Paul Smith's College
Adirondack Watershed Institute

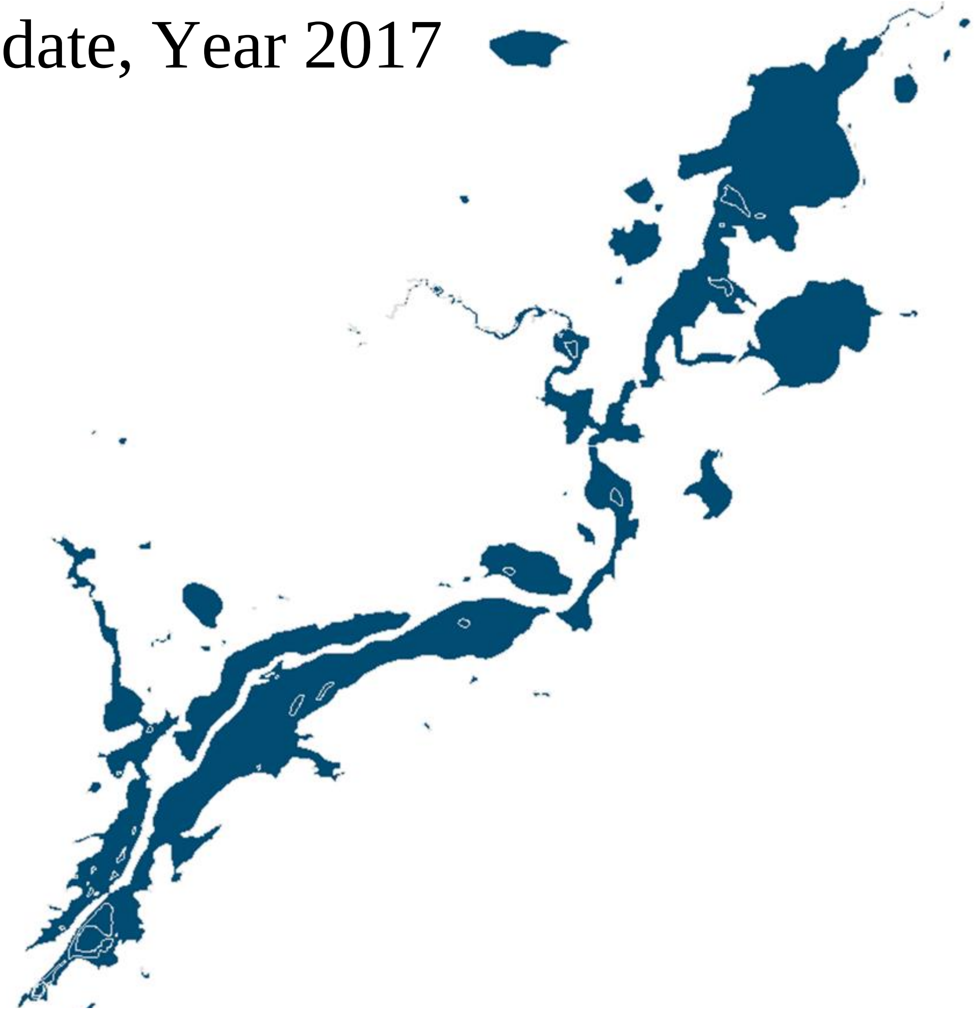
Technical Report

Limnology and Water Quality Program

Rainbow Lake Chain

Water Quality Report:

Program Update, Year 2017



Corey Laxson, Elizabeth Yerger, and Daniel Kelting

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*Corresponding author Corey Laxson at claxson@paulsmiths.edu

Table of Contents

Acknowledgements........2

List of Tables........4

List of Figures........5

Executive Summary........6

Quick Facts – Rainbow Lake........8

Quick Facts – Clear Pond........9

Quick Facts – Lake Kushaqua........10

Introduction........11

Methods........11

Study Area........11

Field Sampling and Analysis........13

Results and Discussion........14

Temperature and Dissolved Oxygen........14

Transparency........22

Chlorophyll-a........22

Phosphorus........26

Trophic Status........27

pH and Alkalinity........28

Color........28

Conductivity........29

Sodium and Chloride........29

Literature Cited........30

List of Tables

Table 1. Morphometry and watershed characteristics of the study lakes in the Rainbow Lake Chain*.... 12

Table 2. Analytical techniques performed at the AWI Environmental Research Lab. 13

Table 3. Trophic classification of lakes based on Carlson's Trophic State Index. 14

Table 4. Water quality and trophic indicators for Rainbow Lake, 2017. BDL = below laboratory detection level, ± indicates an estimated value. 16

Table 5. Water quality and trophic indicators for Clear Pond, 2017. BDL = below laboratory detection level. 17

Table 6. Water quality and trophic indicators for Lake Kushaqua, 2017. BDL = below laboratory detection level 18

Looking east from Lake Kushaqua

List of Figures

Figure 1. The Rainbow Lake Chain, located within the Adirondack Park of northern New York. 11

Figure 2. Temperature (upper panels) and dissolved oxygen (lower panels) of Rainbow Lake, June - August 2016. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L)......19

Figure 3. Temperature (upper panels) and dissolved oxygen (lower panels) of Clear Pond, June - August 2017. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L). 20

Figure 4. Temperature (upper panels) and dissolved oxygen (lower panels) of Lake Kushaqua, June - August 2017. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L). 21

Figure 5. Time series of water quality and trophic indicators in the surface water of Rainbow Lake, 1997-2017. Statistically significant trends ($p < 0.05$) are denoted with a trend line. 23

Figure 6. Time series of water quality and trophic indicators in the surface water of Clear Pond, 1997-2017. Statistically significant trends ($p < 0.05$) are denoted with a trend line. 24

Figure 7. Time series of water quality and trophic indicators in the surface water of Clear Pond, 1997-2017. Statistically significant trends ($p < 0.05$) are denoted with a trend line. 25

Aerial view of the Rainbow Lake Chain (photo credit RLA webpage)

Executive Summary

Limnological monitoring of the Rainbow Lake Chain has been carried out by the Rainbow Lake Association and the Adirondack Watershed Institute since 1997. This report serves as an update to the long term monitoring project by presenting the results of the 2017 field season and describing long term trends in the historical data of the Rainbow Lake Chain. Though the data and accompanying analysis provided in this report give insight into the water quality of the Rainbow Lakes, more detailed limnological studies may be necessary to produce management recommendations. Raw water quality data can be provided upon request. The bullets below represent the primary findings contained within this report.

- The dissolved oxygen profiles of the Rainbow Chain are typical of most lakes of moderate productivity in the Adirondacks, where dissolved oxygen is greatest in the epilimnion (surface water) and gradually decreases towards the bottom. Both Rainbow Lake and Clear Pond are significantly impacted by oxygen depletion in the bottom strata of the lakes. The oxygen depletion was clearly evident during our first visit in mid-June. By August, the bottom 8.5 meters (28 feet) of the deepest portion of Rainbow Lake had very low available oxygen, with the bottom eight meters (26 feet) being essentially anoxic (D.O. less than 0.5 mg/L). We observed a similar hypoxia/anoxia pattern in Clear Pond, but to a lesser extent than observed in Rainbow Lake. Lake Kushaqua exhibited oxygen depletion in the bottom water, but still retained at least 2 mg/L in late August. It is likely the bottom few meters of Lake Kushaqua also becomes anoxic by autumn.

- The transparency of Rainbow Lake typically fluctuates around 3 meters in depth and has not exhibited and positive or negative trend over the past 21 years. The transparencies of Clear Pond and Lake Kushaqua have both exhibited a slight yet significant downward trend over the monitoring period. We observed the transparencies Clear Pond and Kushaqua to be decreasing at a rate of approximately 4 cm/year and 8 cm/year respectively.

- Total phosphorus concentrations in the Rainbow Lake chain have been notably lower over the past 7 years. Some of the observed decrease may be related to improved analytical capabilities of the new AWI laboratory which went online in 2010. Since that time total phosphorus concentrations have been stable, with no significant trend detected in any of the lakes. Anoxic conditions in the bottom strata of Rainbow Lake and Clear Pond have resulted in elevated phosphorus concentrations near the bottom.

- Chlorophyll-concentrations in Rainbow Lake and Clear Pond chain have remained relatively constant over the 21 years of monitoring, generally fluctuating between 4 and 8 µg/L in Rainbow Lake and 2 and 6 µg/L in Clear Pond. We observed an increasing trend in chlorophyll-a concentrations in Lake Kushaqua since 2000.

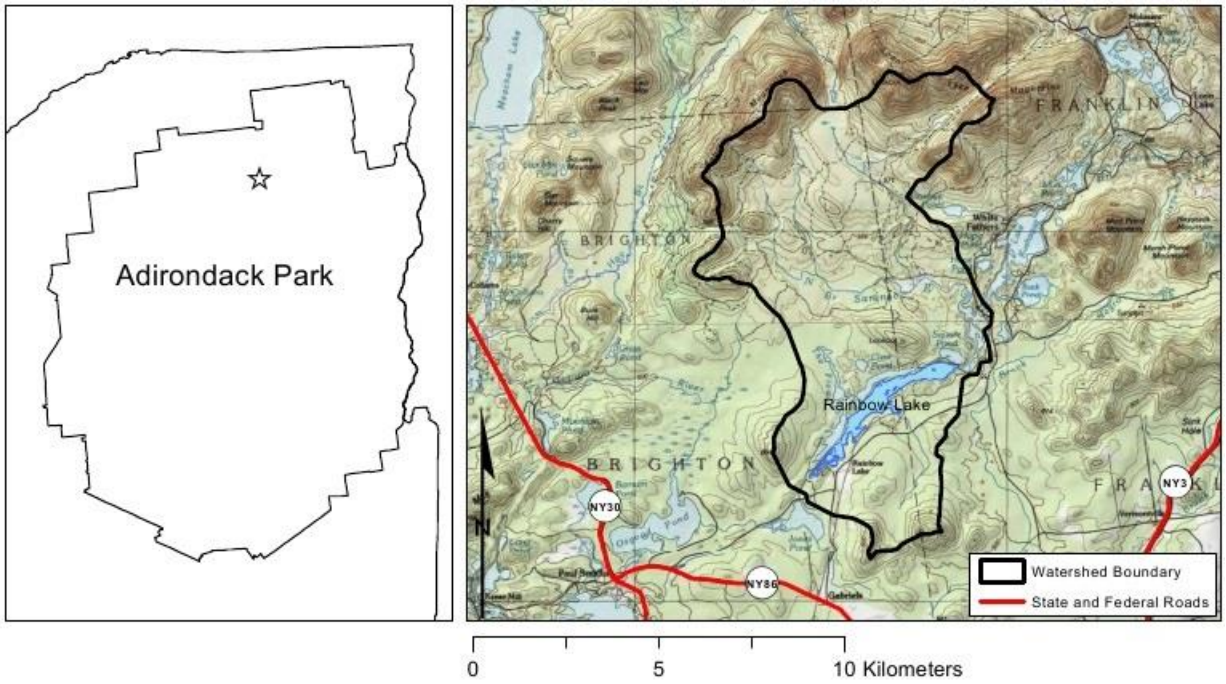
- Carlson's Trophic Status Index based on transparency, chlorophyll-a, and total phosphorus suggests a mesotrophic classification for the three study lakes. The mesotrophic classification for the lakes has been consistent since the monitoring program began. In all of the lakes the TSI values for transparency and chlorophyll are in close agreement, however the TSI for total phosphorus tended to score the lakes in the oligotrophic range in some years. A disparity of this nature typically indicates that the lakes experience periods of phosphorus limitation.

