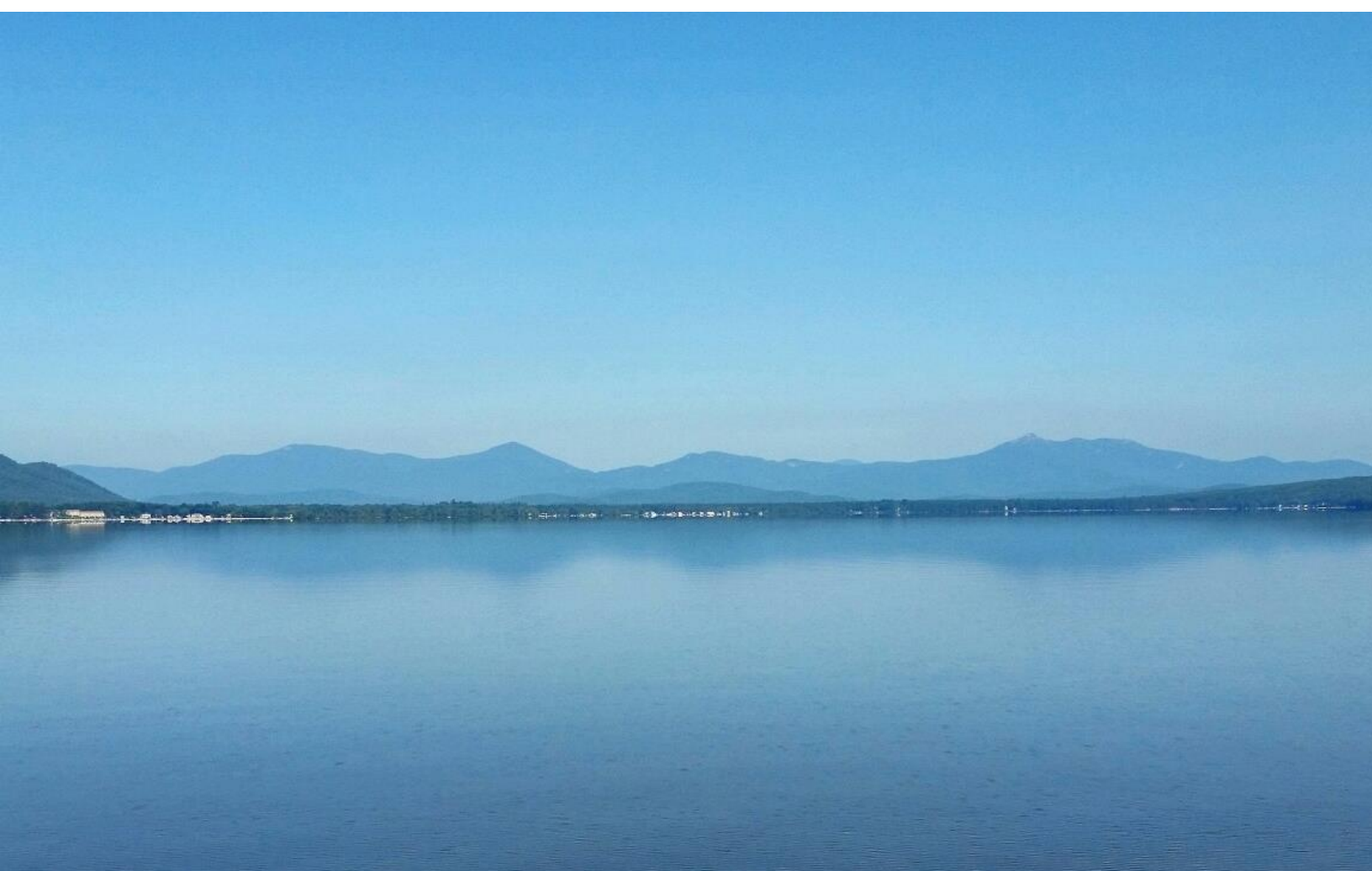


OSSIPEE LAKE

WATER QUALITY ANALYSIS (1976-2016)



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APRIL 2017



Funding for this project was provided in part by: a Watershed Assistance Grant from the NH Department of Environmental Services with Clean Water Act Section 319 funds from the U.S. Environmental Protection Agency.
The NH Charitable Foundation
The Royal Little Family Foundation
The Adelard and Valeda Lea Roy Foundation

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EXECUTIVE SUMMARY

Overall, water quality in Ossipee Lake is generally very good and has been stable over the last 40 years, showing some interannual variation likely related to weather patterns. However, water clarity may be declining and anoxic conditions in bottom waters may be becoming more prevalent in recent years. Furthermore, poor water quality in several tributaries raises concerns about their effect on Ossipee Lake.

OSS�PEE LAKE

- **Total phosphorus (TP)** has been relatively stable since its record high in 1976, with no significant trend, but some interannual variation. Median TP is very low (6.5 ppb; 2007-2016) and meets oligotrophic criteria. One **total Kjeldahl nitrogen (TKN)** sample in 1987 exceeded guidelines from the Volunteer River Assessment Program, possibly indicating pollution, such as fertilizers or septic systems during that time period (likely following a storm event).
- **Secchi disk transparency (SDT)** and **Chlorophyll-a (Chl-a)** do not show any statistically significant trends over the data collection period. Median SDT (4.0 m; 2007-2016 without scope) may vary with summer precipitation as increased sediment delivery during wetter summers causes turbid lake conditions. More data are needed to statistically support a possible degradation in SDT since 1976. Median Chl-a (2.0 ppb; 2007-2017) is better than the oligotrophic criteria (3.0 ppb), but annual medians vary from year to year (1.3 to 4.5 ppb) and appear to be related to spikes in median annual TP.
- **Dissolved oxygen (DO)** and **temperature** profiles from the deep spot in Ossipee Lake show typical midsummer stratification of New Hampshire lakes. Low levels of DO in the hypolimnion may be becoming more frequent at shallower depths since 2008, though sampling in the late summer months (when low DO is more likely to occur) has also increased. Though low DO at bottom depths can be naturally occurring, its persistence can threaten fish species seeking cooler waters in the summer and increase internal phosphorus loading that feed algal growth.
- **pH** and **alkalinity/acid neutralizing capacity** levels indicate that the lake is slightly acidic (typical of NH lakes) and has a “moderately vulnerable” buffering capacity against additional acidic inputs, which is slightly above the typically-low buffering capacity of most NH waterbodies.
- **Specific conductance** is low and similar to State and regional averages of other lakes in NH. **Chloride** was very low (< 8 ppm) and well below the chronic exposure limit of 230 ppm.
- Based on the **Assimilative Capacity Analysis**, Ossipee Lake falls in the Tier 2 category. TP levels are low enough that there is some remaining capacity to assimilate additional phosphorus inputs.

TRIBUTARIES

- Several **tributaries** to Ossipee Lake show elevated TP, elevated TN, high turbidity (i.e., suspended sediments), and low pH, which raises concerns about their effect on water quality in the lake. Of particular concern are **Red Brook (OL-7)** and **Weetamoe Brook (OL-5ua)**, which should be prioritized for future monitoring and land use investigation of potential NPS pollution.

1. PURPOSE

The purpose of this report is to provide a thorough review of available water quality data and determine a list of recommendations that will help guide Green Mountain Conservation Group (GMCG) and stakeholders in setting a water quality goal for Ossipee Lake, located in Freedom and Ossipee, NH. This water quality goal will be used to measure the success of future watershed management actions, which will be a major component of the Ossipee Lake Shoreline and Lovell River Watershed Management Plan. GMCG received funding under Section 319 of the Clean Water Act from the NH Department of Environmental Services (NHDES) to develop the management plan, which will analyze the state of current and historical water quality (described in this report), identify potential sources of nonpoint source (NPS) pollution in the watershed, and make prioritized recommendations that will treat these sources and help the community reach their water quality goal for Ossipee Lake.

2. INTRODUCTION

Bounded by the Sandwich Range to the northwest and Ossipee Mountains to the south, the Ossipee Watershed is a subwatershed of the Saco River Basin and covers about 379 square miles across fourteen towns in eastern New Hampshire. The Ossipee Watershed contains New Hampshire's largest and deepest stratified-drift aquifer, which serves as the region's primary source of drinking water. The Ossipee Watershed also contains 82 lakes and ponds that cover 14.7 square miles with Ossipee Lake, the seventh largest lake in New Hampshire, at its center. Ossipee Lake is connected to five other major waterbodies in the watershed (Broad Bay, Leavitt Bay, Berry Bay, Danforth Ponds, and Huckins Pond), all of which are fed by fourteen major tributaries.

Ossipee is an important recreational resource and economic driver in the region, but its water quality is vulnerable to landscape change from development. The challenge, similar to many other New Hampshire lakes, is to reduce nutrient loading to Ossipee Lake to prevent a future decline in water quality or trophic status. NHDES classifies Ossipee Lake as an oligotrophic lake and the most recent NH Volunteer Lake Assessment Program (VLAP) reports show that though water quality is generally good, there are concerns with pH (on the lower end of the desirable range), Secchi disk transparency (SDT), and internal phosphorus loading (low dissolved oxygen in bottom waters and corresponding hypolimnion phosphorus increases). If not kept in check, unmitigated sources of pollution (i.e., phosphorus) will increase as development or other human activities in the watershed increase (e.g., conversion of small, seasonal properties to large, year-round homes), leading to water quality degradation and loss of property value.

