Province Lake Water Quality Analysis

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Effingham, New Hampshire

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Cover photo: Rainbow over Province Lake (Photo: Barber, PLA)

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1. GOAL & PURPOSE


Source: PLA Website

The goal of this document is to summarize water quality data, apply and compare this data to state water quality standards, present historical water quality trends, and provide recommendations for improving the water quality of Province Lake that will be a major component of the Province Lake Watershed Management Plan.

The purpose of this document is to provide information and recommendations that will help guide the Province Lake Water Quality Subcommittee in setting a water quality goal for Province Lake. This water quality goal will be used to measure the success of future watershed management actions. Due to the complexity of the lake's physical, chemical and biological conditions, there are many questions yet to be answered regarding recent changes in the water quality, and the estimated response of the lake to proposed management actions. Therefore, a thorough review and discussion of data and its use for setting a water quality goal are critical to the watershed planning process.

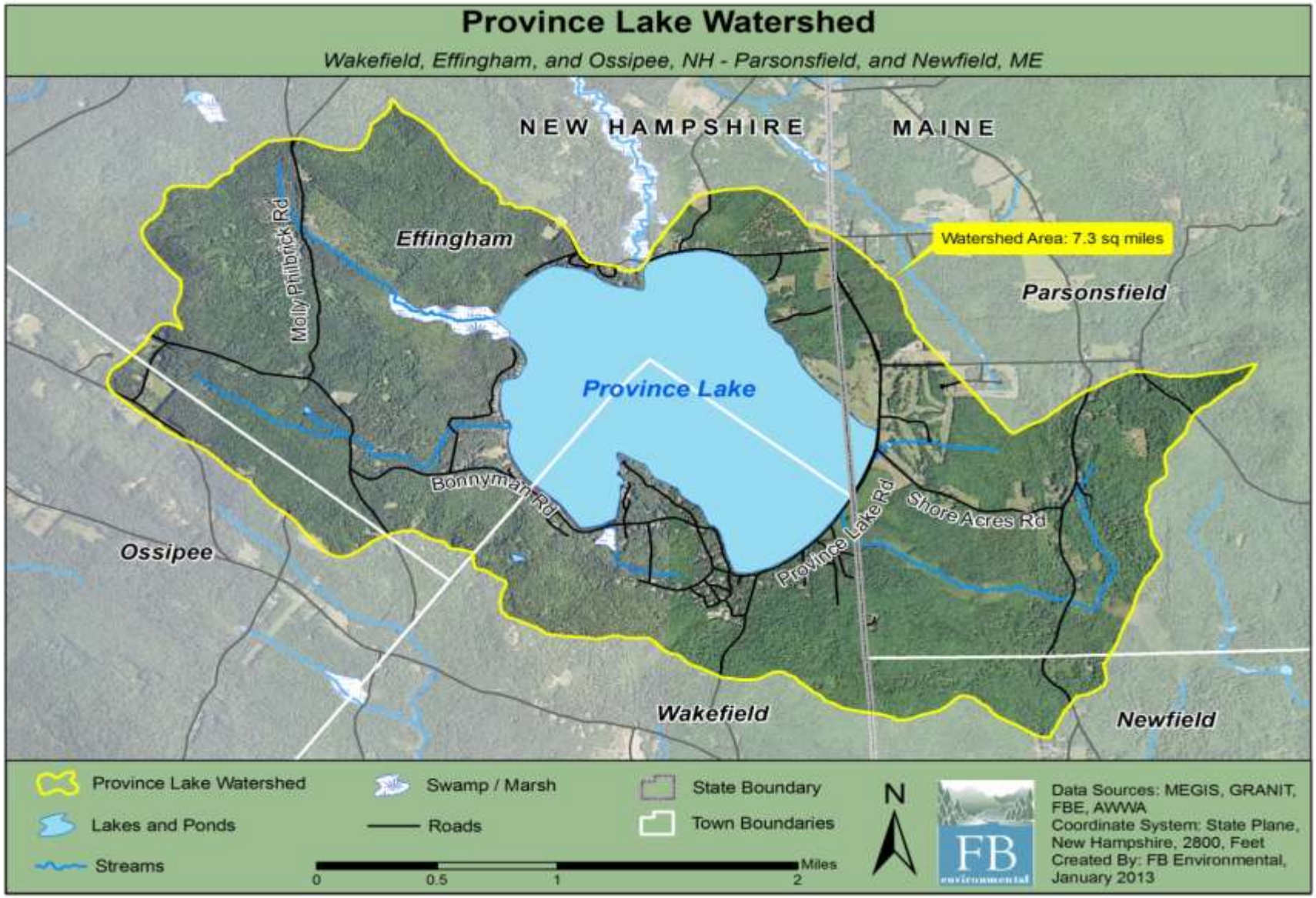
Location: Effingham & Wakefield, NH; Parsonsfield, ME
Counties: Carroll County, NH; York County, ME
State: New Hampshire, Maine
Watershed: Saco River
Watershed Area: 4,672 acres (7.3 sq. mi./ 1,891 ha)
Surface Area: 1,014 acres (410 ha)
Perimeter: 27,887 ft (8,500 m)
Volume: 11,268,500 m^3
Mean Depth: 9 ft (2.8 m)
Max Depth: 16 ft (4.9 m)
Mean Transparency: 8.5 ft (2.6 m)
Flushing Rate: 1.0/year
Drains to: South R. to Ossipee R.
Classification: Olig./Mesotrophic
Watershed Groups: PLA, AWWA