- The waters of the Rainbow Lake chain are circumneutral in terms of their acidity (pH 6.5-7.5). The average alkalinity of the lakes ranged from 12-19 mg/L, indicating that the lakes were fairly well buffered, and as a result are not particularly sensitivity to acid deposition.

- Apparent color values of the lakes were elevated, and historically highly variable. Elevated color is indicative of high amounts of dissolved organic matter in the water and is typically due to watershed characteristics such as wetland, bogs, and coniferous forest cover. Lake Kushaqua is the most highly stained lake in the chain, with color values nearly double those found in Rainbow Lake and Clear Pond.

- Non-impacted Adirondack Lakes have very low levels of sodium and chloride, the only substantial sources being road salt, septic output, and industrial fertilizers. For example, Adirondack lakes in watersheds without paved roads typically have sodium and chloride concentrations less than 0.55 mg/L and 0.24 mg/L respectively. (Kelting et. al 2012). Rainbow and Kushaqua Lakes have slightly elevated concentrations of these chemicals compared to non-impacted baselines. The paved roads in the watershed along with shoreline development were likely responsible for the slightly elevated levels of these chemicals. No statistical trend was detected in the historic chloride levels in the Rainbow Lake chain.

Quick Facts – Rainbow Lake



Trophic Status: Mesotrophic **Years of Data: 21**

County:	Franklin
Town:	Brighton

Lake Area (ac):	356
Watershed Area (ac):	4,216

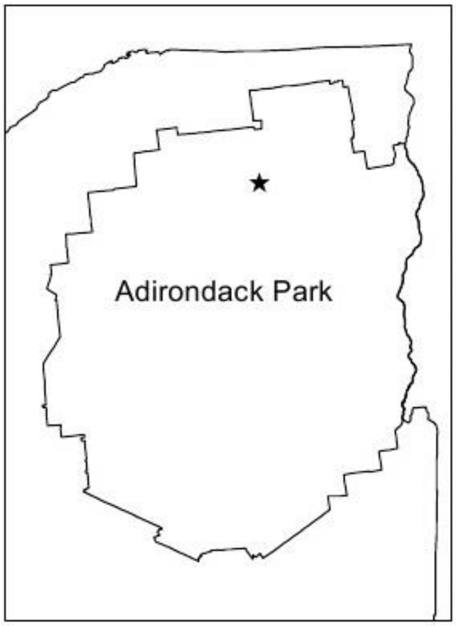
2017 Water Quality Indicators and Historical Trends*:

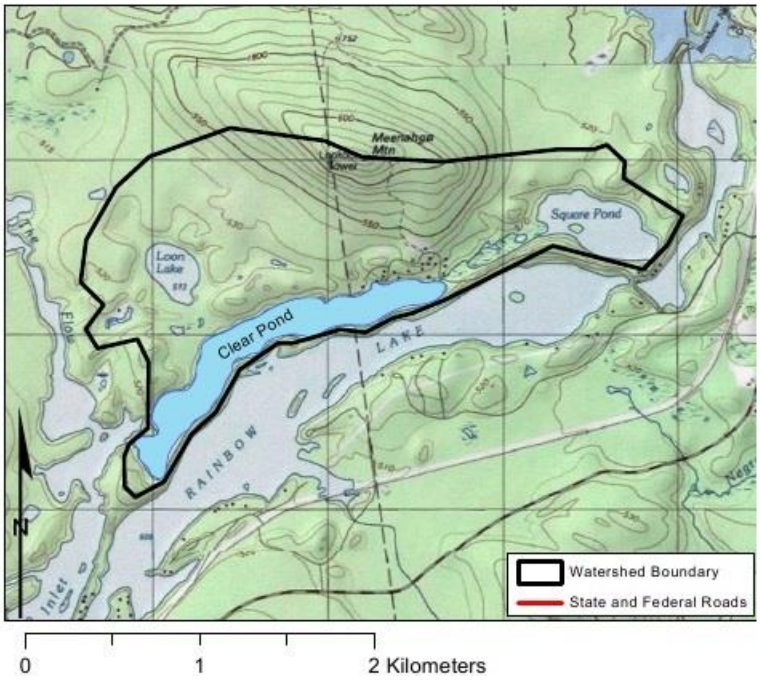
Indicator	Avg.	Trend
Transparency (m)	2.7	**no trend**
Total P (µg/L)	11.2	**no trend**
Chlorophyll-*a* (µg/L)	6.8	**no trend**
Laboratory pH	7.3	**no trend**

Indicator	Avg.	Trend
Conductance (µS/cm)	34.8	**decreasing**
Color (Pt-Co)	51.5	**no trend**
Alkalinity (mg/L)	15.2	**no trend**
Chloride (mg/L)	1.9	**no trend**

*Statistically significant trends in the historical data are indicated as ‘decreasing” if there is a significant decrease in the indicator over time, and ‘increasing” if there is a significant increase in the indicator over time.

Quick Facts – Clear Pond





County:	Franklin
Town:	Brighton

Lake Area (ac):	104
Watershed Area (ac):	798

Trophic Status: Mesotrophic

Years of Data: 21

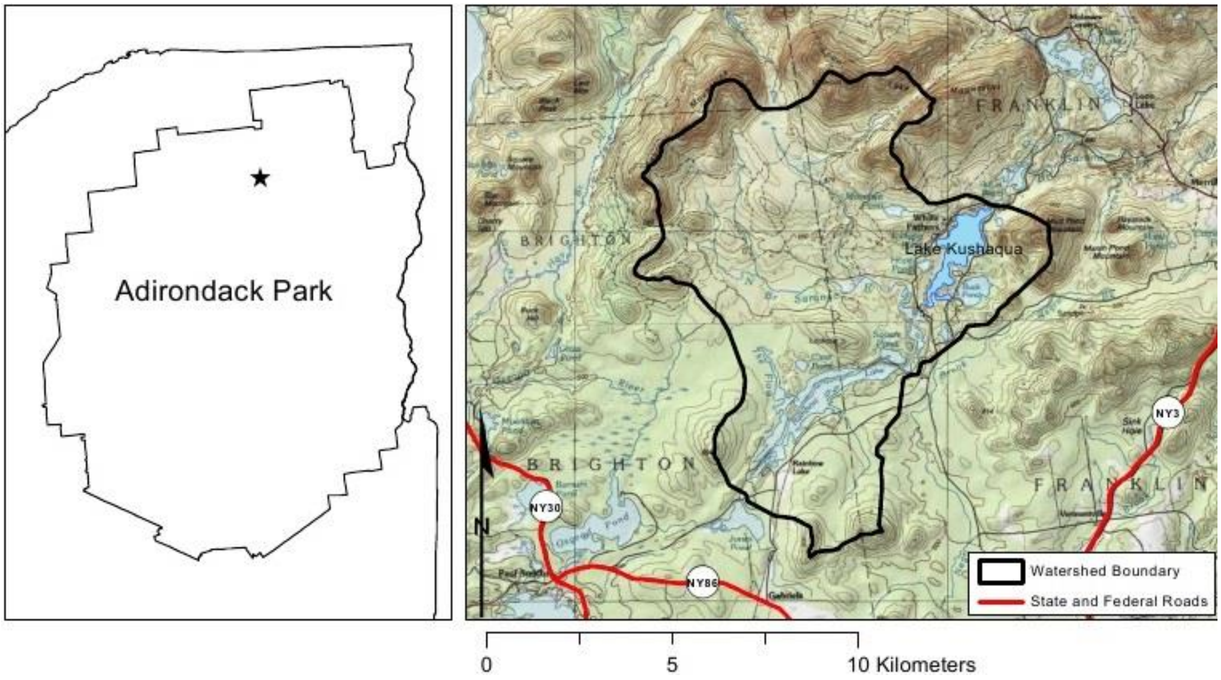
2017 Water Quality Indicators and Historical Trends*:

Indicator	Avg.	Trend
Transparency (m)	3.0	decreasing
Total P (µg/L)	11.2	no trend
Chlorophyll-*a* (µg/L)	5.3	no trend
Laboratory pH	7.3	no trend

Indicator	Avg.	Trend
Conductance (µS/cm)	23.5	no trend
Color (Pt-Co)	35.4	no trend
Alkalinity (mg/L)	11.1	no trend
Chloride (mg/L)	0.8	no trend

* *Statistically significant trends in the historical data are indicated as "decreasing' if there is a significant decrease in the indicator over time, and 'increasing' if there is a significant increase in the indicator over time.