Green Mountain Conservation Group
Ossipee Watershed

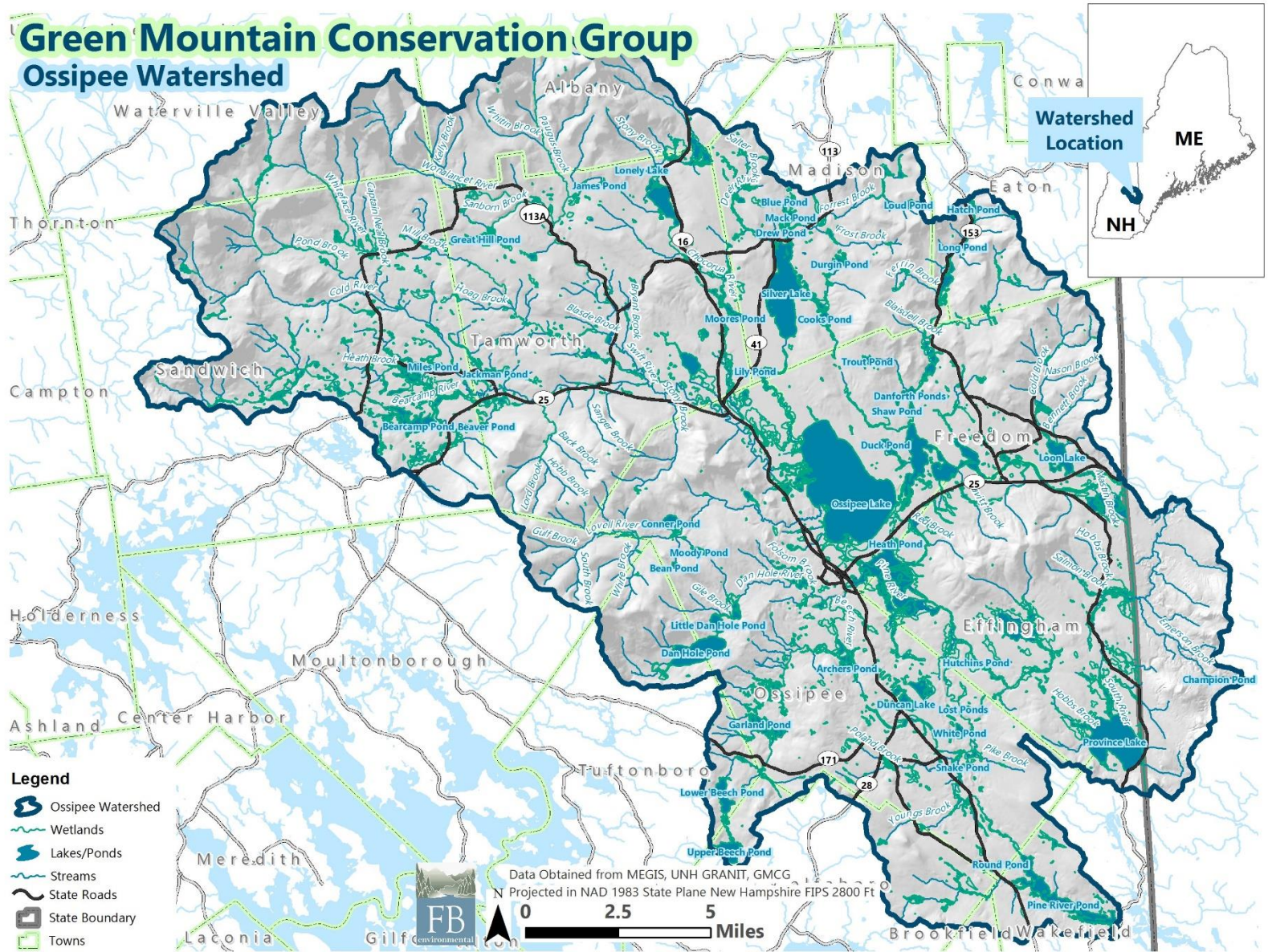


FIGURE 1. Ossipee Watershed.

3. SUMMARY OF EXISTING WATER QUALITY DATA

The water quality of Ossipee Lake was first monitored by NHDES during a trophic survey in 1976 at the deepest spot on the lake (OSSOSSD). Subsequent trophic surveys were conducted by NHDES in 1987 and 2003, with more consistent data collected through the VLAP program (in conjunction with GMCG volunteers) from 2003-2015 (Table 1). Additional data were collected by the UNH Lakes Lay Monitoring Program (LLMP) from 1993-1999, but from a different lake station (OSS01NL).

TABLE 1. Sources of water quality data for Ossipee Lake.

Data Source	Agency/Org.	Yrs Sampled	# of Yrs Sampled
NH VLAP	NHDES	2003-2016	14
NH Trophic Survey	NHDES	1976, 1987, 2003	3
UNH LLMP	UNH/NHDES	1993-1999	7

During this period, multiple water quality parameters were measured with varying frequency, including total phosphorus (TP), Secchi disk transparency (SDT), chlorophyll-a (Chl-a), dissolved oxygen (DO), pH, alkalinity, chloride, specific conductance, turbidity, color, and bacteria. With the exception of late winter sampling by NHDES for the trophic surveys, the majority of sampling was performed 3-5 times during ice-free conditions (May 15 – Oct 15) at the deep spot.

In addition to monitoring at the deep spot, GMCG has also monitored tributaries throughout the Ossipee Watershed since 2003, with 22 locations sampled five or more years. GMCG collaborated with its downstream neighbors, the Saco River Corridor Commission (SRCC) to create a shared, bi-state Quality Assurance Project Plan (QAPP) for the Saco River basin that was approved in 2003 and updated in 2014 (GMCG and SRCC, 2014). Six tributary monitoring locations that flow directly to Ossipee Lake were selected for analysis of the following parameters: TP, turbidity, pH, and specific conductance (Table 2, Figure 2). Additional parameters, such as chloride, were also collected at these tributary locations, but not consistently since 2008. A water quality report summarizing the first 10 years of data collection by GMCG was completed by FB Environmental Associates (FBE) and GMCG in March 2015 (FBE and GMCG, 2015).

A detailed summary of available data, including sources and years available, can be found in Appendix A.

TABLE 2. Tributary monitoring locations that flow directly to Ossipee Lake.

Site Name	Site ID	Years Sampled
Bearcamp River 3	GO-4	2004-2013
Bearcamp River 4	OL-2	2003-2008, 2010-2011, 2013-2015
Lovell River 1	OL-4u	2005-2006, 2008-2015
Red Brook 3	OL-7	2003-2015
Weetamoe Brook 1	OL-5ua	2006, 2008-2012
West Branch River 1	OL-1u	2005-2015

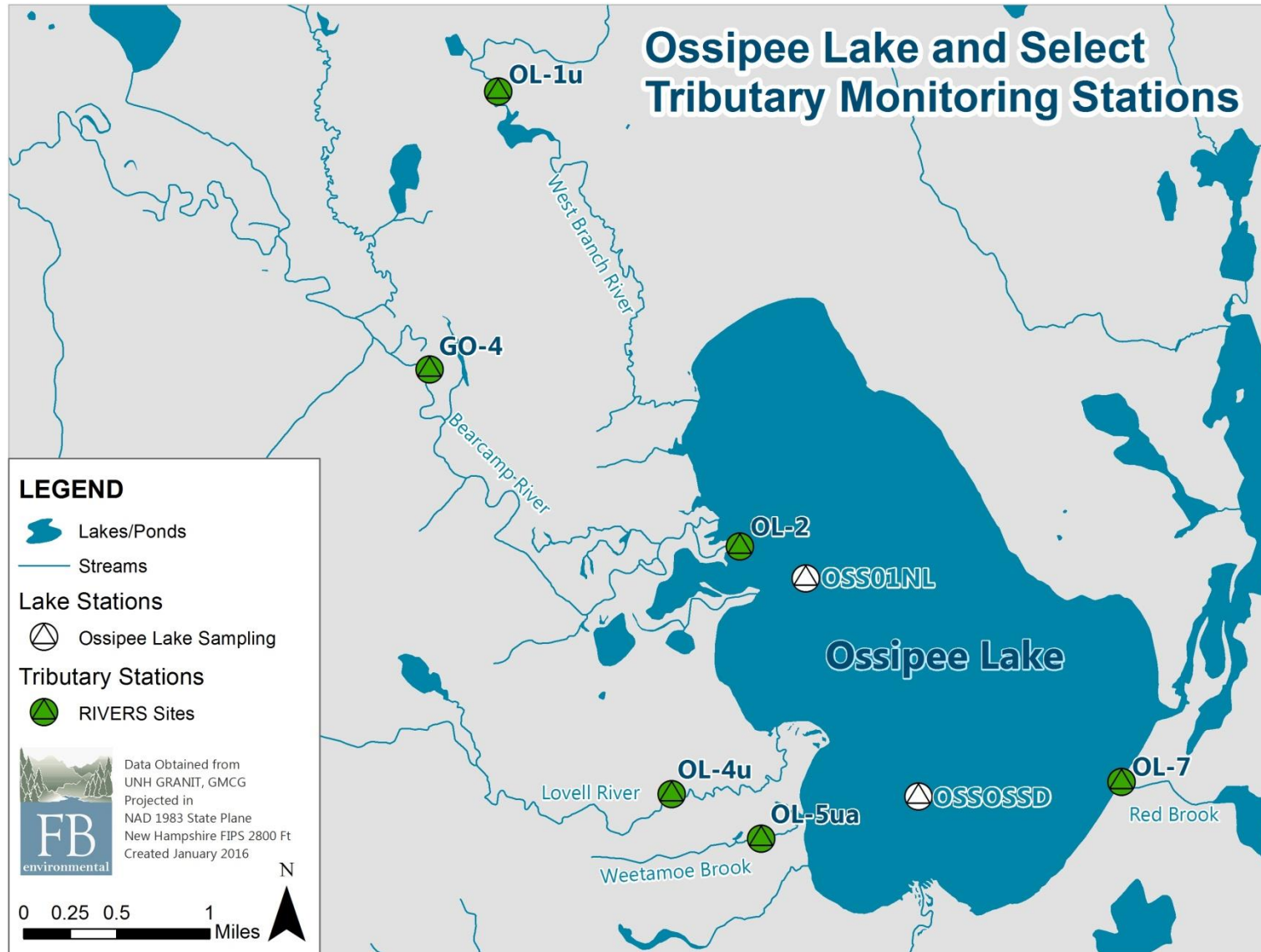


FIGURE 2. Ossipee Lake and select tributary monitoring locations. Only six sites that flow directly to Ossipee Lake were selected for analysis: GO-4, OL-2, OL-4u, OL-7, OL-5ua, and OL-1u.