2. INTRODUCTION

PROVINCE LAKE (NHLAK600020902-01) is a 1,014 acre lake located in the towns of Effingham and Wakefield, in Carroll County, New Hampshire and the Town of Parsonsfield in York County, Maine (Figure 1). Province Lake has a small watershed relative to the lake's surface area at just 7.3 square miles (4,672 acres). The lake is a shallow, non-stratified, wind-driven system with a maximum depth of 16 feet (4.9 meters), and a mean depth of 9 feet (2.8 meters), and a low flushing rate of once per year.[1] The watershed includes a large wetland area, and Province Lake's primary inflow, Hobbs Brook to the northeast, the primary outflow is the through the South River on the north end of the lake, where it flows north to the Ossipee River, a tributary of the Saco River. Several other tributaries flow into Province Lake including the South River on the south east side of the lake, and several unnamed tributaries near Bonnyman Road in Effingham, at the Island Inlet and Route 153 Inlet in Wakefield, and at the Rte. 153 crossing in Parsonsfield (Figure 2).

[1] *Based on NHDES Trophic survey reports. The 2014 Province Lake Phosphorus Model calculated slightly different values.*

Figure 1. *Province Lake watershed.*



Province Lake was listed on the NH Department of Environmental Services (NHDES) 2010 and 2012 draft 303(d) list as impaired for Aquatic Life Use due to high levels of chlorophyll a (Chl-a) and total phosphorus. This is because the median epilimentic phosphorus concentration exceeds 8 parts per billion (ppb) and the chlorophyll-a concentration exceeds 3.3 ppb- the thresholds set for oligotrophic lakes. It was also on the 2012 draft list as impaired for Primary Contact Recreation (swimming) due to the presence of cyanobacteria (hepatotoxic). Local residents have documented cyanobacteria blooms on the lake every fall since 2010.

In 2012, the Province Lake Association (PLA) applied for and received a NHDES Watershed Assistance and Restoration grant from the NHDES to develop a watershed-based plan. The purpose of the plan is to identify potential sources of nonpoint source pollution in the watershed and to develop recommendations that will address these sources of pollution, and ultimately reduce the amount of phosphorus and the overall productivity in the lake, so that the lake will not continue to experience cyanobacteria blooms.

A major component of the watershed plan is to review the current and historical water quality data to determine, what trends if any are causing the impairment, and then to set goals to improve the water quality. Analyzing trends of measured parameters over a long-term sampling period provides critical insight into the function and health of a waterbody. By identifying the processes within Province Lake, local mangers, residents, lake associations and watershed groups can work together to develop manageable goals for improving water quality.

3. SUMMARY OF EXISTING WATER QUALITY

The water quality of Province Lake was first monitored by NHDES in 1979 at the deepest spot on the lake (PROEFFD). Subsequent trophic surveys were conducted by NHDES in 1987/88 and 2006/07, with more consistent data collected through the VLAP program between 1991-2012 (Table 1).