Quick Facts – Lake Kushaqua



County:	Franklin
Town:	Franklin

Lake Area (ac):	368
Watershed Area (ac):	18,875

Trophic Status: Mesotrophic

Years of Data: 11

2017 Water Quality Indicators and Historical Trends*:

Indicator	Avg.	Trend
Transparency (m)	2.1	**decreasing**
Total P (µg/L)	12.8	**no trend**
Chlorophyll-*a* (µg/L)	5.6	**no trend**
Laboratory pH	7.2	**no trend**

Indicator	Avg.	Trend
Conductance (µS/cm)	33.6	**no trend**
Color (Pt-Co)	72.9	**no trend**
Alkalinity (mg/L)	16.3	**no trend**
Chloride (mg/L)	1.0	**no trend**

**Statistically significant trends in the historical data are indicated as “decreasing” if there is a significant decrease in the indicator over time, and ‘increasing” if there is a significant increase in the indicator over time.

Introduction

First initiated in 1997, the Rainbow Lake Monitoring Program was specifically designed to describe the trophic status of Rainbow Lake and Clear Pond and to detect impacts from shoreline areas with dense concentrations of camps. Now 21 years later it represents an excellent example of long term limnological monitoring in the Adirondacks. Long term limnological data sets are very important for evaluating ecosystem response to disturbances, providing baseline to evaluate change, or detecting change in response to management intervention. The objective of this report is to provide reliable information to support lake management by summarizing the results from 2017, and describing trends in the historical dataset. This report is designed to provide information for informed lay audience as well as members of the scientific community.

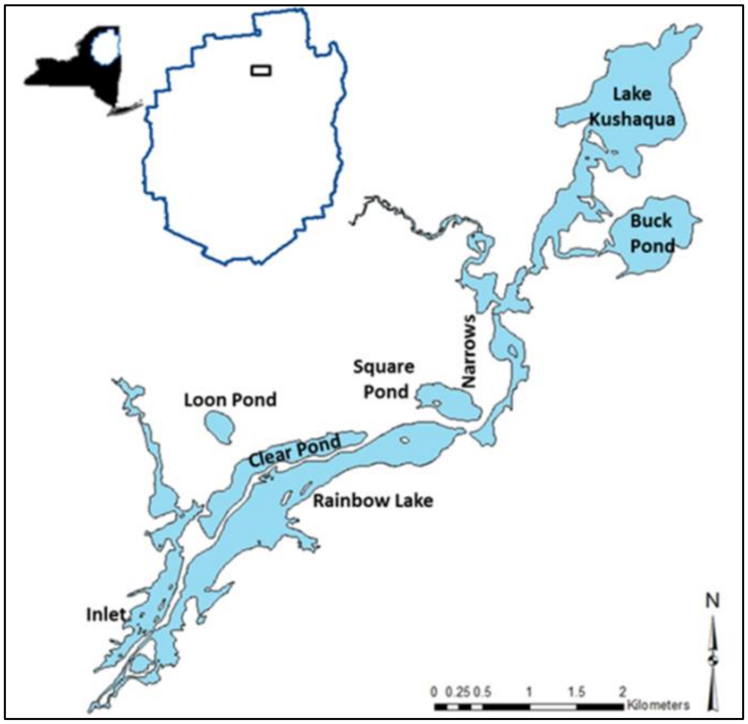


Figure 1. The Rainbow Lake Chain, located within the Adirondack Park of northern New York.

Methods

Study Area

The Rainbow Lake chain is located within the towns of Brighton and Franklin, in the northern Adirondacks of New York State. The Rainbow Lake watershed consists of a number of water bodies, including Rainbow Lake, Clear Pond, Square Pond, Loon Pond, The Flow and The Inlet. Within the watershed, water flows from Square Pond and Loon Pond into Clear Pond. Clear Pond drains into the Flow and directly to Rainbow Lake. The Flow drains through the Inlet and into Rainbow Lake. The Outlet of Rainbow Lake enters the North Branch of the Saranac River by way of Kushaqua Narrows, Lake Kushaqua and Mud Pond (**Figure 1**). This study specifically focuses on Rainbow Lake, Clear Pond and Lake Kushaqua. The morphometrics and watershed characteristics of the study lakes are described in **Table 1**.

Table 1. Morphometry and watershed characteristics of the study lakes in the Rainbow Lake Chain*.

	Rainbow Lake			
Location	County:	Franklin	Latitude:	44.1813
	Town:	Brighton	Longitude:	-74.2754
Lake Characteristics	Lake Area (ac):	356	Z-max (m):	17.1
	Lake Perimeter (mi):	11.8	Volume (m^3):	6,535,932
			Flushing Rate (T/Y):	1.7
Watershed Characteristics	Watershed Area (ac):	4,216	Residential (%):	0
	Surface Water (%):	6.3	Agriculture (%):	0
	Deciduous Forest (%):	48.7	Commercial (%):	0
	Evergreen Forest (%):	28.6	Local Roads (mi):	6.6
	Mixed Forest (%):	0.9	State Roads (mi):	0.0
	Wetlands (%):	0.8		
	Clear Pond			
Location	County:	Franklin	Latitude:	44.1813
	Town:	Brighton	Longitude:	-74.2754
Lake Characteristics	Lake Area (ac):	104	Z-max (m):	17
	Lake Perimeter (mi):	3.1	Volume (m^3):	2,840,976
			Flushing Rate (T/Y):	0.7
Watershed Characteristics	Watershed Area (ac):	798	Residential (%):	0
	Surface Water (%):	23	Agriculture (%):	0
	Deciduous Forest (%):	24	Commercial (%):	0
	Evergreen Forest (%):	29	Local Roads (mi):	0.0
	Mixed Forest (%):	1	State Roads (mi):	0.0
	Wetlands (%):	11		
	Lake Kushaqua			
Location	County:	Franklin	Latitude:	44.1813
	Town:	Franklin	Longitude:	-74.2754
Lake Characteristics	Lake Area (ac):	368	Z-max (m):	28
	Lake Perimeter (mi):	7.8	Volume (m^3):	9,541,862
			Flushing Rate (T/Y):	4.6
Watershed Characteristics	Watershed Area (ac):	18,875	Residential (%):	0
	Surface Water (%):	8.6	Agriculture (%):	0
	Deciduous Forest (%):	50	Commercial (%):	0
	Evergreen Forest (%):	28	Local Roads (mi):	10.2
	Mixed Forest (%):	1	State Roads (mi):	0.0
	Wetlands (%):			

*Watershed and lake areas are reported in English units as per request by the RLA. All other values in this report are in metric units, a standardized system of measurement used by scientists and lake managers throughout the world.

Field Sampling and Analysis

Lake data was collected from the deepest section of the lakes once a month during June, July, and August beginning in 1997 and continuing through 2016 for Rainbow Lake and Clear Pond. Monitoring of Lake Kushaqua was initiated in 2000 but was not repeated annually until 2009. Transparency was observed using a 20 cm black and white Secchi disk from the shady side of the vessel. Temperature and dissolved oxygen were determined every meter from the surface to the bottom with a YSI EXO-1 multi-meter. Surface water samples were collected using a 2 meter integrated tube sampler. The hypolimnetic water was collected from approximately 1 meter off the bottom using a 1 liter Kemmerer bottle. 250 mL of the surface water was immediately passed through a 0.45 µm cellulose membrane filter. The filter was collected, wrapped in foil and put on ice for chlorophyll-a analysis. All samples were kept on ice after collection and chemically preserved or stored at 4°C until analysis could be completed. Samples were analyzed for pH, conductivity, color, alkalinity, total phosphorus, nitrate, chlorophyll-a chloride and sodium at the AWI Environmental Research Lab following the analytical methods described in **Table 2**. Note, though the methods have been automated they are the same methods as those used historically, with the exception of chloride which has been updated to match the current standard method.

Table 2. Analytical techniques performed at the AWI Environmental Research Lab.

Analyte	Method Description	Reference
Lab pH	Mettler Toledo standard pH electrode	APHA
Conductivity	Conductivity at 25° C via Mettler Toledo conductivity cell	APHA 2510 B
Apparent Color	Single wavelength method with PtCO standards	APHA 2120 C
Chlorophyll-a	Trichromatic method uncorrected for phaeophyton	APHA 10200 H
Total Phosphorus	Acid-persulfate digestion, automated ascorbic acid	APHA 4500-P H
Nitrate + Nitrite	Automated cadmium reduction	APHA 4500-NO_3 I
Alkalinity	Automated methyl orange method	EPA 301.2
Chloride	Automated ion chromatography	EPA 300.0
Sodium	Inductively coupled plasma spectrophotometry	EPA 200.7

Average annual values for secchi disk transparency, total phosphorus, and chlorophyll-a were used to calculate Carlson's Trophic Status Index, (TSI), a commonly used quantitative index for classifying lakes based on trophic status (Carlson 1977). TSI values were calculated as follows:

- TSI (Secchi Disk) = 60 – 16.41xln[Secchi Disk (m)]
- TSI (Chlorophyll) = 30.6 + 9.81xln[Chlorophyll a(µg/L)]
- TSI (Total Phosphorus) = 4.15 + 14.42xln[Total Phosphorus (µg/L)]

Typically TSI values are between 0 and 100. Lakes with TSI values less 40 are classified as oligotrophic, TSI values between 40 and 50 are classified as mesotrophic, and TSI values greater than 50 are classified as eutrophic. A detailed description of TSI values and likely lake attributes is found in **Table 3**.

Average values for 2017 were calculated from the field and lab data and reported by sampling date and location (**Table 4 - 6**). Time series charts were constructed for the water quality indicators of water bodies, and trend analysis was conducted using Kendall's non-parametric regression to test the hypothesis "there is no relationship between the indicator and time". Simple linear trend lines were fit to data with significant trends and displayed on the corresponding chart.

Table 3. Trophic classification of lakes based on Carlson's Trophic State Index.

TSI Value	Trophic Classification	Likely Attributes
<30	Oligotrophic	Clear water, high oxygen throughout hypolimnion during the entire year
30-40	Oligotrophic	Clear water, periods of hypolimnetic anoxia possible during the summer in relatively shallow lakes
40-50	Mesotrophic	Moderately clear, increasing probability of hypolimnetic anoxia during the summer
50-60	Eutrophic	Mildly eutrophic. Decreased transparency, hypolimnetic anoxia, and warm water fishery only. Supports all recreational / aesthetic uses but threatened.
60-70	Eutrophic	Dominance of blue-green algae, algal blooms likely, extensive macrophytes growth in shallow water
70-80	Eutrophic	Heavy algal blooms possible throughout summer, hyper eutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes due to algal shading

Results and Discussion

The opening paragraphs in this section provide basic background information for understanding lake data followed by a discussion of the results for the study lakes. The 2017 water quality and trophic indicators of the Rainbow Lake Chain are tabulated in **Tables 4-6** and the historical trends are plotted in **Figures 7-8**.