4. STUDY DESIGN AND DATA ACQUISITION

Water quality monitoring data were accessed and analyzed by FB Environmental for several key water quality parameters, including water clarity (SDT), Chl-a, TP, pH, specific conductance, alkalinity/acid neutralizing capacity (ANC), DO, and temperature. The analysis included statistical testing of historical trends, determination of median in-lake phosphorus concentration, and modeling of the assimilative capacity for Ossipee Lake. These results will help guide GMCG and stakeholders in setting a water quality goal for the lake.

Data acquisition and analysis for Ossipee Lake followed protocols set forth in the Site Specific Project Plan (SSPP). Water quality monitoring data were accessed from the NHDES OneStop Environmental Monitoring Database (EMD). All data used in this analysis were collected by volunteer monitors through NHDES VLAP, NH Trophic Survey (only included if they were not duplicates of VLAP data), or GMCG (tributary data). Data from the UNH LLMP program were also included, but not used in trend analyses due to differing location.

Water quality data were combined into a common spreadsheet, and then sorted by date and station for Quality Assurance/Quality Control (QA/QC). QC field duplicates from the same sampling date were averaged, and samples below the method detection limit were included as half the detection limit value. Any data that were not marked as “valid” within EMD were excluded from analysis¹. Only data collected between May 24 and September 15 were included in the analysis. Data were further divided into historical (1976-2006) and recent (2007-2016) monitoring results. Summary statistics (minimum, maximum, mean, and median) for TP were determined for Ossipee Lake – Deep Spot (OSSOSSD) by both time period and sampling depth: epilimnion (upper), metalimnion (middle), and hypolimnion (bottom). Median TP for all seasonal (May 24-September 15) epilimnetic samples from 2007-2016 represents the ‘Existing Median Water Quality’ applied to the NHDES Assimilative Capacity Analysis for determining if a waterbody is Impaired, Tier 1, or Tier 2 (see Section 7 for details of Assimilative Capacity Analysis). Similar methodology was used to calculate summary statistics for Chl-a, SDT, pH, alkalinity/ANC, and specific conductance within the epilimnion. SDT records were separated into those collected with and without a viewscope, as the use of a viewscope can increase SDT². If adequate data existed (at least 10 years), trends in water quality parameters over time (annual medians, except means

KEY DEFINITIONS

Chlorophyll-a (Chl-a) is a measurement of the green pigment found in all plants, including microscopic plants such as algae. Measured in parts per billion (ppb), it is used as an estimate of algal biomass; the higher the Chl-a value, the greater amount of algae.

Total Phosphorus (TP) is one of the major nutrients needed for plant growth. Generally present in small amounts (measured in ppb), it limits plant growth in lakes. In general, as the amount of TP increases, algae also increase.

Secchi Disk Transparency (SDT) is a measure (in meters) of vertical water clarity or transparency. SDT is measured by lowering a black and white disk into the water until it is no longer visible. While several factors contribute to transparency, SDT is used as an indirect measure of algal populations.

¹ 2014-2015 tributary samples for TP, TDN, and CI have not yet been validated by NHDES, and were excluded. 2016 data were also excluded for pH, alkalinity/ANC, and specific conductance due to time constraints.

² SDT data were received from Melanie Cofrin (NHDES) due to issues with acquisition of this data from the EMD.

for SDT) were analyzed by the Mann-Kendall test (*rkt*, R statistical program; Marchetto, 2015).

5. Water Quality Standards and Criteria

5.1 LAKE NUTRIENT CRITERIA

New Hampshire’s water quality standards provide a baseline measure of water quality that surface waters must meet to support designated uses. Water quality standards are the “yardstick” for identifying water quality exceedances and for determining the effectiveness of state regulatory pollution control and prevention programs. Water quality criteria are designed to protect those designated uses. To determine if a waterbody is meeting its designated uses, water quality thresholds for various water quality parameters (e.g., *Chl-a*, *TP*, *DO*, *pH*, and *toxics*) are applied to the water quality data. If a waterbody meets or is better than the water quality criteria, the designated use is supported. If the waterbody does not meet water quality criteria, it is considered impaired for the designated use.

Water quality criteria for each classification and designated use in New Hampshire can be found in RSA 485 A:8, IV and in the State’s surface water quality regulations (NHDES, 2008). New Hampshire recently developed thresholds for the narrative criteria based on trophic classes (Table 3). These thresholds, based on summer median TP and Chl-a, were incorporated into the *Consolidated Assessment and Listing Methodology (CALM)* for determining impairment status for the 2010 water quality report to Congress (NHDES, 2012a). The data indicate that a lake will exhibit characteristics of a lower trophic class when the “nutrient indicator” (i.e., TP) and “response indicator” (i.e., Chl-a) levels exceed the identified thresholds. The nutrient and response indicators are intricately linked since increased phosphorus loading frequently results in increased phytoplankton levels, which can be estimated by Chl-a in the lake. Increased phytoplankton may lead to decreased oxygen at lake bottom, decreased water clarity, and possibly changes in aquatic species composition. For aquatic life use (ALU) assessment determinations, Chl-a and TP results are combined according to the decision matrix presented in Table 4. The Chl-a concentration will dictate the assessment if both Chl-a and TP data are available and the assessments differ.

TABLE 3. Aquatic life use (ALU) nutrient criteria ranges by trophic class in New Hampshire.

Trophic State	TP (ppb)	Chl-a (ppb)
Oligotrophic	< 8.0	< 3.3
Mesotrophic	> 8.0 - 12.0	> 3.3 - 5.0
Eutrophic	> 12.0 - 28.0	> 5.0 - 11.0

TABLE 4. Decision matrix for aquatic life use assessment (ALU) determinations in New Hampshire.

Nutrient Assessments	TP Threshold Exceeded	TP Threshold <u>NOT</u> Exceeded	Insufficient Info for TP
Chl-a Threshold Exceeded	Impaired	Impaired	Impaired
Chl-a Threshold <u>NOT</u> Exceeded	Potential Non-support	Fully Supporting	Fully Supporting
Insufficient Info for Chl-a	Insufficient Info	Insufficient Info	Insufficient Info

5.2 ANTIDegradation

The Antidegradation Provision (Env-Wq 1708) in New Hampshire's water quality regulations serves to protect or improve the quality of the State's waters. The provision outlines limitations or reductions for future pollutant loading. Certain development projects (e.g., projects that require Alteration of Terrain Permit or 401 Water Quality Certification) may be subject to an Antidegradation Review to ensure compliance with the State's water quality regulations. The Antidegradation Provision is often invoked during the permit review process for projects adjacent to waters that are designated impaired, high quality, or outstanding resource waters. While NHDES has not formally designated high quality waters, unimpaired waters are treated as high quality with respect to issuance of water quality certificates. Antidegradation requires that a permitted activity cannot use more than 20% of the remaining assimilative capacity of high quality waters. This is on a parameter-by-parameter basis. For impaired waters, antidegradation requires that permitted activities discharge no additional loading of the impaired parameter.

6. LAKE WATER QUALITY ANALYSIS

Overall, water quality in Ossipee Lake is generally good and has been stable over the last 40 years, showing some interannual variation likely related to weather patterns. However, water clarity may be declining and anoxic conditions in bottom waters may be becoming more prevalent in recent years.

OSS�PEE LAKE

- **Total phosphorus (TP)** has been relatively stable since its record high in 1976, with no significant trend, but some interannual variation. Median TP is very low (6.5 ppb; 2007-2016) and meets oligotrophic criteria. One **total Kjeldahl nitrogen (TKN)** sample in 1987 exceeded guidelines from the Volunteer River Assessment Program, possibly indicating pollution, such as fertilizers or septic systems during that time period (likely following a storm event).
- **Secchi disk transparency (SDT)** and **Chlorophyll-a (Chl-a)** do not show any statistically significant trends over the data collection period. Median SDT (4.0 m; 2007-2016 without scope) may vary with summer precipitation as increased sediment delivery during wetter summers causes turbid lake conditions. More data are needed to statistically support a possible degradation in SDT since 1976. Median Chl-a (2.0 ppb; 2007-2016) is better than the oligotrophic criteria (3.0 ppb), but annual medians vary from year to year (1.3 to 4.5 ppb) and appear to be related to spikes in median annual TP.
- **Dissolved oxygen (DO)** and **temperature** profiles from the deep spot in Ossipee Lake show typical midsummer stratification of New Hampshire lakes. Low levels of DO in the hypolimnion may be becoming more frequent at shallower depths since 2008, though sampling in the late summer months (when low DO is more likely to occur) has also increased. Though low DO at bottom depths can be naturally occurring, its persistence can threaten fish species seeking cooler waters in the summer and increase internal phosphorus loading that feed algal growth.