Table 1. *Sources of water quality data for Province Lake.*

Water Quality Data Available for Province Lake			
Data Source	***Agency/Organization***	***Years Sampled***	***# of Years Sampled***
NH VLAP	NHDES	*1991-2012*	22
NH Trophic Survey	NHDES	*1979, 1987, 1988, 2006, 2007*	5

During this period, basic chemical information, including total phosphorus, chlorophyll-a, dissolved oxygen, pH, and specific conductivity was collected, in addition to Secchi disk transparency (SDT) readings. Additional water quality parameters, including chloride, turbidity, color, bacteria, and alkalinity, were measured during this historical sampling period, but not for all years (see Appendix A). With the exception of late winter sampling by NHDES for the trophic surveys, the majority of sampling

was performed primarily on a monthly basis during ice-free conditions (May 15 – Oct 15) at the deepest spot on the lake (PROEFFD).

In addition to monitoring at the deep spot, there are four locations considered current monitoring locations (Table 2).

Table 2. *Description of current monitoring stations at Province Lake.*

Province Lake Historical Sampling Locations		
Site Name	***SITE ID***	***Description/Notes***
Current Sampling Stations		
Deep spot	PROEFFD	North of mid-lake
Campground inlet	PROEFFC	Above campground, culvert below Remmick Rd.
Island inlet	PROEFFI	Inlet to culvert above Bonnyman Rd.
Rt. 153 inlet	PROEFFR	Inlet to culvert above Rt. 153
Outlet	PROEFFO	Province Lake Association dam

Two of these, Island Inlet (PROEFFI) and the Route 153 Inlet (PROEFFR) have been monitored consistently since 1991. The primary parameters collected at these stations include: total phosphorus, specific conductance and pH, though color, turbidity, and chloride have also been collected at these stations, but not as consistently over the historic sampling period.

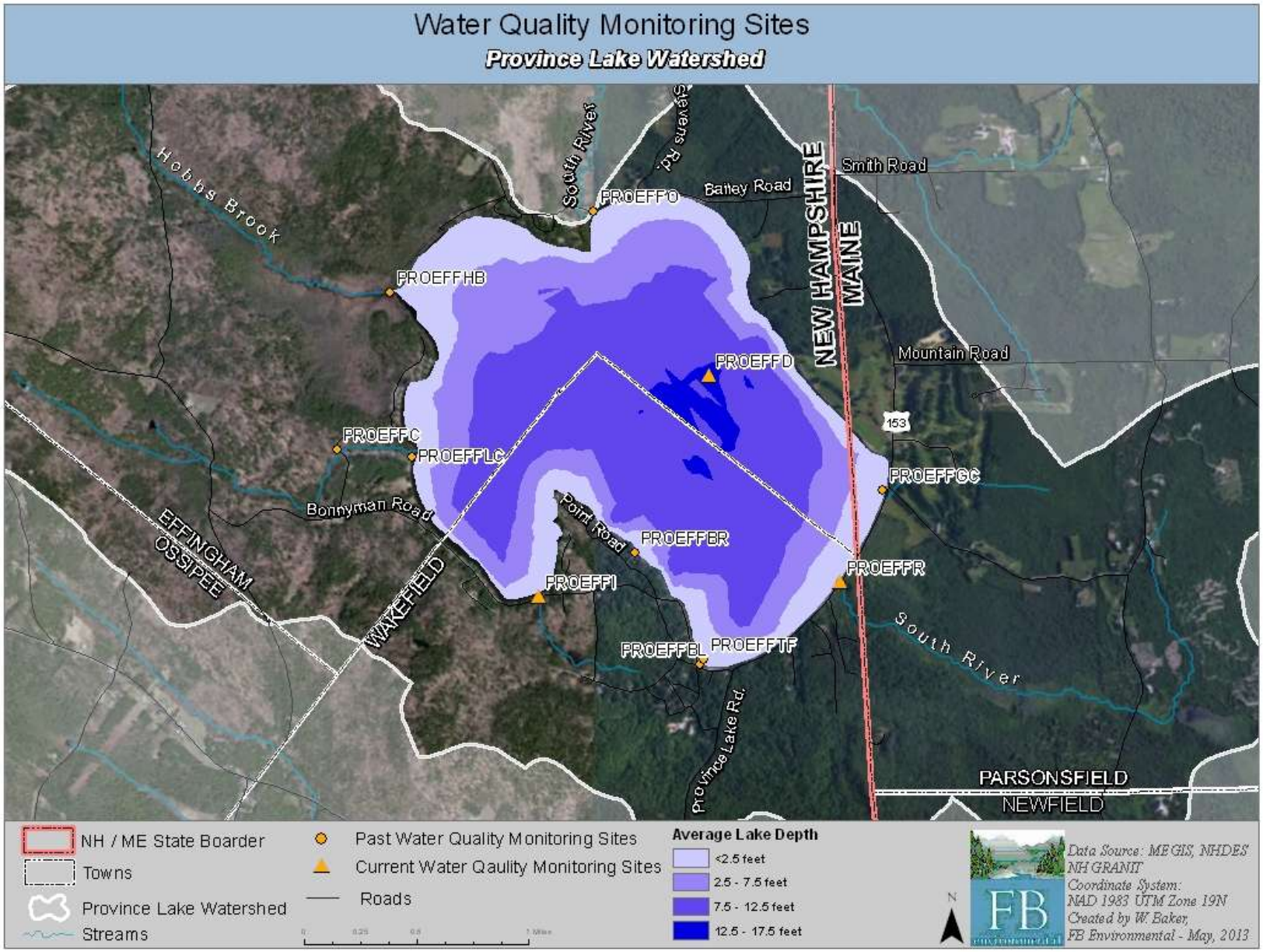
Ten other stations are believed to have been monitored historically in the Province Lake watershed (Table 3). However, the exact location of a few of these sites is currently unknown. The location of known stations is presented in Figure 2. A full list of sampling locations, parameters measured and dates is presented in Appendix A.