Temperature and Dissolved Oxygen

Vertical mixing within the water column of a lake is a function of the waters temperature dependent density gradient (as water warms, it becomes less dense). When the ice comes off the lake in the spring the water column is isothermal, meaning it's all the same temperature, and thus all the same density. During isothermal conditions in the spring the lake can completely mix from top to bottom, this is referred to as "spring turnover". As spring progresses the surface waters are heated more rapidly than heat can be distributed by mixing. The thermal resistance to mixing increases between warm surface water and cooler and denser bottom water. If the lake is deep enough the water column will becomes stratified into three distinct strata. The epilimnion is the upper strata that is uniformly warm and freely mixes with itself. The hypolimnion is the bottom stratum that is uniformly cold and dense. In between the two strata is the metalimnion, a zone of sharp thermal change that prevents mixing between the surface and the bottom (Wetzel 2001). As the lake loses heat in the fall, the epilimnion becomes cooler and deeper. Eventually the lake is once again isothermal and freely mixes. This is referred to as "fall turnover"

Dissolved oxygen has been described as the most fundamental parameter of a lake, aside from the water itself (Wetzel 2001). Available oxygen is essential for aerobic metabolism and non-biotic chemical reactions. In addition the presence or absence of oxygen directly affects the solubility of a number of important inorganic nutrients such as phosphorus. The primary source of oxygen in a lake is the atmosphere, thus the in lakes that are thermally stratified the hypolimnion is isolated from the oxygen source. When lake sediments contain high amounts of organic material, bacterial decomposition consumes all of the dissolved oxygen resulting in hypolimnetic hypoxia (very low O_2 in hypolimnion). In some lakes a certain amount of hypolimnetic hypoxia may be natural; however nutrient enrichment resulting from human activities stimulates algal productivity and subsequent algal settlement, decomposition, and oxygen loss (i.e. Bertram 1993).

Several ecological processes are influenced by hypolimnetic hypoxia. The most obvious impact is loss to the fishery. Hypoxia has the potential to negatively affect individual fish growth, survival, reproduction, and ultimately population growth (Wu 2009). For example many game fish such as bass, pike and perch require oxygen concentrations above 4 mg/L, and native salmonid species such as brook trout and lake trout require oxygen concentrations greater than 5 mg/L (Spoor 1990). Many Adirondack lakes, including Rainbow Lake, have seen the extirpation of native trout due to hypolimnetic hypoxia (among other factors). Hypoxia also results in internal phosphorus loading to the lake. Lack of oxygen in the hypolimnion allows the release of dissolved phosphorus from the lake sediments. During fall turnover the phosphorus gets distributed through the entire water column (Wetzel 2001).

Temperature and dissolved oxygen data for the Rainbow Lake Chain are depicted as line graphs in **Figures 2-4**. The study lakes were strongly stratified during the entire study period, with epilimnion depths ranging from 2 to 4 meters all three lakes. All three of the lakes show strong hypolimnetic oxygen depletion by August. The depletion of oxygen in the bottom water certainly continues well into October. Since the last sampling date is in late-August, we don't have good data on the extent of oxygen depletion for the entire ice-free season. The hypolimnion of Rainbow Lake (**Figure 2**) exhibited its typical pattern of oxygen depletion. The hypolimnion was already devoid of oxygen during our first sampling trip on June 15th. The region of oxygen depletion increased to 8.5 meters by August, with 60% of the water column being hypoxic (D.O. < 2.0mg/L) or anoxic (D.O. <0.5mg/L). A similar pattern was observed in Clear Pond (**Figure 3**). Severe oxygen depletion was documented in the bottom five meters in July, and the bottom 12 meters in August (70% of the water column). Results indicate that Lake Kushaqua experienced oxygen depletion as well (**Figure 4**). We did not observe hypoxic conditions in the lake by August, but it likely occurred in the very deepest part of the lake by the autumn. The hypoxic condition of the Rainbow Lake chain can affect the concentrations of other chemical parameters, which will be discussed later in this report.

Table 4. Water quality and trophic indicators for Rainbow Lake, 2017. BDL = below laboratory detection level, ± indicates an estimated value.

Rainbow Lake: Water Quality Indicator	Sampling Date			Average
	6/15/2017	7/28/2017	8/22/2017	
		Epilimnion (surface water)		
Secchi Transparency (m)	3.0	2.6	2.6	2.7
Total Phosphorus (µg/L)	9.6	13.6	10.5	11.2
Chlorophyll-*a* (µg/L)	6.6	7.8	6.1	6.8
Laboratory pH	7.2	7.5	7.3	7.3
Specific Conductance (µS/cm)	37.0	32.7	34.8	34.8
Color (Pt-Co)	50.4	53.6	50.4	51.5
Alkalinity (mg/L)	14.9	14.8	15.9	15.2
Nitrate-Nitrogen (µg/L)	BDL	BDL	BDL	BDL
Chloride (mg/L)	1.9	1.9	2.0	1.9
Sodium (mg/L)	1.3	1.3	1.4	1.3
		Hypolimnion (bottom water)		
Total Phosphorus (µg/L)	16.5	13.7	62.7	31.0
Laboratory pH	6.7	6.5	6.7	6.6
Specific Conductance (µS/cm)	42.2	42.4	59.5	48.0
Color (Pt-Co)	95.4	85.5	191.9	124.3
Alkalinity (mg/L)	17.7	19.0	24.1	20.3
Nitrate-Nitrogen (µg/L)	55.8	112.0	BDL	± 55.9
Chloride (mg/L)	1.4	2.0	2.1	1.8
Sodium (mg/L)	1.4	1.4	1.5	1.4

Table 5. Water quality and trophic indicators for Clear Pond, 2017. BDL = below laboratory detection level.

Clear Pond: Water Quality Indicator	Sampling Date 6/15/2017	7/28/2017	8/22/2017	Average
	Epilimnion (surface water)			
Secchi Transparency (m)	3.7	2.7	2.7	3.0
Total Phosphorus (µg/L)	12.0	13.0	8.7	11.2
Chlorophyll-*a* (µg/L)	3.8	5.7	6.4	5.3
Laboratory pH	7.6	7.0	7.4	7.3
Specific Conductance (µS/cm)	23.7	23.8	23.0	23.5
Color (Pt-Co)	34.3	37.5	34.3	35.4
Alkalinity (mg/L)	11.1	10.7	11.6	11.1
Nitrate-Nitrogen (µg/L)	BDL	BDL	BDL	BDL
Chloride (mg/L)	0.6	0.8	0.9	0.8
Sodium (mg/L)	0.8	0.8	0.9	0.9
	Hypolimnion (bottom water)			
Total Phosphorus (µg/L)	16.6	21.1	20.3	19.3
Laboratory pH	6.7	6.2	6.3	6.4
Specific Conductance (µS/cm)	27.9	29.6	29.5	29.0
Color (Pt-Co)	60.0	117.9	150.1	109.3
Alkalinity (mg/L)	13.2	13.1	14.2	13.5
Nitrate-Nitrogen (µg/L)	46.1	134.0	65.4	81.8
Chloride (mg/L)	0.8	0.8	0.9	0.8
Sodium (mg/L)	0.9	0.9	1.0	0.9

Table 6. Water quality and trophic indicators for Lake Kushaqua, 2017. BDL = below laboratory detection level, ± indicates an estimated value.

Lake Kushaqua: Water Quality Indicator	Sampling Date			Average
	6/15/2017	7/28/2017	8/22/2017	
	Epilimnion (surface water)			
Secchi Transparency (m)	2.4	1.6	2.4	2.1
Total Phosphorus (µg/L)	11.5	14.4	12.4	12.8
Chlorophyll-*a* (µg/L)	4.8	6.4	5.6	5.6
Laboratory pH	7.2	7.0	7.3	7.2
Specific Conductance (µS/cm)	34.0	31.5	35.4	33.6
Color (Pt-Co)	56.8	89.0	72.9	72.9
Alkalinity (mg/L)	16.1	14.9	17.9	16.3
Nitrate-Nitrogen (µg/L)	BDL	BDL	BDL	BDL
Chloride (mg/L)	1.0	1.0	1.1	1.0
Sodium (mg/L)	1.0	1.0	1.2	1.0
	Hypolimnion (bottom water)			
Total Phosphorus (µg/L)	11.0	16.8	21.1	16.3
Laboratory pH	6.9	6.4	6.4	6.6
Specific Conductance (µS/cm)	29.7	31.7	32.5	31.3
Color (Pt-Co)	76.1	92.2	134.0	100.8
Alkalinity (mg/L)	13.8	14.0	14.9	14.2
Nitrate-Nitrogen (µg/L)	153.0	183.0	209.0	181.7
Chloride (mg/L)	0.8	0.9	0.9	0.9
Sodium (mg/L)	0.9	0.9	1.0	0.9