- **pH** and **alkalinity/acid neutralizing capacity** levels indicate that the lake is slightly acidic (typical of NH lakes) and has a “moderately vulnerable” buffering capacity against additional acidic inputs, which is slightly above the typically-low buffering capacity of most NH waterbodies.
- **Specific conductance** is low and similar to State and regional averages of other lakes in NH. **Chloride** was very low (< 8 ppm) and well below the chronic exposure limit of 230 ppm.
- Based on the **Assimilative Capacity Analysis**, Ossipee Lake falls in the Tier 2 category. TP levels are low enough that there is some remaining capacity to assimilate additional phosphorus inputs.

A more detailed analysis of the parameters mentioned above are elaborated in the sections that follow.

6.1 HISTORICAL WEATHER

Annual weather patterns can have an effect on in-lake water quality. Wetter summers may result in increased runoff and increased pollutant loads to waterbodies. Since 1976, summer precipitation (defined as total precipitation from May through September) near Ossipee Lake has ranged from a low of 13.1 inches in 1995 to a high of 34.1 inches in 2006 (Figure 3). No statistically significant trend was found for summer precipitation from 1976 to 2015.

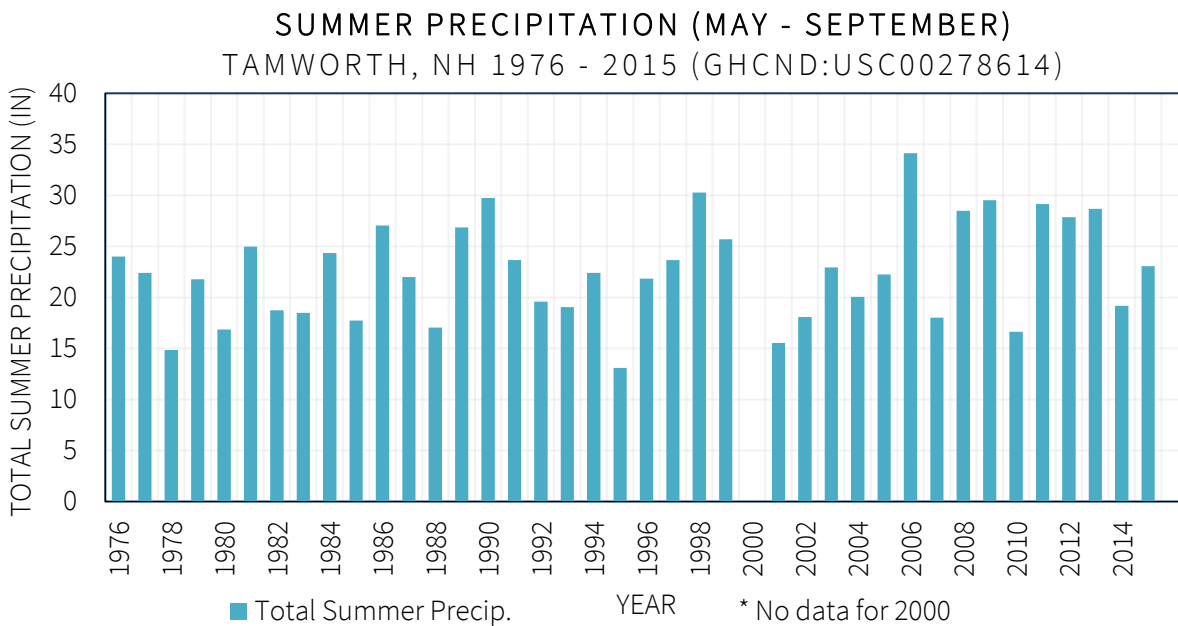


FIGURE 3. Summer precipitation data (May – September) for 1976 -2015 in Tamworth, NH.

6.2 TROPHIC STATUS

From 1974 through 2010, NHDES conducted trophic surveys of lakes to determine trophic state. The trophic surveys evaluated physical lake features and chemical and biological indicators. Trophic state may be designated as: oligotrophic, mesotrophic, or eutrophic. These are broad categories used to describe how productive a lake is. Generally, oligotrophic lakes are less productive or have less nutrients, while eutrophic lakes have more nutrients and are therefore more productive and exhibit algal blooms more frequently than oligotrophic lakes. Mesotrophic lakes fall in-between with an intermediate level of productivity and often have a higher quantity of submerged aquatic plants than oligotrophic lakes.

More specifically, oligotrophic lakes have high DO levels (> 5 ppm), high transparency (> 4.5 m), low Chl-a (< 3 ppb), low TP (< 8 ppb), and sparse aquatic plant growth. Eutrophic lakes have low levels of DO (< 2 ppm), low transparency (< 2 m), high Chl-a (> 5 ppb), high TP (> 12 ug/L), and abundant aquatic plant growth. Mesotrophic lakes have characteristics that fall in-between those of oligotrophic and eutrophic lakes for the parameters listed (NHDES, 2012b).

For Ossipee Lake, the **trophic state** was determined to be oligotrophic during all surveys (1976, 1987, 2003). This means that in-lake water quality (i.e., TP, Chl-a, and DO) should be consistent with the standards for oligotrophic lakes.

To examine any potential changes in trophic state over the last 10 years, we recalculated the trophic classification for Ossipee Lake using the NHDES Trophic Classification System for New Hampshire Lakes and Ponds. In the past, trophic state has been determined based on data collected by NHDES every 5 to 10 years, and Ossipee Lake has not been re-assessed since 2003. Based on water quality data from the last 10 years at Ossipee Lake, the trophic classification would be in-line with the 2003 NHDES trophic survey. Table 5 provides a summary of the scoring.

TABLE 5. NHDES Trophic Classification for Ossipee Lake.

WQ Parameter	Mean WQ Value (2007-2016)	Trophic Points	Trophic State
Summer Bottom DO (ppm)	4.7	0	> 4 ppm = 0
Mean SDT (m)	4.1	2	> 3 m – 5 m = 2
Aquatic Plant Abundance	Scattered	1	Based on 1976, 2003 NHDES surveys
Mean Chl-a (ppb)	2.0	0	< 4 ppb = 0
Total		3	Oligotrophic (0 - 6 pts)

6.3 TOTAL PHOSPHORUS, CHLOROPHYLL-A, AND SECCHI DISK TRANSPARENCY

TP, Chl-a, and SDT are inter-related and together provide insight to water quality and potential causes of impairment. In Ossipee Lake, both median TP and Chl-a in the epilimnion are below the NHDES ALU criteria for oligotrophic lakes (refer to Table 3); median TP in Ossipee Lake since 1976 is 7.0 ppb (6.5 ppb for 2007-2016), while median Chl-a is 2.0 ppb (2.0 for 2007-2016; Table 6). Additionally, annual medians for Chl-a at the LLMP site OSS01NL (Figure 4, Table 7) are slightly below annual medians for the Deep Spot (OSSOSSD) in later years; these sites are in different parts of the lake, but may have similar depth based on bathymetry maps. Interannual variability in SDT (ranging from 2.5 m without a viewscope to 7.5 m with a viewscope) likely reflects year-to-year weather influences. Wetter years may increase the amount of sediment delivered to the lake (e.g., 2006, Figure 3) and cause lower SDT readings (e.g., 2006 with viewscope; Figure 5). In contrast, drier years (e.g., 2010) may result in deeper SDT readings (e.g., 2010 with viewscope). Overall, Ossipee Lake shows no statistically significant trends in TP, Chl-a, and SDT over the last 40 years (Figures 4 and 5). While it is difficult to make any strong conclusions about a change in water quality based on limited historical data (prior to 2003), SDT may have worsened slightly.

In addition to TP, total dissolved nitrogen (TDN) is also an important nutrient in freshwater systems, though often less limiting than TP. Minimal data are available for TDN, but historical results by NHDES show concentrations ranging from 0.21 to 0.63 ppm, with components of Total Kjeldahl Nitrogen (TKN; organic nitrogen + ammonia) being the dominant source and inorganic nitrogen ($\text{NO}_3\text{-NO}_2$) being favorably low. Though numeric criteria do not exist for nitrogen in lakes, the NH Volunteer River Assessment Program (VRAP) provides a guideline for TKN such that samples >0.50 ppm may indicate nuisance pollution, such as fertilizers or septic pollution (NHDES, 2014). TKN exceeded this guideline in 1987, but had returned to an acceptable level in 2003 (Table 6). More data are needed to determine any significant trends.

HOW DOES THIS COMPARE TO OTHER NH LAKES? In New Hampshire lakes, median summer epilimnetic (upper layer) TP is about 12 ppb, while TP for the White Mountains Region is about 8 ppb. Similarly, median Chl-a for New Hampshire lakes is 4.6 ppb, and median Chl-a for the White Mountains Region is 3.1 ppb (NHDES, 2012c). Median SDT at Ossipee Lake is comparable to State and regional medians (3.2 m for New Hampshire lakes and 4 m for the White Mountains Region).