Table 3. *Description of other monitoring stations at Province Lake.*

Prior Sampling Stations Needing Verification		
Bass Rock	PROEFFBR	Close to shore, coordinates on nearest shore
Golf course	PROEFFGC	Outlet of Rt. 153 culvert draining course ponds
Hobbs Brook	PROEFFHB	At first old beaver dam (long gone)
Lower campground	PROEFFLC	Where campground stream meets lake
Right side beach	PROEFFBR	Unknown
Towle Farm	PROEFFTF	At boat ramp
Boat Launch	PROEFFBL	Boat launch
Keith Bay	?	Unknown
Left side beach	?	Unknown
Little Sandy Beach	?	Unknown
Above farm	?	Unknown

** Source: Sara Steiner, NHDES*

Figure 2. *Province Lake sampling location map.*



More recently, blooms of cyanobacteria were reported to NHDES in 2010, 2011, 2012 and 2013. Samples were tested for toxic cyanobacteria in 2010 and twice in 2012 (September & November). A summary of these findings is described in Section 5.5.

4. STUDY DESIGN AND DATA ACQUISITION

The water quality analysis for Province Lake utilized data for several key water quality parameters, including water clarity, chlorophyll-a (Chl-a), color, total phosphorus (TP), turbidity, dissolved oxygen (DO), and temperature.

Historical water quality monitoring data was analyzed by FB Environmental to determine historical water quality trends across multiple parameters, and to determine the median phosphorus concentration and the assimilative capacity for Province Lake. Data from the NHDES OneStop Environmental Monitoring Database was used to assess the water quality of Province Lake. With the exception of three years of trophic surveys conducted by NHDES, the remainder of the data was collected by volunteer monitors through the NHDES Volunteer Lake Assessment Program (VLAP). Despite a small portion of the lake, and a significant percentage of the watershed being located in Maine, no data is available from the Maine Department of Environmental Protection (Maine DEP) or volunteer monitors.

Water Quality Parameters

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 higher the amount of algae in the lake.*

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

Data acquisition and analysis for Province Lake followed protocols set forth in the Site Specific Project Plan (SSPP). Water quality monitoring data was analyzed in order to: 1) determine trends in several key water quality parameters such as water clarity, chlorophyll-a, color, dissolved oxygen and temperature, 2) determine the median phosphorus concentration of the lake and the assimilative capacity, and 3) provide recommendations that will help guide the Province Lake water quality subcommittee to set a water quality goal for the lake. The analysis includes a comparison of historical (2002 and earlier) and recent (2003-2012) total phosphorus monitoring results, and a seasonal analysis (samples collected between May 15 and October 15), as well as a summary of available data and sources of this data (Appendix A).