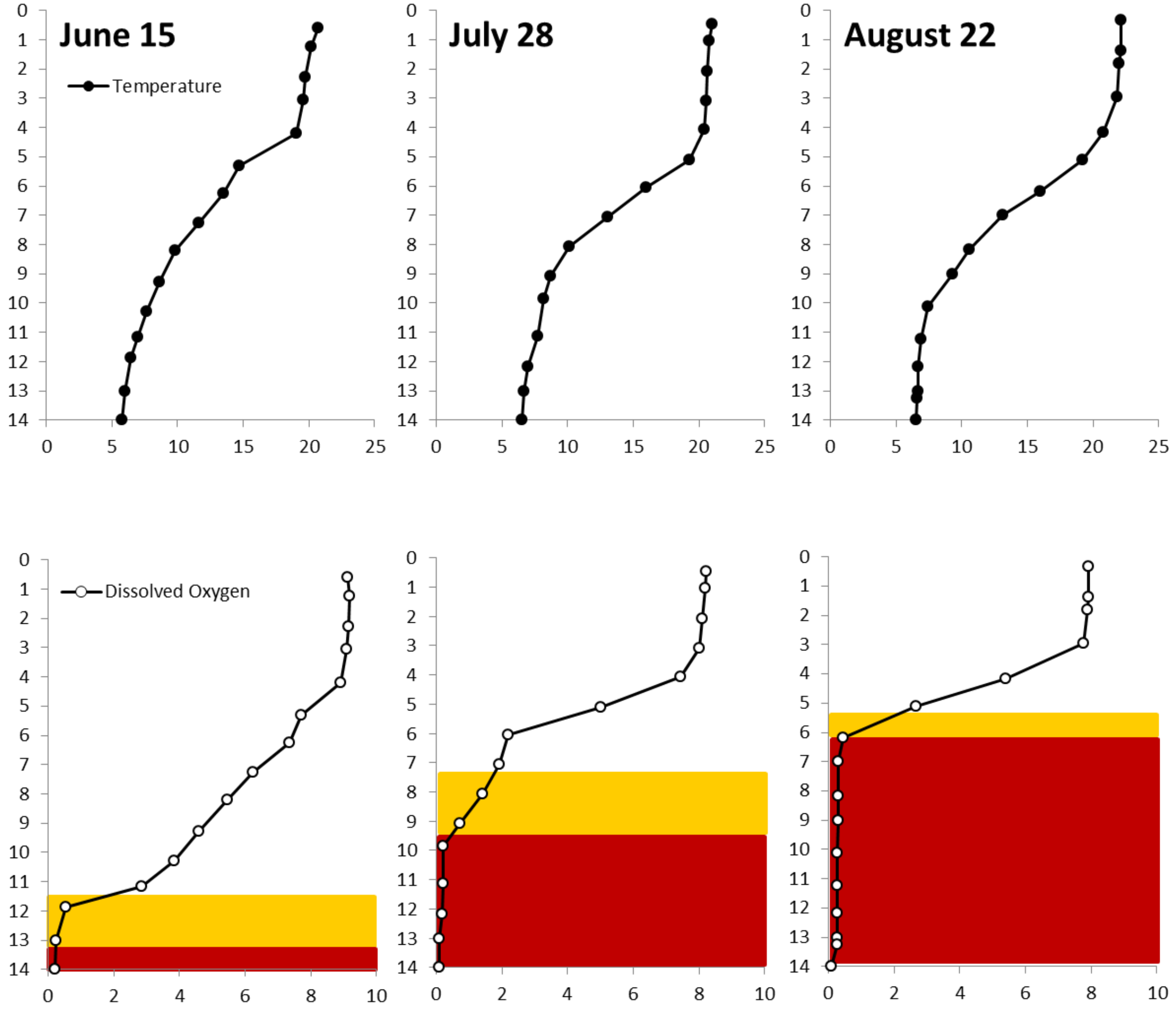


Figure 2. Temperature (upper panels) and dissolved oxygen (lower panels) of Rainbow Lake, June - August 2017. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L)

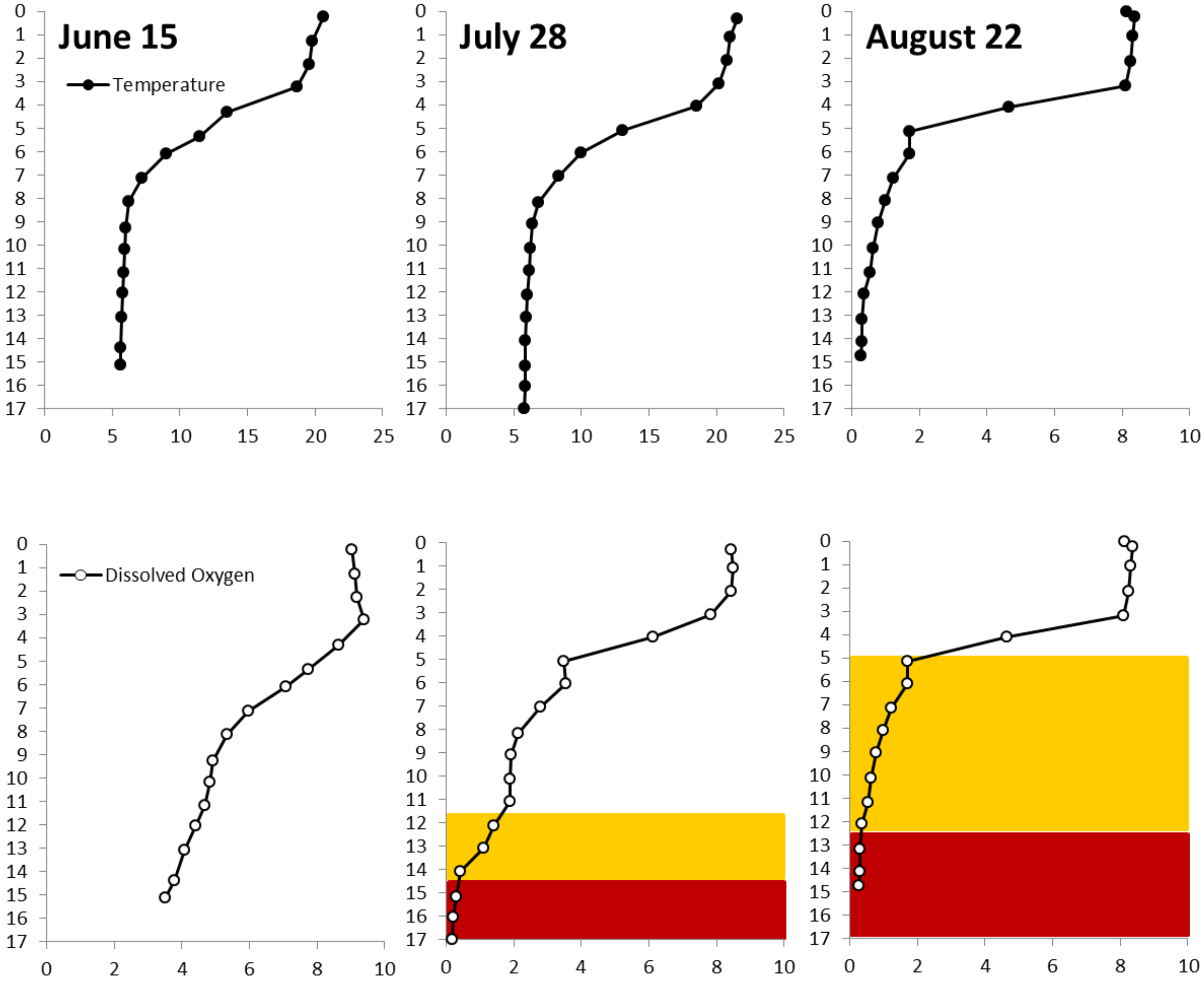


Figure 3. Temperature (upper panels) and dissolved oxygen (lower panels) of Clear Pond, June - August 2017. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L).

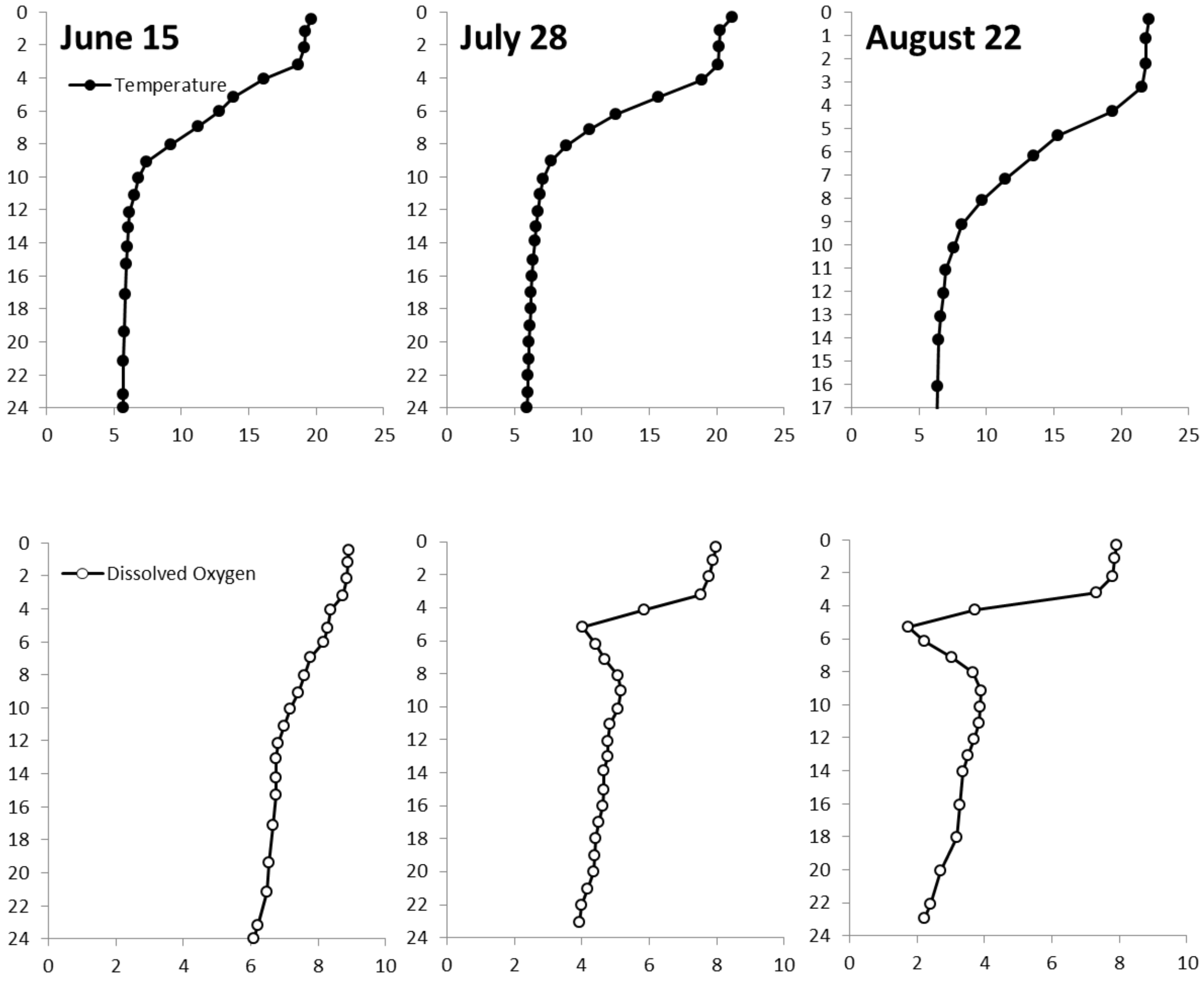


Figure 4. Temperature (upper panels) and dissolved oxygen (lower panels) of Lake Kushaqua, June - August 2017. Yellow shaded boxes indicate zones of hypoxia (D.O. <2.0 mg/L), red shaded boxes indicate zones of anoxia (D.O. <0.5 mg/L).