TABLE 6. Summary statistics for total phosphorus (TP), chlorophyll-a (Chl-a), Secchi disk transparency (SDT), and nitrogen for Ossipee Lake deep spot, based on seasonal, epilimnetic samples. y = years (used in M-K analysis), n = total number of sampling events (used in summary statistics). M-K analyses conducted on annual medians except SDT (mean). NS=not significant.

TP	n	Mean (ppb)	Median (ppb)	Min. (ppb)	Max. (ppb)	Mann-Kendall
All Seasonal (y = 16)	39	8.2	7.0	2.5	39.0	NS
Historical (1976-2006, y = 6)	11	10.5	8.0	6.0	39.0	--
Recent (2007-2016, y = 10)	28	7.3	6.5	2.5	20.2	NS

Chl-a	n	Mean (ppb)	Median (ppb)	Min. (ppb)	Max. (ppb)	Mann-Kendall
All Seasonal (y = 16)	41	2.1	2.0	0.3	4.5	NS
Historical (1976-2006, y = 6)	12	2.1	2.1	0.3	3.3	--
Recent (2007-2016, y = 10)	29	2.0	2.0	1.1	4.5	NS

SDT - without scope	n	Mean (m)	Median (m)	Min. (m)	Max. (m)	Mann-Kendall
All Seasonal (y = 15)	41	4.1	3.9	1.8	6.8	NS
Historical (1976-2006, y = 6)	12	4.0	3.6	2.1	6.2	0.02
Recent (2007-2016, y = 9)	29	4.1	4.0	1.8	6.8	NS
With scope (2007-2016, y = 9)	26	4.7	4.6	2.7	7.5	--

Year	Total Dissolved Nitrogen (ppm)*	NO ₃ -NO ₄ (ppm)	Total Kjeldahl Nitrogen (ppm)
1976	0.21	0.09	0.12
1987	0.63	<0.05	0.58
2003	<0.25	<0.05	<0.25

*Total Kjeldahl Nitrogen (TKN) + NO₃+NO₄+N; NO₃+NO₄+N values < 0.05 were added to TKN as 0.05

TABLE 7. Annual summary statistics for Secchi disk transparency (SDT) and chlorophyll-a (Chl-a) for station OSS0NL1 in Ossipee Lake, based on seasonal, epilimnetic samples.

Year	SDT (m.)				Chl-a (ppb)			
	Mean	Median	Min.	Max.	Mean	Median	Min.	Max.
1993	6.3	6.0	5.5	7.5	2.1	2.1	1.6	2.4
1994	5.6	5.6	5.4	5.7	1.5	1.5	0.9	2.1
1995	5.9	6.5	3.0	7.3	1.1	1.2	0.6	1.4
1996	5.8	5.7	4.5	7.0	1.9	1.9	1.1	2.2
1997	5.3	5.1	4.6	6.6	1.5	1.5	1.3	1.8
1998	3.5	3.7	3.0	4.5	1.6	1.6	1.4	2.0
1999	5.6	5.5	4.5	7.0	1.8	1.8	1.4	2.1

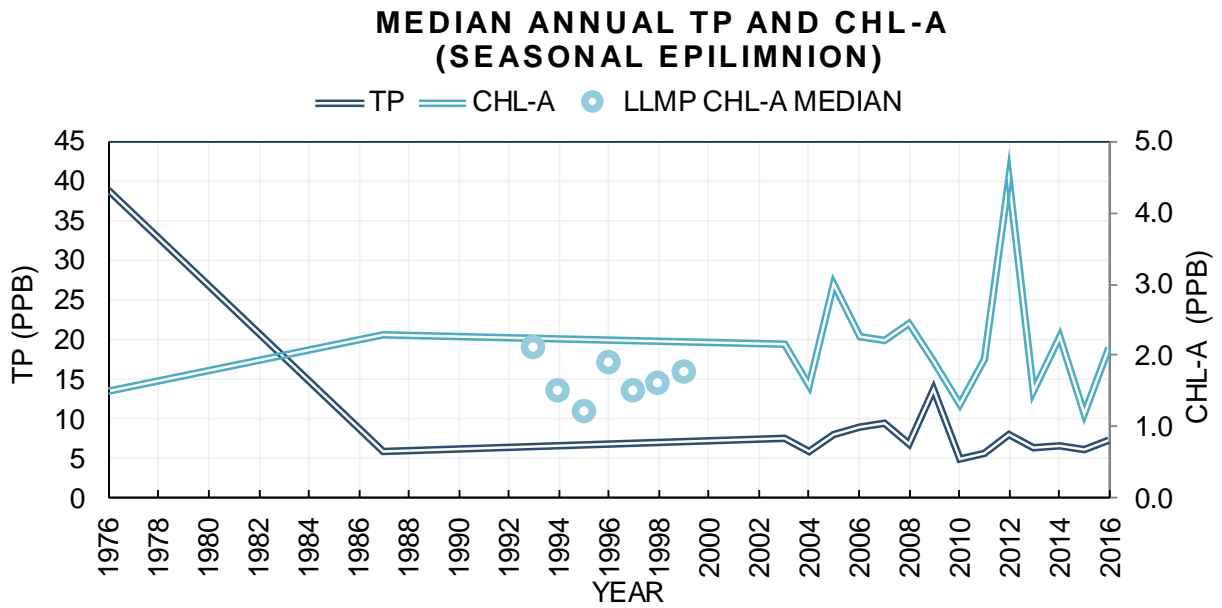


FIGURE 4. Annual median epilimnetic total phosphorus (TP) and chlorophyll-a (Chl-a) for Ossipee Lake Deep Spot (OSSOSSD, 1976-2016) and LLMP site (OSS01NL).

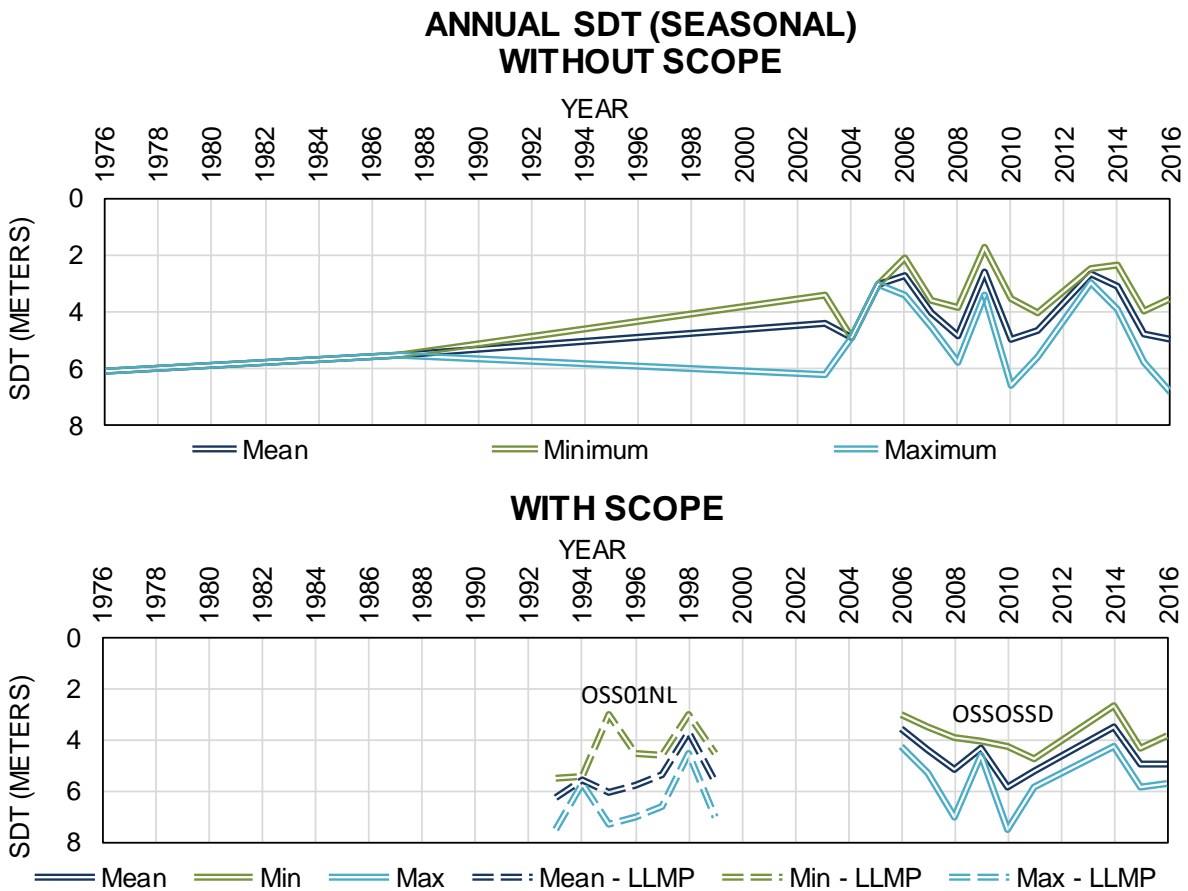


FIGURE 5. Annual mean, minimum, and maximum Secchi Disk Transparency (SDT) with and without a viewscope for Ossipee Lake Deep Spot (OSSOSSD) and LLMP site (OSS01NL).

6.4 TEMPERATURE AND DISSOLVED OXYGEN

DO and temperature profiles from the deep spot in Ossipee Lake show typical midsummer stratification of New Hampshire lakes, with high DO and warm water temperatures near the surface followed by a marked decrease in temperature and DO below the metalimnion (i.e., thermocline) around 3-8 m below the surface (Figures 6, 7). DO concentrations can change dramatically with lake depth as 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). DO less than 5 ppm can stress fish and other bottom-dwelling organisms, including amphibians, and can reduce habitat for sensitive coldwater fish species (NHDES, 2013).