Water quality data from multiple sources were combined into a common spreadsheet, and then sorted by date and station for Quality Assurance/Quality Control (QA/QC) in order to avoid duplicate data sets. All duplicates were removed, and multiple samples collected on the same day were averaged. The analysis for total phosphorus (TP) included an initial analysis to determine median total phosphorus (TP)

based on all samples regardless of their location in the water column. Secondly, minimum, maximum, mean, and median TP concentrations were determined for the deepest spot on the lake, and were sorted by depth of sample (labeled as either epilimnetic/upper samples or hypolimnion/lower). Data were further refined using only samples collected in the epilimnion/upper to calculate the median epilimnetic TP concentration. The seasonal (May 15 - October 15), TP concentration 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. Similar methodology was used to calculate average Chlorophyll-a, Secchi disk transparency (SDT), and color. In addition, TP, turbidity and color were analyzed for two primary tributary locations including the Island Inlet (PROEFFI) and Rt. 153 Inlet (PROEFFR).

5. WATER QUALITY STANDARDS AND CRITERIA

5.1 General Standards

New Hampshire's water quality standards are used to protect the state's surface waters. They provide a baseline measure of water quality that surface waters must meet to support designated uses. Water quality thresholds 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 the designated uses. To determine if a waterbody is meeting its designated uses, water quality thresholds for various water quality parameters (e.g. ***chlorophyll-a, total phosphorus,*** *dissolved oxygen****, 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 Env-Wq 1700 (NHDES, 2008). New Hampshire recently developed thresholds for the narrative criteria based on trophic classes. The draft water quality threshold for aquatic life use was set by analyzing 233 New Hampshire lakes (or about one-fourth of all lake in New Hampshire), for phosphorus and chlorophyll-a, and trophic class. The results of that analysis indicated that statistically significant values for phosphorus could be determined for each trophic class (as shown in Table 3.3). These thresholds, based on summer median TP were incorporated into the *Consolidated Assessment and Listing Methodology (CALM)* for determining impairment status for the 2010 water quality report to Congress. The data indicate that a lake will exhibit characteristics of a lower trophic class when chlorophyll-a levels exceed the identified thresholds.

Table 4. *Aquatic life 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

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 and outstanding resource waters. High quality waters is a special designation that NHDES assigns to waters of significantly better quality than set forth by water quality standards.

5.3 Lake Nutrient Criteria

New Hampshire incorporates criteria in its water quality regulations to help determine whether nutrients are affecting lake water quality. For aquatic life uses (ALU), the state has a narrative nutrient criteria with a numeric translator or threshold, consisting of a "nutrient indicator" (for example, phosphorus) and a "response indicator" (in this case, chlorophyll-a). Sampling results from both the nutrient indicator and the response indicator are used to assess aquatic life uses (ALU) in New Hampshire Lakes (Table 4). For primary contact recreation (PCR), New Hampshire has a narrative criteria with a numeric translator or threshold for chlorophyll-a. The nutrient indicator and response indicator are intricately linked since increased phosphorus loading frequently results in increased phytoplankton levels, which can be estimated by measuring chlorophyll-a levels in the lake. Increased phytoplankton may lead to decreased oxygen at the bottom of the lake, decreased water quality, and possibly changes in aquatic species composition.

5.3.1 Primary Contact Recreation

The narrative criteria for primary contact recreation (PCR) can be found in Env-Wq 1703.03, 'General Water Quality Criteria' and reads, "*All surface waters shall be free from substances in kind or quantity which float as foam, debris, scum or other visible substances, produce odor, color, taste or turbidity which is not naturally occurring and would render it unsuitable for its designated uses or would interfere with recreation activities*". Nutrient response indicators chlorophyll-a (Chl-a) and cyanobacteria scums (cyano) are used as secondary indicators for PCR assessments. These indicators can provide reasonable evidence to classify the designated use as "not supporting," but cannot result in a "fully supporting" designation. *E. coli* is the primary indicator for "fully supporting" designations. Elevated Chl-a levels or the presence of cyanobacterial scums interfere with the aesthetic enjoyment of swimming or may pose a health hazard. Chl-a levels greater than or equal to 15 ppb or cyanobacteria scums are considered "not supporting" for this designated use.

5.3.2 Aquatic Life Use

Measurements for Aquatic Life Use (ALU) ensures that waters provide suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms. For ALU assessment, the combination of TP and Chl-a nutrient indicators is used to make support determinations. The ALU nutrient criteria vary by lake trophic class, since each **trophic state** has a certain phytoplankton biomass (Chl-a) that represents a balanced, integrated, and adaptive community. Exceedances of the Chl-a criterion suggests that the phytoplankton community is out of balance. Since phosphorus is the primary limiting growth nutrient for Chl-a, it is included in this evaluation process.