Transparency

Transparency is a measure of water clarity in lakes. It is measured by lowering a 20 cm black and white disk (Secchi disk) to the depth where it is no longer visible from the surface. The transparency of a lake is influenced by many factors, including algal abundance, turbidity, suspended sediments, and dissolved organic matter (Hutchinson 1957). Transparency can serve as an important indicator of overall trophic condition of a lake as well as influencing human perception of water quality. In general, lakes that have low productivity and low algal abundance have greater secchi transparencies. As algal productivity increases secchi depths become much shallower. Transparency can also be influenced by the amount of dissolved organic material in the water. Dissolved organic matter rapidly attenuates light, resulting in lower transparencies.

Transparency of Rainbow Lake averaged 2.7 meters in 2017, which is 20% lower than the average from the previous year. Historically, annual average Secchi transparency has ranged from 2.6 to 4.1 meters, with no significant trend detected (p value = 0.39, **Figure 5**).

In Clear Pond transparency ranged from 2.7 to 3.7 meters in 2017, and averaged 3.0 meters. Historically transparency in Clear pond has ranged between 3.0 to 4.6 meters, with a significant downward trend detected at a rate of approximately 4 cm/year (p value = 0.1, T = -0.35, **Figure 6**).

Transparency of Lake Kushaqua ranged from 1.6 to 2.4 meters in 2017. Since 2000, the average transparency of Lake Kushaqua has ranged from a low of 2.3 to a high of 3.7 meters. We have observed a steady decrease in transparency of Lake Kushaqua, decreasing at a rate of approximately 8 centimeters per year (p value = 0.05, T = -0.54, **Figure 7**).

Chlorophyll-a

Chlorophyll-a is the primary photosynthetic pigment found in all species of algae. A measurement of chlorophyll in a lake provides a surrogate measure of algal productivity (Wetzel 2001). Chlorophyll-a is not a direct measure of algal biomass as the concentration of chlorophyll varies somewhat by species and environmental conditions. This said, increases in chlorophyll are generally associated with increased algal production, and the concentration of chlorophyll is widely considered as the most direct measure of the trophic state of lakes. Algal biomass is affected by nutrient availability, water temperature, and light, so there can be considerable variation in chlorophyll concentrations throughout the year depending on which of these three factors is limiting growth at a particular time. Though, major changes in algal biomass (e.g. an algae bloom), and thus chlorophyll, are usually related to changes in the availability of phosphorus, nitrogen, silica or inorganic carbon (Wetzel 2001; Klemer 1990).

Chlorophyll concentration in Rainbow Lake ranged from 6.1 to 7.8 µg/L and averaged 6.8 µg/L in 2017. Historically, chlorophyll concentrations in Rainbow have ranged from 4.6 to 9.8 µg/L. No significant trend was detected in the historical data for chlorophyll-a (p value = 0.13, **Figure 5**).

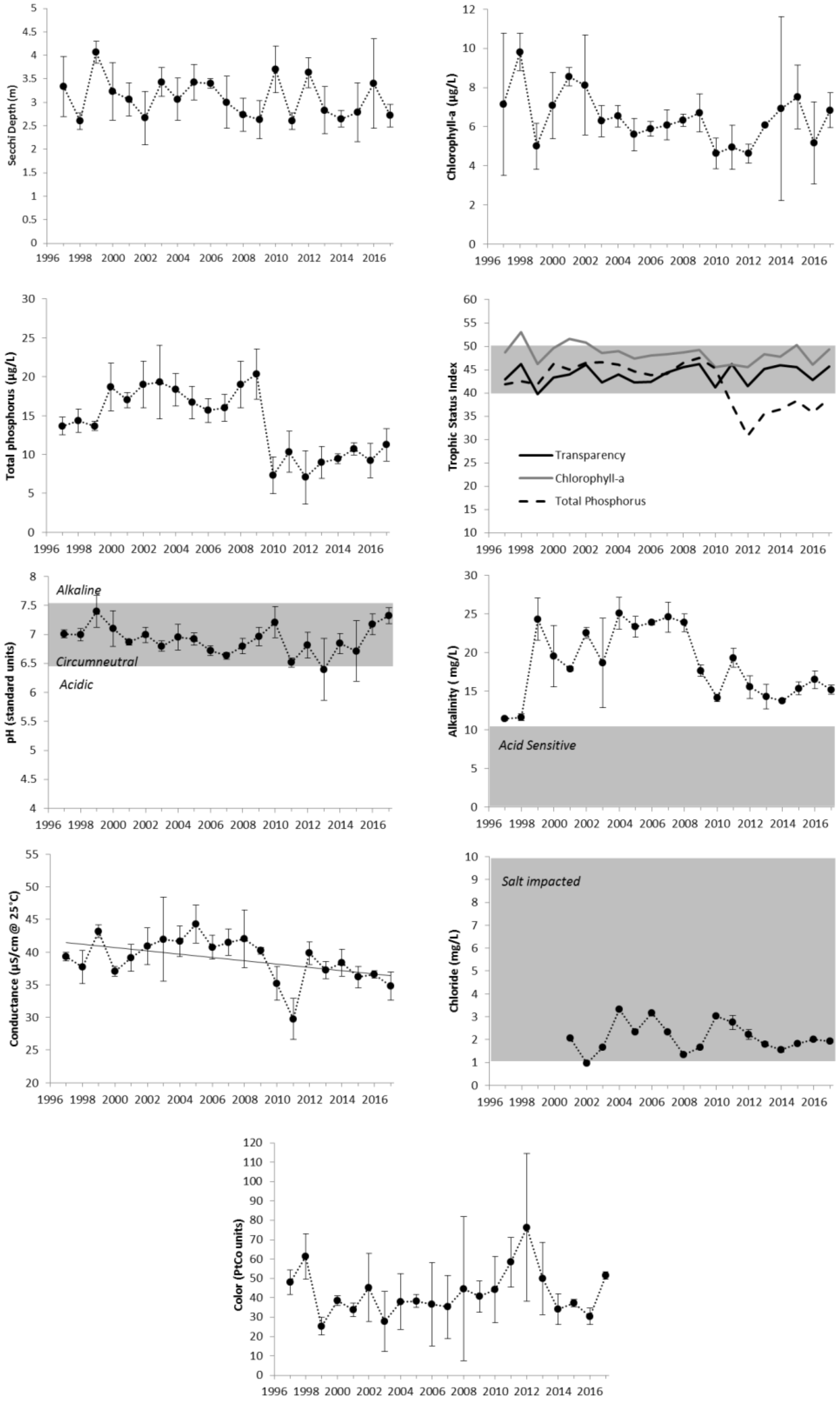


Figure 5. Time series of water quality and trophic indicators in the surface water of Rainbow Lake, 1997-2017. Statistically significant trends ($p < 0.05$) are denoted with a trend line.