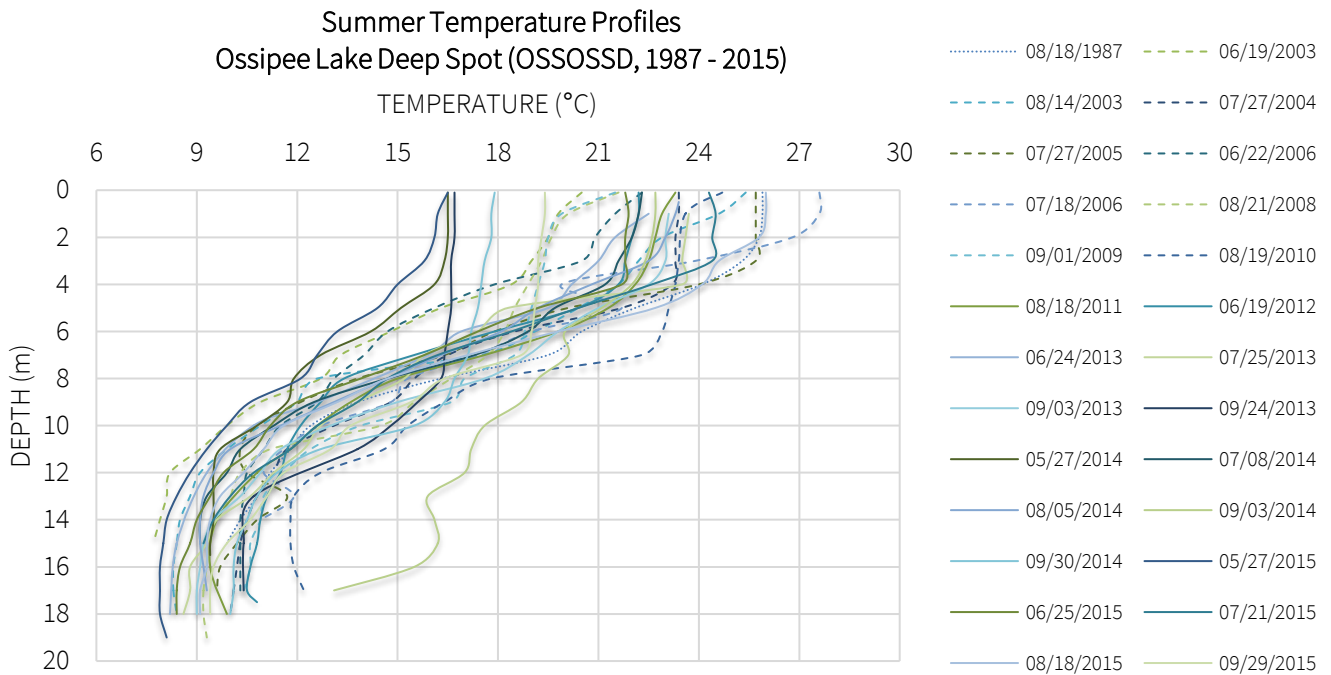


FIGURE 6. Temperature profiles for Ossipee Lake Deep Spot (OSSOSSD, 1987-2015). Dashed and solid lines separate 2003-2010 from 2011-2015 sampling years, respectively.

Low levels of DO (< 5 ppm) in the hypolimnion (e.g., bottom waters) have become more common since 2008 and on average impact 74% of lake volume each year (Table 8). It should be noted that these readings have occurred in August and September, when bottom waters can naturally become anoxic as the season progresses. Very low DO (< 2 ppm) can trigger a release of phosphorus in lake sediments, also known as internal phosphorus loading. This was evident in 2010, 2014, and 2015 when on average 50% of lake volume was impacted by DO < 2 ppm (Table 8) and hypolimnion TP spiked above 8 ppm (Figure 8). Though TP measured in the hypolimnion of Ossipee Lake has not been high overall (Figure 8), internal phosphorus loading is a concern for the lake if the recent pattern of low DO in bottom waters continues or extends to include earlier parts of the season. When thermal stratification of the lake breaks down in the fall, potentially phosphorus-rich waters in the hypolimnion are mixed and re-distributed throughout the

rest of the water column (a.k.a., fall turnover), which can stimulate algal and/or cyanobacteria growth for the next season.

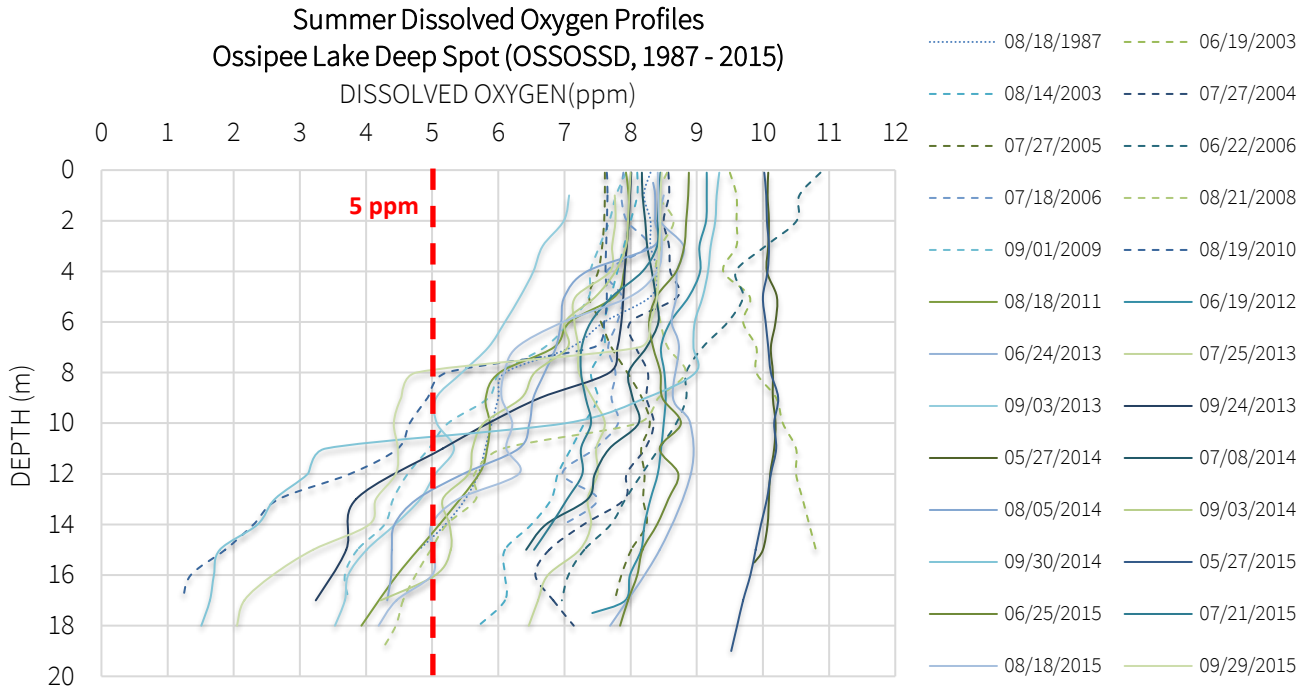


FIGURE 7. Dissolved oxygen profiles for Ossipee Lake Deep Spot (OSSOSSD, 1987-2015). Red vertical line marks 5 ppm DO threshold, below which can stress aquatic life. Dashed and solid lines separate 2003-2010 from 2011-2015 sampling years, respectively.

TABLE 8. Percent of observations below 5 ppm DO and the associated shallowest depth (meters) for Ossipee Lake.

Year	Dates	% Volume <5 ppm DO	Start Depth (m) <5 ppm DO	% Vol <2 ppm DO	Start Depth (m) <2 ppm DO
1987	08/18/1987	64%	15		
2008	08/21/2008	64%	15		
2009	09/01/2009	82%	11		
2010	08/19/2010	85%	9	64%	15
2011	08/18/2011	55%	16		
2013	Sept. (2)	74%	13		
2014	Aug. (1), Sept. (2)	82%	11	64%	15
2015	Aug. (1), Sept. (1)	89%	8	23%	18
Across All Years		74%	12	50%	16

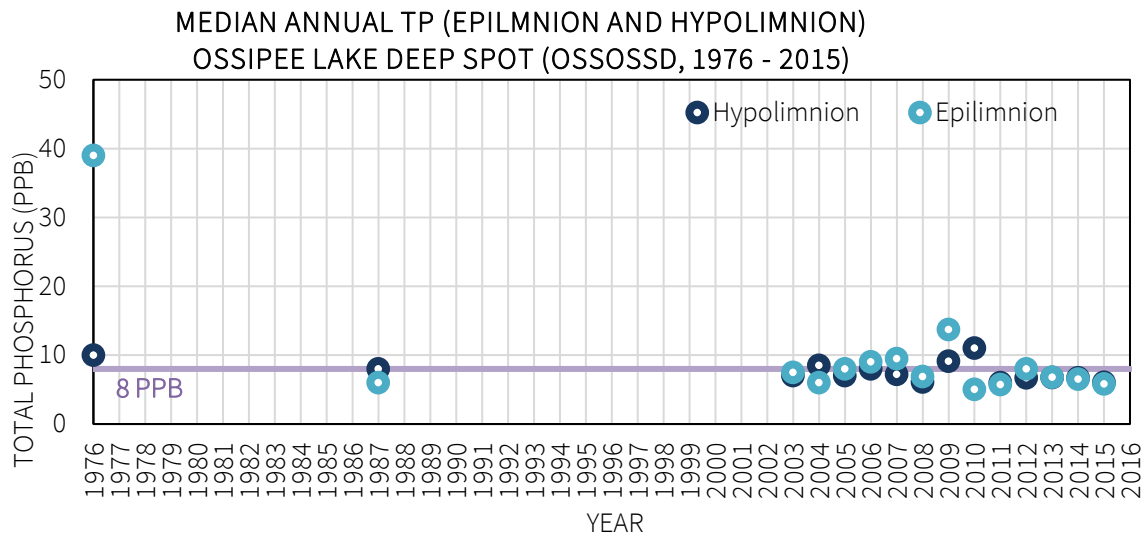


FIGURE 8. Median annual total phosphorus (TP) in the epilimnion and hypolimnion of Ossipee Lake. Purple line represents the TP threshold (8 ppb) for aquatic life use in oligotrophic lakes.