Trophic State *is the degree of eutrophication of a lake as assessed by the transparency, Chl-a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the hypolimnion.*

For ALU assessment determinations, Chl-a and TP results are combined according to the decision matrix presented in Table 5. The Chl-a concentration will dictate the assessment if both Chl-a and TP data are available and the assessments differ. While dissolved oxygen and pH are also core indicators for aquatic life for lakes, this analysis, and forthcoming watershed plan focuses on the stressor phosphorus and its response indicator, chlorophyll-a.

Table 5. *Decision matrix for aquatic life use assessment determinations in New Hampshire.*

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

6. WATER QUALITY ANALYSIS RESULTS

6.1 Trophic Status

From 1974 through 2010, NHDES conducted trophic surveys on lakes to determine ***trophic state***. The trophic surveys evaluate 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 very 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.

As described in Section 4, an assessment of 233 New Hampshire Lakes indicated that significant values could be derived for each trophic class. Oligotrophic lakes have high dissolved oxygen levels (> 5 mg/L),

high transparency (> 12 ft.), low chlorophyll-a concentrations (< 4 mg/L), low phosphorus concentrations (< 10 ug/L), and sparse aquatic plant growth. Eutrophic lakes have low levels of dissolved oxygen (< 2 mg/L), low transparency (< 6 ft.), high chlorophyll-a concentrations (> 15 mg/L), high phosphorus concentrations (> 20 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, 2013).

For Province Lake, the trophic status was determined to be oligotrophic in 1979 and 1987. However, the status was changed to mesotrophic during the 2006 trophic survey conducted by NHDES. Because water quality assessments in New Hampshire are based on the highest trophic status reported for a lake, technically, Province Lake should be considered an oligotrophic lake. This means that in-lake water quality concentrations such as total phosphorus, chlorophyll-a and dissolved oxygen should be consistent with the thresholds set for oligotrophic lakes.

Table 6. *Trophic state determination for Province Lake.*

Year	Trophic State
1979	Oligotrophic
1987	Oligotrophic
2006	Mesotrophic

A water quality committee should review and discuss the historical trophic state classification to make a final determination of trophic state for Province Lake which will guide efforts to set a water quality goal for the lake. Additional analysis, including running an alternative Trophic State Index (TSI), the Carlson TSI- which is commonly used to characterize trophic state in lakes, may be helpful for this discussion. The Carlson TSI varies slightly from the NHDES Trophic Classification System in that only transparency, chlorophyll-a and total phosphorus are used. Whereas, NHDES uses transparency, chlorophyll-a, summer dissolved oxygen levels, and aquatic plant abundance.

The Carlson TSI assigns values based on logarithmic scales that describe the relationship between the three major water quality parameters and the lake's overall biological productivity. TSI scores below 40 are considered oligotrophic, scores between 40 and 50 are mesotrophic, scores between 50 and 70 are eutrophic, and scores from 70 to 100 are hypereutrophic. The Carlson TSI for Province Lake is mesotrophic (Table 7), which is in-line with the 2006 NHDES classification. Note that the TSI is based on the most recent annual average for each parameter (2003-2012). Historical averages (2002 and prior) were similar to recent averages in all cases.

Table 7. *Carlson Trophic State Index for Province Lake.*

WQ Parameter	Mean WQ Value (2003-2012)	TSI	Trophic State
Mean SDT (m)	2.6 m	46.3	Mesotrophic
Mean Chl_a (ppb)	3.7 ppb	43.5	Mesotrophic
Mean TP (ppb)	14.6 ppb	42.8	Mesotrophic

Similarly, the NHDES Trophic Classification System for New Hampshire Lakes and Ponds was used to recalculate trophic status based on the last ten years of data. In the past, trophic state has been determined based on data collected by NHDES every five to 10 years. As described above, the classification has included both oligotrophic and mesotrophic. Using the water quality data from the last ten years at Province Lake, the trophic classification would be in-line with the 2006 NHDES trophic survey and the Carlson TSI index. Table 8 (below) provides a summary of the scoring.