Clear Pond

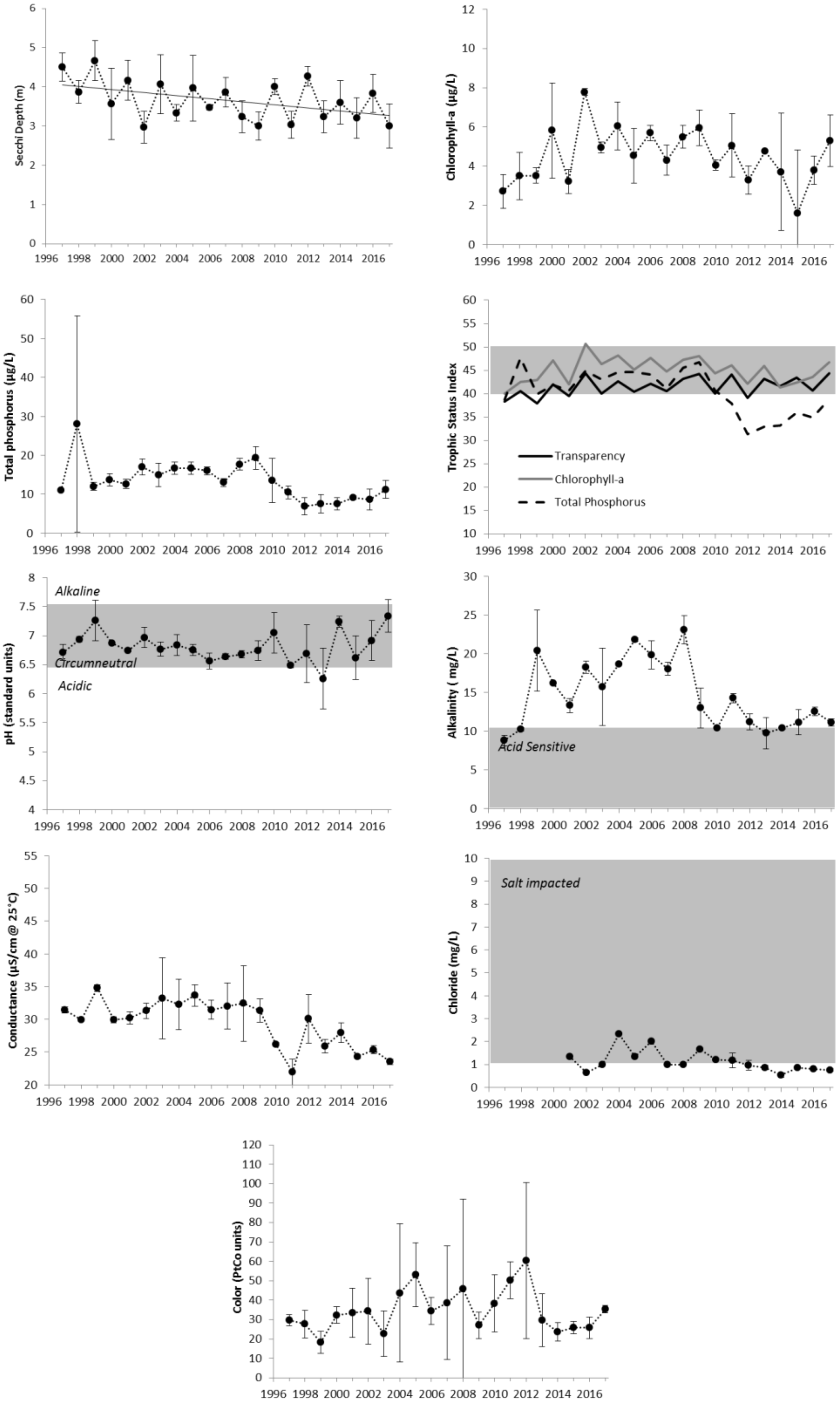


Figure 6. Time series of water quality and trophic indicators in the surface water of Clear Pond, 1997-2017. Statistically significant trends ($p < 0.05$) are denoted with a trend line.

Lake Kushaqua

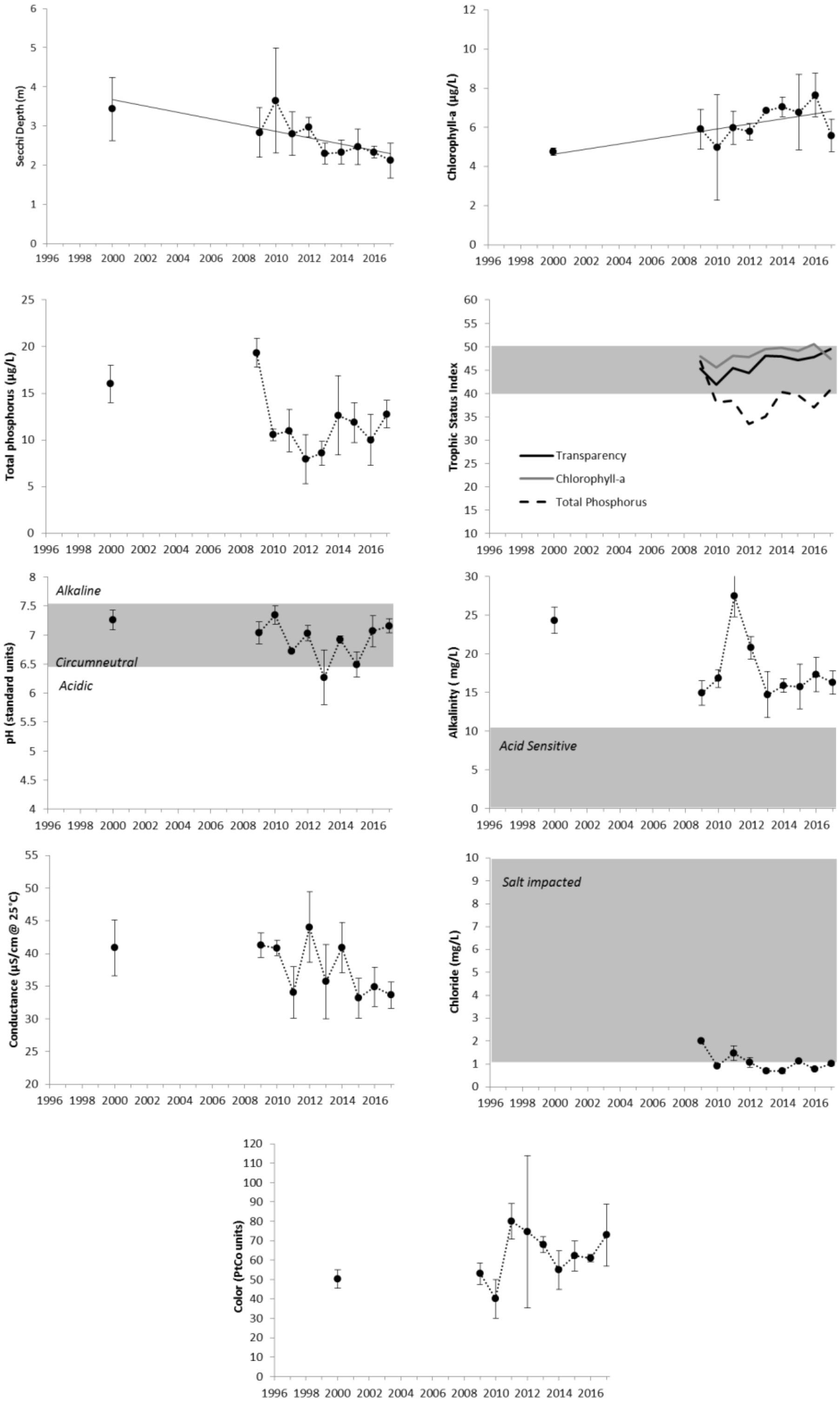


Figure 7. Time series of water quality and trophic indicators in the surface water of Clear Pond, 1997-2016. Statistically significant trends ($p < 0.05$) are denoted with a trend line.

In Clear Pond chlorophyll concentration ranged from 3.8 to 6.4 µg/L in 2017. Over the past 21 years average chlorophyll concentrations in Clear Pond have ranged from as low as 2.7 to as high as 7.7 µg/L with no statistical trend in the data (p value = 0.71, **Figure 6**).

In Lake Kushaqua chlorophyll-a ranged from 4.8 to 6.4 µg/L and averaged 5.6 µg/L in 2017. We observed a significant increase in average chlorophyll in Lake Kushaqua since 2010, increasing at a rate of approximately 0.1 µg/L/year (p value = 0.03, T = 0.64, **Figure 7**).

Phosphorus

Phosphorus is of major importance to structure and metabolism of all organisms. However, it exists in relatively small amounts in freshwater systems compared to other essential nutrients such as carbon, hydrogen, oxygen, and sulfur. The addition of extra phosphorus to an aquatic system allows production to increase greatly because all other essential elements are typically available in excess. Thus phosphorus is typically the limiting nutrient in aquatic systems (Schindler 1974, Wetzel 2001), and widely considered as the most important contributor to reduced water quality in lakes (Søndergaard et al. 2003). Natural weathering releases phosphorus from rocks and soils, and it also enters our watersheds in fertilizers, human waste, and atmospheric deposition. Phosphorus exists in a number of forms in aquatic systems, including readily available dissolved phosphorus, and organically and inorganically bound phosphorus. Total phosphorus is all of the forms of phosphorus combined and serves as an important indicator of overall trophic status of a lake. Generally speaking, lakes of low productivity (oligotrophic) have total phosphorus concentrations less than 10 µg/L, while highly productive lakes (eutrophic) have total phosphorus concentrations greater than 20 (NYS DEC assessment criteria).

Total phosphorus in the epilimnion of Rainbow Lake ranged from 9.6 to 13.6 µg/L in 2017. Historically, total phosphorus concentrations in the epilimnion have been notably lower over the past 8 years. However, when we consider the entire 21 year data set no significant trend is apparent (p value = 0.07, **Figure 5**). In the hypolimnion total phosphorus was significantly higher, ranging from 13.7 to 62.7 µg/L. The elevated phosphorus in the hypolimnion is the result of the anoxic conditions exhibited in Figure 2. Oxygen depletion in the hypolimnion creates reducing conditions that allows the release of dissolved phosphorus from the lake sediments in process known as internal loading.

In the epilimnion of Clear Pond the total phosphorus concentration ranged from 8.7 to 13.2 µg/L. Values in the hypolimnion of Clear Pond were also elevated and ranged from 16.6 to 21.1µg/L. Historically, average total phosphorus concentrations in the epilimnion of Clear Pond have ranged from 6.8 to as high as 28. There was no statistical trend in the historical data (p value = 0.07, **Figure 7**).

The total phosphorus concentration in the epilimnion of Lake Kushaqua ranged from 11.5 to 14.4 µg/L, and averaged 12.8 µg/L in 2017. Total phosphorus was only slightly elevated in the hypolimnion of Lake Kushaqua, were concentrations ranged from 11.0 to 21.1 µg/L. Historically, total phosphorus has ranged from 8 to 19.3 µg/L in the epilimnion with no statistical trend in the data (p value = 0.71, **Figure 7**).

Trophic Status

Trophic status is a term derived from the Greek word *trophi*, meaning food or nourishment, and is used by limnologists to explain the overall productivity of a lake. Lake productivity is naturally influenced by the rate of nutrient supply from the watershed, climatic condition, and lake and watershed morphology. Human activities and development within a watershed has the potential to increase the rate of nutrient supply into the lake, and thereby accelerate algal productivity (cultural eutrophication).

Lakes are typically assigned into one of three trophic or productivity classes (oligotrophic, mesotrophic, eutrophic) based on total phosphorus, chlorophyll *a*, and Secchi transparency.

- Oligotrophic - From the Greek words *oligo*, meaning few and *trophi*, meaning nourishment; oligotrophic lakes have low levels of available nutrients. As a result of low nutrients, oligotrophic lakes have high transparency, low algal abundance, low organic matter in the sediments, sparse aquatic plant growth, and abundant dissolved oxygen throughout the water column the entire year. Oligotrophic lakes are most likely to support a cold water fishery (Wetzel 2001).

- Eutrophic - From the Greek words *Eu*, meaning good. Eutrophic lakes have abundant levels of nutrients. As a result of high nutrient availability eutrophic lakes are typified by high algal productivity, low transparency, high organic matter in the sediments, and periods of anoxia in the bottom of the water column (hypolimnion). Eutrophic lakes tend to support dense aquatic plant growth in the littoral zone. Eutrophic lakes are unlikely to support a viable cold water fishery (Wetzel 2001).