6.5 PH AND ALKALINITY/ACID NEUTRALIZING CAPACITY

pH is the standard measure of the acidity or alkalinity of a solution on a scale of 0 (acidic) to 14 (basic). As related measures, alkalinity or acid neutralizing capacity (ANC)³ is a measure of the buffering capacity of lake water. A higher alkalinity means that a waterbody has a greater ability to neutralize acidic inputs. A waterbody is considered impaired in New Hampshire when the pH falls below 6.5 or above 8.0. Median pH for Ossipee Lake since 1976 is 6.7 (Table 9), which is suitable for aquatic life (>6.5; NHDES, 2012c). Alkalinity and ANC fall within the “moderately vulnerable” range (NHDES, 2012c), though Ossipee Lake has slightly better buffering capacity compared to other lakes in the region and the State (Figure 9). A trend analysis could not be performed, but recent years show a pattern of improving buffering capacity.

HOW DOES THIS COMPARE TO OTHER NH LAKES? Median pH for New Hampshire lakes is 6.6, while the median pH for the White Mountains Region is 6.7 (NHDES, 2012c). Most New Hampshire lakes have naturally-low ANC waters (New Hampshire lakes median: 4.8 ppm; NHDES, 2012c) due to the dominance of granite bedrock, which provides only a small amount of natural buffering elements. Median ANC for the White Mountains Region is 4.4 (NHDES, 2012c).

TABLE 9. pH in the epilimnion of Ossipee Lake Deep Spot (OSSOSSD, 1976-2015). y = number of years sampled, n = total number of sampling events (used in summary statistics).

pH	n	Mean	Median	Min.	Max.
All Seasonal (y = 15)	37	6.7	6.7	6.2	7.0
Historical (1976-2006, y = 5)	8	6.8	6.8	6.7	6.9
Recent (2006-2015, y = 10)	29	6.6	6.7	6.2	7.0

³ NHDES switched from measuring buffering capacity as alkalinity to ANC in 2008. There is a small difference between alkalinity and ANC methodologically, in that alkalinity is measured from filtered water (neutralizing ability of solutes only) and ANC is from unfiltered water (meaning neutralizing ability of solutes + particulates, if present). These are often used interchangeably in the literature, but differences between the two types should be noted when interpreting historical data.

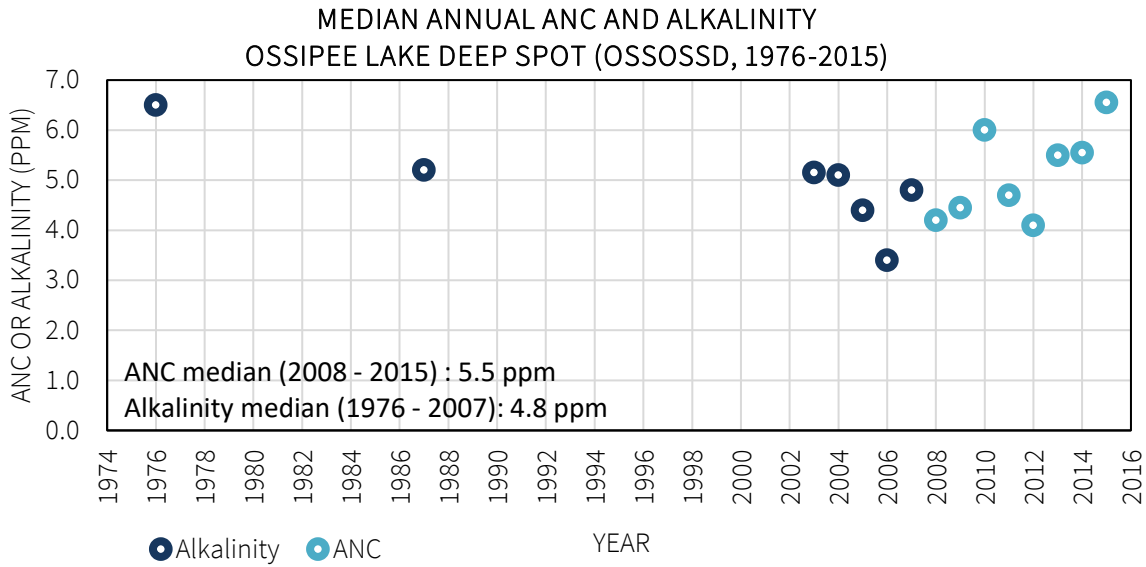


FIGURE 9. Median annual alkalinity/acid neutralizing capacity (ANC) for Ossipee Lake Deep Spot (OSSOSSD, 1976-2015).

6.6 SPECIFIC CONDUCTANCE/CHLORIDE

Specific conductance is a measure of how well water can conduct an electrical current, which varies with the amount of ions present in solution. Though specific categories for good and bad levels can't be determined for conductivity (due to the influence of geology), conductance values exceeding 100 $\mu\text{S}/\text{cm}$ generally indicate human disturbance. Specific conductance in Ossipee Lake is close to the State median of 40 $\mu\text{S}/\text{cm}$, as well as the White Mountains regional median of 42.9 $\mu\text{S}/\text{cm}$ (NHDES, 2012c; Figure 10) and does not appear to be severely impacted by human activity. Chloride was very low and well below the chronic exposure limit of 230 ppm (Table 10).

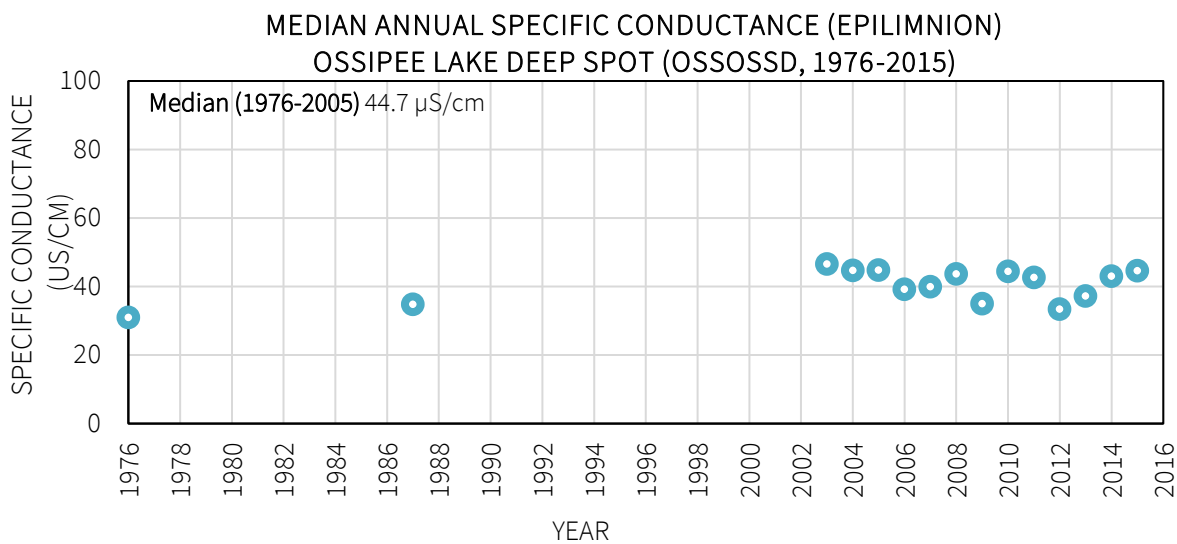


FIGURE 10. Median annual specific conductance for Ossipee Lake Deep Spot (OSSOSSD, 1976-2015).

TABLE 10. Summary statistics for chloride at Ossipee Lake Deep Spot (OSSOSSD, 1976-2015).

	Historical			Mean	Recent (2010-2015)		
	1976	1987	2003		Median	Min.	Max.
Chloride (ppm)	8	3	6	5	5	4	7

7. ASSIMILATIVE CAPACITY ANALYSIS

The assimilative capacity of a lake is its ability to resist the effects of landscape disturbance without water quality impairment. The watershed management plan will focus on phosphorus as a driver of overall lake health and the likely culprit for low bottom DO at Ossipee Lake. Lakes with excess nutrients, particularly phosphorus, which is considered the limiting nutrient in freshwater systems, are overproductive and may experience symptoms of water quality decline, including algal blooms, fish kills, decreased water clarity, loss of aesthetic values, and beach closures. Decomposition of accumulated organic matter from dead algal blooms and plants can result in anoxia in bottom waters, which can release phosphorus back into the water column (i.e., internal loading) as food for algae and plants and can also be lethal to fish and other aquatic organisms.