Table 8. *NHDES Trophic Classification for Province Lake.*

WQ Parameter	Mean WQ Value (2003-2012)	Trophic Points	Trophic State
Summer Bottom DO (mg/L)	~ 7 - 9 ppm	0.0	N/A for non-stratified lakes
Mean SDT (m)	2.6 m	3.0	> 2 to 3 m
Aquatic Vasc. Plant Abundance	Scattered/Common	2.0	Based on '06 Trophic Survey
Mean Chl_a (ppb)	3.7 ppb	0.0	< 4 ppb = 0
Total		**5.0**	**Mesotrophic (5 - 9)**

6.2 Secchi Disk Transparency (SDT) is a vertical measure of water transparency (the ability of light to penetrate water) obtained by lowering a black and white disk into the water until it is no longer visible. Measuring Secchi disk transparency (SDT) is one of the most useful ways to determine whether a lake is changing from year to year. Changes in transparency may be due to increased or decreased algal growth, or the amount of dissolved or particulate materials in a lake, resulting from human disturbance or other impacts to the lake watershed area. Factors that affect transparency include algae, water color, and sediment. Since algae are usually the most common factor, transparency is an indirect measure of algal populations.

Average annual SDT for Province Lake = 2.59 m

Average summer transparency for New Hampshire's lakes and ponds is 3.2 meters, and 4.0 meters for the 21 lakes in the White Mountain Region, which includes Province Lake (NHDES, 2013). As seen above, shallow lakes, like Province Lake often have transparency readings lower than the state or regional average compared to deeper lakes. This is true of Province Lake, where the recent (2003-2012), average (mean), seasonal (May 15-October 15) transparency value is 2.56 (historical average is 2.59), more than half a meter lower than the state average, and close to one and a half meters less than the regional average. Therefore, an important factor of the water quality analysis is to examine how transparency has changed over time (Figure 3).

