 271732. NOAA National Climatic Data Center. July 21, 2015.

Robinson, S. Infectious Disease Epidemiology Report: Lyme Disease Surveillance Report—Maine, 2013. Augusta, ME (2014): Maine Center for Disease Control and Prevention.

Rodenhouse, N. L., et al. "Potential effects of climate change on birds of the Northeast." *Mitigation and Adaptation Strategies for Global Change* 13.5-6 (2008): 517-540.

Skinner, C.B., A.T. DeGaetano, and B. Chabot. "Implications of twenty-first century climate change on Northeastern United States maple syrup production: impacts and adaptations." Climatic Change 100 (2010):685–702.

Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore. "Improvements to NOAA's Historical Merged Land–Ocean Temp Analysis (1880–2006)." Journal of Climate 21 (2008):2283–2296.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). "Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge, United Kingdom and New York, NY: Cambridge University Press (2007): 996. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

Stewart, Iris T., Daniel R. Cayan, and Michael D. Dettinger. "Changes toward earlier streamflow timing across western North America." Journal of climate 18.8 (2005): 1136-1155.

Whitman, A., et al. "Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Brunswick, ME (2013): Manomet Center for Conservation Sciences.

APPENDIX A

Anoxic Factor: a method that summarizes individual dissolved oxygen profiles as annual values that represent the extent and duration of anoxia (depth at which dissolved oxygen falls below 2 ppm) in lakes and ponds. This method normalizes complex, 2-dimensional data into a single factor that can be used to assess within-lake changes over time or compare among other waterbodies. Waterbodies can reach "tipping points," when the extent and duration of anoxia in late summer increases to a point when major ecological changes take root (e.g., algal blooms).

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 algal biomass; higher Chl-a equates to greater amount of algae in the lake.

Color: The influence of suspended and dissolved particles in the water as measured by Platinum Cobalt Units (PCU). A variety of sources contribute to the types and amount of suspended material in lake water, including weathered geologic material, vegetation cover, and land use activity. Colored lakes (>25 PCU) can have reduced transparency readings and increased total phosphorus concentrations. When lakes are highly colored, the best indicator of algal growth is chlorophyll-a.

Dissolved Oxygen: The concentration of oxygen that is dissolved in the 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, concentration of algae and other plants in the water, and amount of nutrients and organic matter that flow into the waterbody from the watershed. Too little oxygen severely reduces the diversity and abundance of aquatic communities. 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 the presence of fecal contamination in the water.

Eutrophication: Refers to lakes with high productivity, high levels of phosphorus and chlorophyll-a, low Secchi disk readings, and abundant biomass with significant accumulation of organic matter on the bottom. Eutrophic lakes are susceptible to algal blooms and oxygen depletion in the hypolimnion.

Integrated Epilimnetic Core: A water sample that is collected with a long tube extending from the surface of the lake to the upper part of the thermocline to determine average nutrient concentration in the epilimnion.

pH: The standard measure of the acidity 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.

Platinum Cobalt Units (PCU): A unit of measurement used to determine the color of lake water. Lake water with 30 PCU will look slightly brown or tea-colored (formerly reported as SPU - Standard Platinum Units).

Sample Station: Location where water quality readings and samples are taken. Some of the larger lakes or basins are sampled at more than one location, resulting in multiple station numbers. In lakes with more than one basin, at least one station is usually located in each basin.

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 (a.k.a., Secchi disk transparency). Measuring water clarity is one of the most useful ways to show whether a lake is changing from year to year. Changes in transparency may be due to increased or decreased algal growth, or the amount of dissolved or particulate materials in a lake, resulting from human disturbance or other impacts to the lake watershed area. Factors that affect transparency include algae, water color, and suspended sediment. Since algae are usually the most common factor, transparency is an indirect measure of algal populations.

Thermocline: The markedly cooler, dynamic middle layer of rapidly changing water temperature. The of this layer is distinguished by at least a degree Celsius change per meter of depth.

Total Alkalinity: A measure of the buffering capacity of a lake, or the capacity of water to neutralize acids. It is a measure of naturally-available bicarbonate, carbonate, and hydroxide ions in the water, which is largely determined by the geology of soils and rocks surrounding the lake. Alkalinity is important to aquatic life because it buffers against changes in pH that could have dire effects on animals and plants.

Total Phosphorus (TP): The total concentration of phosphorus found in the water, including organic and inorganic forms. TP is one of the major nutrients needed for plant growth, and is generally present in small amounts. Humans can add phosphorous to a lake through stormwater runoff, lawn or garden fertilizers, and leaky or poorly maintained wastewater disposal systems. Excess phosphorus can lead to increased plant and algae growth in lakes.

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.