A lake receives natural and human-derived inputs of phosphorus in runoff from its watershed. This phosphorus can be taken up by aquatic life within the lake, settle in the bottom sediments, or flow out of the lake to downstream waterbodies. In this sense, there is a natural balance between the amount of phosphorus flowing in and out of a lake system, also known as the ability of a lake to “assimilate” phosphorus. The assimilative capacity is based on factors such as lake volume, watershed area, precipitation, and runoff coefficients. If a lake is receiving more phosphorus from the watershed than it can assimilate, then its water quality will decline over time as algal or cyanobacteria blooms become more frequent.

Median TP at the deep spot on Ossipee Lake over the last ten years (2007-2016) was used to calculate the total, reserve, and remaining assimilative capacity (Table 11), using procedures described in the Standard Operating Procedures for Assimilative Capacity Analysis for New Hampshire Waters (NHDES, 2008) and the CALM (NHDES, 2012a). Tier 2 waters, or high quality waterbodies, have one or more water quality parameters that are better than the water quality standard and that also exhibit a reserve capacity of at least 10% of the waterbody’s total assimilative capacity. Tier 2 waters have some assimilative capacity remaining, whereas Tier 1 and Impaired Waters do not. Based on the NHDES assimilative capacity analysis, Ossipee Lake falls in the Tier 2 category for oligotrophic lakes. This classification holds true, since Chl-a is better than the water quality standard for oligotrophic lakes and there is still some remaining assimilative capacity for phosphorus inputs.

TABLE 11. Assimilative capacity analysis results for Ossipee Lake.

Lake and Station	Existing Median TP 2007 - 2016 (ppb)	TP WQ Threshold (ppb)	AC Threshold (ppb)	Remaining AC (ppb)	Analysis Results
Ossipee Lake Deep Spot (OSSOSSD)	6.5	8.0 (oligotrophic)	7.2	0.7	Tier 2

The watershed restoration plan will state the water quality goal, which will be guided by the water quality analysis and forthcoming watershed load modeling. The model will predict the effect of existing watershed development on current in-lake water quality at Ossipee Lake. Water and phosphorus loads (in the form of mass and concentration) are traced from various sources in the watershed, through tributary basins, and into the lake. The model incorporates data about land cover, watershed boundaries, point sources, septic systems, waterfowl, rainfall, and an estimate of internal lake loading, combined with many coefficients and equations from scientific literature on lakes and nutrient cycles. This information can be used to determine how much phosphorus loading it takes to increase or decrease TP in the lake and therefore can be extrapolated to estimate the annual mass of phosphorus that needs to be prevented from entering the lake to improve water quality and retain current assimilative capacity.

8. TRIBUTARY WATER QUALITY ANALYSIS

Many of the tributaries to Ossipee Lake have been monitored by GMCG since 2003 for TP, pH, specific conductance, chloride, and turbidity (Appendix A). Analysis of tributary water quality can help to identify which tributaries could have a negative contribution to water quality in Ossipee Lake. Determination of median TP for these tributaries will also help inform the land use model.

Since 2003, median TP was low for most tributaries (< 8 ppb), with the notable exceptions of Red Brook and Weetamoe Brook with >60 ppb (Table 12). As TKN was unavailable for tributaries, nitrogen results from these tributaries could not be compared to VRAP guidelines. However, qualitative assessment of total dissolved nitrogen (TDN; Total Kjeldahl Nitrogen (TKN) + NO₃+NO₂-N) again point to Red Brook and Weetamoe Brook for the highest concentrations. Mean turbidity was also relatively high in these two tributaries. The land area draining to these tributaries should be prioritized during watershed reconnaissance to determine if a local perturbation, such as soil erosion, is causing the increased turbidity and TP. Decreasing the phosphorus load from land areas draining to tributaries of Ossipee Lake will help maintain or improve the current levels of phosphorus in the lake.

pH in all tributaries is considered acidic (< 7.0) and of poor quality for aquatic life (< 6.5). Red Brook and Weetamoe Brook stand out with the lowest pH among all tributaries (Table 12). Though Ossipee Lake appears to have moderate buffering capacity compared to other lakes in the region, the acidic contributions of these tributaries could further decrease the pH in the lake, which is only slightly better than the minimum aquatic life criteria.

Specific conductance⁴ and chloride were fairly consistent among the tributaries. Given typical New England geology, specific conductance above 100 µS/cm generally indicates some human disturbance, and was not observed in any of the tributaries. However, the highest mean specific conductance was found in Red Brook, providing additional evidence that this tributary may be a problem source of NPS pollutants. The highest mean chloride was measured in West Branch River, though all chloride concentrations fell far below the chronic exposure limit of 230 ppm.

From these data, Red Brook and Weetamoe Brook should be prioritized for future monitoring and land use investigation of potential NPS pollution.

TABLE 12. Summary data for Ossipee Lake tributaries. Values represent the mean or median of all available data (see Appendix A for years sampled). Red text highlights parameters and sites of concern.

SITE ID	TRIBUTARY	MEDIAN TP (PPB)	MEAN TDN (PPB)	MEAN TURBDITY (NTU)	MEAN PH	MEAN SPCOND (µS/CM)	MEAN CHLORIDE (PPM)
GO-4	Bearcamp River 3	8	193	0.9	5.2	41	6
OL-2	Bearcamp River 4	9	183	0.8	6.1	51	7
OL-4u	Lovell River 1	4	168	0.6	5.8	25	1
OL-7	Red Brook 3	69	517	1.3	5.2	56	8
OL-5ua	Weetamoe Brook 1	65	670	2.3	5.4	45	5
OL-1u	West Branch River 1	9	248	0.6	5.9	45	13

9. RECOMMENDATIONS

The following are recommendations to improve water quality monitoring for the Ossipee Watershed:

- Calculate the anoxic factor for Ossipee Lake to assess changes over time in DO and whether Ossipee Lake has reached a “tipping point,” when the hypolimnion waters are anoxic for a long enough duration to release excess phosphorus that stimulates productivity. If this tipping point has been reached, watershed management measures will be costly and difficult to implement.
- Continue to take regular, annual DO and temperature profiles of the deep spot in the lake.
- Continue epilimnion and hypolimnion TP sampling. This will allow for better estimates of internal loading and how it changes in the future.
- Add nitrogen species (TKN, TDN, etc.) to yearly in-lake sampling to see if nitrogen levels have changed since 2003.
- Monitor tributaries for pH and alkalinity.
- Prioritize land area draining to Red Brook and Weetamoe Brook during watershed reconnaissance to determine if a local perturbation, such as soil erosion, is causing the increased turbidity and TP.
- Prioritize Red Brook and Weetamoe Brook for future monitoring.

⁴ Specific conductance (temperature adjusted) was calculated for tributaries with only conductivity data available, using USGS methods (http://water.usgs.gov/owq/FieldManual/Chapter6/6.3_contents.html).

10. REFERENCES

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APPENDIX A - SUMMARY OF AVAILABLE WATER QUALITY DATA FOR OSSIPEE LAKE

Summary of Available Water Quality for Ossipee Lake, Ossipee/Freedom NH		
Trophic Survey Data and Chemistry from NHDES		
Ossipee Lake Deep Spot (OSSOSSD)	Ossipee, NH	Date
DO (mg/L), Secchi disk transparency (SDT), Chl-a, pH, Sp. Cond., TP, TKN, ApparentColor, Alkalinity, Nitrogen (Nitrite+Nitrate), Cl, Mg, Na, K, Ca		1976, 1987, 2003
DO (% Saturation), Temperature, Sulfate		1987, 2003
Turbidity		1976
Ossipee Lake - Generic (OSSOSS-GEN)	Freedom, NH	Date
Bacteria Sample Sites		
E. coli		2003
Total coliform		1987
UNH Lay Lakes Monitoring Program		
Ossipee Lake-1 NE (OSS01NL)	Ossipee, NH	Date
Secchi disk transparency (SDT), True Color, Alkalinity, Chl-a		1993-1998
TP		1995
VLAP Data from Sara Steiner, NHDES		
Ossipee Lake Deep Spot (OSSOSSD)	Ossipee, NH	Date
DO (mg/L, % saturation), Temperature		2003-2006, 2008-2015
Secchi disk transparency (SDT)		2003-2011, 2013-2015
pH, Sp. Cond., TP, Chl-a, Turbidity		2003-2015
Acid Neutralizing Capacity		2008-2015
Alkalinity		2003-2007
Cl		2010-2015
GMCG RIVERS Monitoring Program		
Tributaries (pH, Sp. Cond, TP, Turbidity, TDN, with varying degrees of consistency)		<i>Cl = chloride</i>
Bearcamp River 3 (GO-4)	2004-2013	(Cl: 2004-2009)
Bearcamp River 4 (OL-2)	2003-2008, 2010-2011, 2013-2015	(Cl: 2003-05, 2007-08, 2015)
Lovell River 1 (OL-4u)	2005-2006, 2008-2015	(Cl: 2005, 2008)
Red Brook 3 (OL-7)	2003-2015	(Cl: 2003-05, 2007-09)
Weetamoe Brook 1 (OL-5ua)	2006, 2008-2012	(Cl: 2008)
West Branch River 1 (OL-1u)	2005-2015	(Cl: 2005, 2007-2008)
*all 2014-2015 TP, TDN, and Cl not yet validated by NHDES		
Complaint Investigations		
Ossipee Lake - various locations (E. coli)	<i>various</i>	2002, 2006