- Mesotrophic - from the Greek words *Meso*, meaning the middle. Mesotrophic lakes and an intermediate trophic classification on the continuum between oligotrophy and eutrophy.

The Carlson Trophic Status Index (TSI) is a common and valuable metric for evaluating the productivity of a lake (Carlson 1977). The index is calculated by logarithmically converting the values of Secchi transparency, chlorophyll-a concentration and total phosphorus to a scale of relative trophic state ranging from 0-100. TSI values less than 40 are considered oligotrophic, values between 40 and 50 are considered mesotrophic, and values grater that 50 are eutrophic (**Table 3**) Calculation the TSI scores from three trophic indicators allows further interpretation of productivity status of the lake.

The TSI Index for Rainbow Lake calculated with secchi transparency (46) and chlorophyll-a (49) indicate a mesotrophic classification, while the TSI for total phosphorus (39) suggest an oligotrophic classification for the lake. This disparity is not unusual for phosphorus limited lakes. The trophic state of the lake typically fluctuated within the mesotrophic boundaries since monitoring began, with all three indicators generally in fairly close agreement (**Figure 5**).

The Trophic State Index for Clear Pond calculated with secchi transparency (44), chlorophyll (47), and total phosphorus (40) all indicate a mesotrophic condition for the pond. The trophic state of the pond typically fluctuated within the mesotrophic boundaries since monitoring began, with all three indicators in fairly close agreement (**Figure 6**).

The Trophic State Index for Lake Kushaqua calculated with secchi transparency (49), chlorophyll (47), and phosphorus (41) indicated a mesotrophic status. The lake has exhibited mesotrophic characteristics since monitoring began in 2000 (**Figure 7**).

pH and Alkalinity

pH is a measurement of the concentration of hydrogen ions in water (acidity). Hydrogen ions are very active, and their interaction with other molecules determines the solubility and biological activity of gasses, nutrients, and heavy metals; thus pH is considered a master variable for its influence on chemical processes and aquatic life. pH exists on a logarithmic scale between 0 and 14. Because pH is logarithmic a decrease in 1 pH unit represents a 10 fold increase in hydrogen ion activity. Lakes are considered circumneutral when they have a pH between 6.5 and 7.5, pH values less than that are considered acidic and greater than that are considered basic. The majority of lakes in temperate and tropical regions have pH values between 6.5 and 9. Lakes can become acidified when they are influenced by organic acids from wetlands and bogs or when acidic precipitation falls on a poorly buffered watershed (Dodson 2005, Wetzel 2001).

Alkalinity (or acid neutralizing ability) measures the buffering capacity of a lake, which is the ability of the lake to resist a change in pH. High alkalinity lakes are well buffered against changes in pH, while low alkalinity lakes are poorly buffered against changes in pH. Thus, a high alkalinity lake would have a more stable pH compared to a low alkalinity lake, and a more stable pH is less stressful to aquatic life. Alkalinity largely depends on the concentration of calcium carbonate in the water, and lakes with less than 10 ppm calcium carbonate are highly sensitive to acidification, while lakes with greater than 20 ppm calcium carbonate are not sensitive to acidification (Godfrey et al. 1996).

The lakes of the Rainbow Chain are circumneutral water bodies, and all have moderate acid neutralizing ability. In 2017, the pH of the water typically ranged between 7.0 and 7.5, and the alkalinity often ranged between 11 and 16 mg/L (**Tables 4-6**). For example, the pH of Rainbow Lake averaged 7.3, and the alkalinity averaged 15 mg/L. Historically, the pH and acid neutralizing ability of the lakes in the chain have remained relatively constant, and have not exhibited any significant trends over time (acidity P values: Rainbow lake = 0.16, Clear = 0.53, Kushaqua = 0.91; **Figures 5, 6 and 7**).

Color

The observed color of a lake is an optical property that results from light being scattered upwards after selective absorption by water molecules as well as dissolved (metallic ions, organic acids) and suspended materials (silt, plant pigments). For example, alkaline lakes with high concentrations of calcium carbonate scatter light in the green and blue wavelength and thus appear turquoise in color. Lakes rich in dissolved organic matter and humic compounds absorb shorter wavelengths of light such as green and blue and scatter the longer wavelengths of red and yellow, thus these lakes appear to be brown in color (Wetzel 2001). Thus analysis of color can provide us with information about the quantity of dissolved organic material in the water. For objective quantification of apparent color we compare water samples to standards of platinum-cobalt solution. (Pt-Co units).

Lake Kushaqua was the most highly colored of the study lakes, with color values ranging from 56 to 89 Pt-Co units. Average surface water color for Rainbow Lake and Clear Pond were substantially lower than Kushaqua, averaging 51 and 35 Pt-Co units respectively (**Tables 4-6**). No historical trend was detected in color in any of the study lakes (**Figures 5-7**).

Conductivity

Pure water is a poor conductor of electricity. The ability of water to conduct electricity increases as the concentration of dissolved ions in the water increases. Thus, conductivity is measured as an indicator of dissolved ions in water. Typically the conductivity of clean undeveloped lake in the Adirondacks is in the range of 10-25 µS/cm. Elevated conductance may be indicative of road salt pollution, faulty septic systems or the influence of bogs and wetlands in the watershed. Conductivity is a very useful surrogate when the relationships between ion concentrations and conductivity are known. For example, conductivity can be used to estimate sodium and chloride concentrations (Daley et al. 2009).

The lowest conductivity in the Rainbow Lake Chain was found in Clear Pond, where the 2017 average was 23.5 µS/cm. Clear Pond also has the smallest watershed with the least amount of development. Average surface conductivity in Rainbow Lake and Lake Kushaqua were 34.8 and 33.6 µS/cm respectively (**Tables 4-6**). No historical trend was detected in the conductivity Clear Pond (p value = 0.26), of Lake Kushaqua (p value = 0.51); However, we did detect a slight downward trend in conductance in Rainbow lake, as a rate of approximately 0.25 µS/cm /year of the study lakes (p value: Rainbow = 0.03, **Figures 5-7**).

Sodium and Chloride

Non-impacted Lakes in the Adirondack region have naturally low concentrations of sodium and chloride, with median background concentrations of 0.5 mg/L and 0.2 mg/L respectively. However, wide spread use of road deicers (primarily sodium chloride) have significantly increased the concentration of these chemicals in lakes that have salted roads in their watersheds (Kelting et al 2012). In the Adirondack region chloride concentrations exceeding 1 mg/L are indicative of external salt loads (Kelting and Laxson 2015). Sodium and chloride can have negative effects on aquatic life when at high concentrations (Corsi et al. 2010), and can impart an undesirable taste to drinking water. The US EPA has a drinking water guideline of 250 mg/L for chloride and 20 mg/L for sodium, but these is not an enforceable standard.

Average chloride concentrations in 2017 were 1.9 mg/L for Rainbow Lake, and 0.8 mg/L for Clear Pond and 1.0 mg/L for Lake Kushaqua Average sodium concentrations were 1.3 mg/L for Rainbow Lake, 0.9 mg/L for Clear Pond, and 1.0 mg/L for Lake Kushaqua (**Tables 4-6**). Rainbow and Kushaqua Lakes have paved roads in the watershed, which along with shoreline development, are likely responsible for the slightly elevated concentrations of sodium and chloride above the levels observed for non-impacted lakes. No statistical trend was detected in the historical chloride concentrations for the Rainbow Lake chain (p value: Rainbow = 0.61, Clear = 0.16, Kushaqua = 0.10(**Figures 5-7**).

Literature Cited

Bertram, P. E. 1990. Total phosphorus and dissolved oxygen trends in the central basin of Lake Erie, 1970–1991. 19:224-236.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, 22(2):361-369.

Corsi, S.R., Graczyk, D.J., Geis, S.W., Booth, N.L., and Richards, K.D. 2010. A fresh look at road salt: aquatic toxicity and water quality impacts on local, regional, and national scales. Environmental Science and Technology, 44(19):7376-7382.

Daley, M.L., J.D. Potter, and W.H. McDowell. 2009. Salinization of urbanizing New Hampshire streams and groundwater: effects of road salt and hydrologic variability. Journal of the North American Benthological Society, 28(4):929–940.

Dodson, S.I. 2005. Introduction to Limnology. McGraw Hill, New York. 400pp.

Driscoll, C.T., K.M. Driscoll, M.J. Mitchell, and D.J. Raynal. 2003. Effects of acidic deposition on forest and aquatic ecosystems in New York State. Environmental Pollution, 123:327–336.

Godfrey, P.J., M.D. Mattson, M.-F. Walk, P.A. Kerr, O.T. Zajicek, and A.Ruby III. 1996. The Massachusetts Acid Rain Monitoring Project: Ten Years of Monitoring Massachusetts Lakes and Streams with Volunteers. Publication No. 171. University of Massachusetts Water Resources Research Center.

Hutchinson, G. E. 1957. A Treatise on Limnology. Vol. 1. Geology, Physics, and Chemistry. John Wiley and Sons, New York. 1015pp.

Kelting, D.L., C.L. Laxson, E.C. Yerger. 2012. A regional analysis of the effect of paved roads on sodium and chloride in lakes. Water Research, 46(8):2749-2758.

Kelting, D.L., and C.L. Laxson. 2015. State of Adirondack Lakes. Adirondack Lake Alliance Meeting. July 28th 2015. Paul Smith's College, Paul Smiths NY

Klemer, A.R. 1991. Effects of nutritional status on cyanobacterial buoyancy, blooms, and dominance, with special reference to inorganic carbon. Canadian Journal of Botany, 69: 1133-1138.

Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: implications for lake management. Science 184:897-899.

Søndergaard, M., J.P. Jensen, and E. Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia, 506-509:135-145.

Spoor, W. A. 1990. Distribution of fingerling brook trout, *Salvelinus fontinalis*, in dissolved oxygen concentration gradients. Journal of Fish Biology 36: 363-373.

Wetzel, R.G. 2001. Limnology, Lake and River Ecosystems, 3rd Edition. Academic Press, New York. 1006pp.

Wu, R.S. 2009. Effects of hypoxia on fish reproduction and development. Fish physiology 27: 79-141.