Figure 3. *Historical water transparency for Province Lake.*

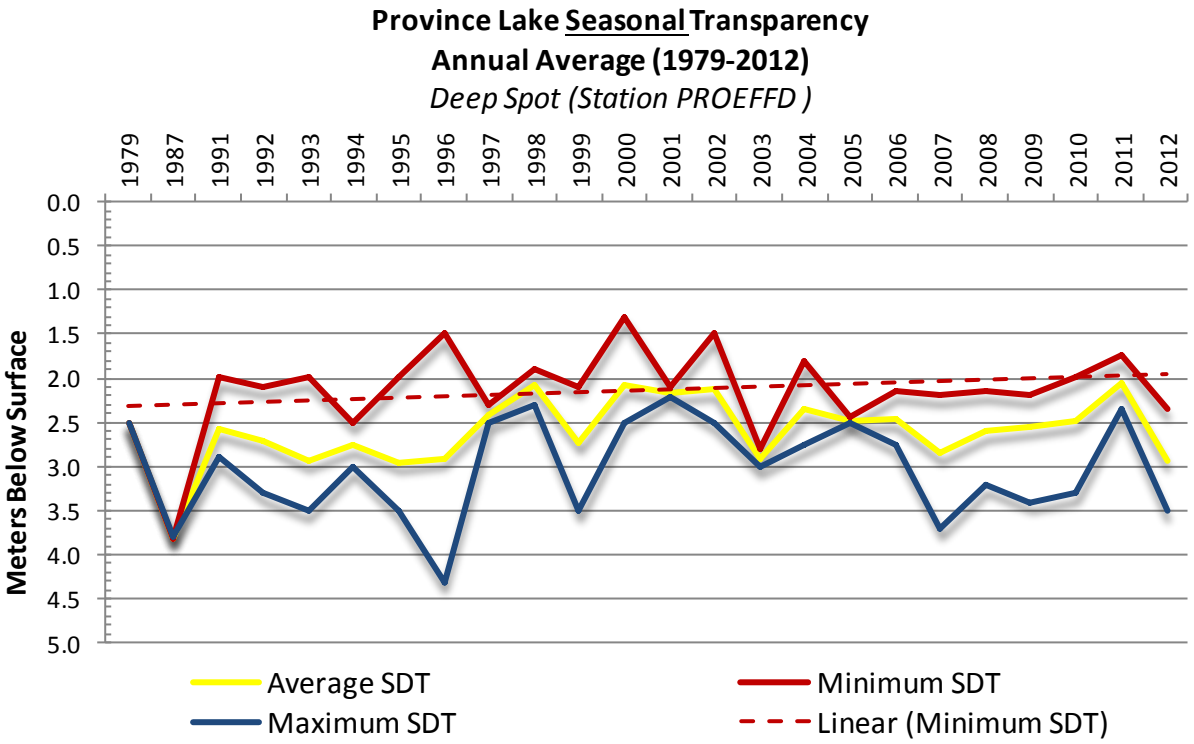


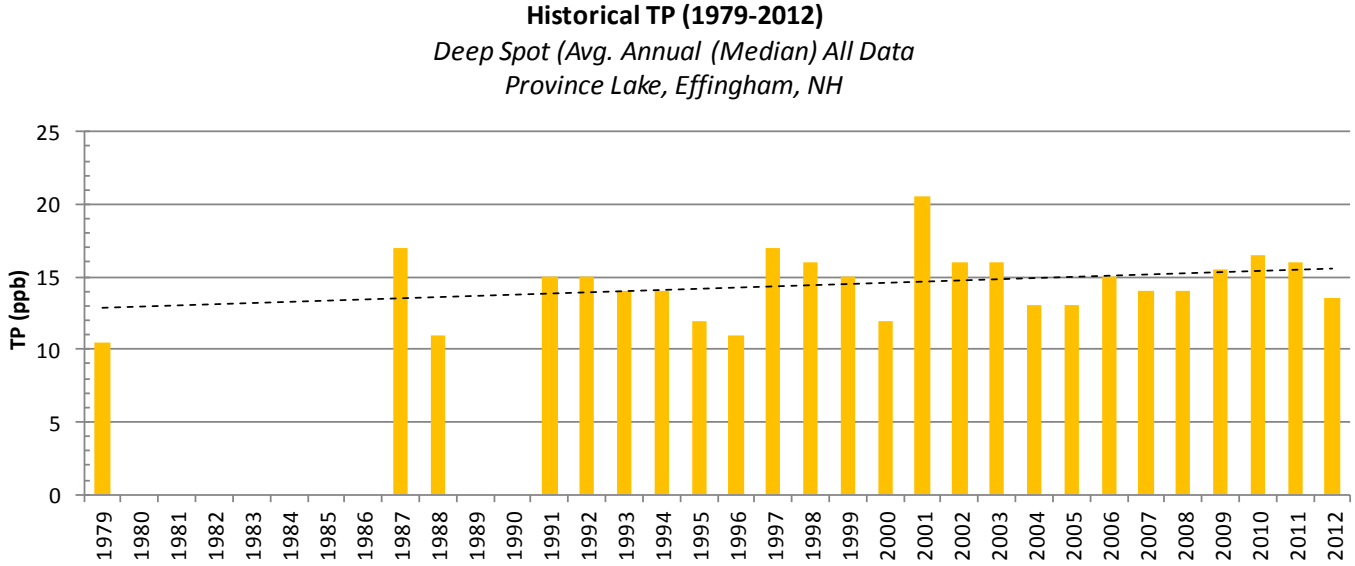
Figure 3 indicates that minimum water clarity readings in Province Lake have been relatively stable over time. In fact historic (1979-2002) annual average of 2.62 m, is only slightly better than the recent (2003-2012) annual average of 2.56 m. A difference of only 0.06 m (~ 2.4 "). The slightly declining trend in minimum transparency is likely due to a single reading in July 1987 at 3.8 m. Other than 1979, which had a single SDT value of 2.5 m, all other years have at least two to four months of data. Minimum SDT was at or below 2.0 m in 10 of the 24 years sampled (40%). However, mean SDT did not fall below 2.0 in any of the sampling years. Major fluctuations in SDT (extreme high and low values) occurred in 1993, 1995, 1996 and 2010. The lowest reading (1.3 m) was recorded in June of 2000, while the highest reading (4.3 m) was recorded in August and September of 1996. Extreme fluctuations in SDT is likely driven by changes in weather between dry (high SDT) and very wet (low SDT) conditions that either limit or increase the amount of sediment delivered to the lake.

6.3 Total Phosphorus (TP) refers to the total concentration of phosphorus found in the water, including organic and inorganic forms. TP is one of the major nutrients needed for plant growth. It is generally present in small amounts and limits plant growth (both vascular plants and algae) in freshwater ecosystems. Anoxia (low dissolved oxygen) can release phosphorus bound to sediments into the water column, thereby increasing the amount of available phosphorus. Humans can also add phosphorus to lakes through stormwater runoff, lawn or garden fertilizers, and leaky or poorly maintained septic tanks. In shallow lakes, like Province Lake, heavy motorboat activity has been shown to increase the potential

for phytoplankton growth (Wagner, 1990). As TP increases within a system, the amount of algae also increases, and may lead to nuisance algal blooms and low water clarity. In New Hampshire lakes, the median summer epilimentic (upper layer) TP is 12 parts per billion (ppb), while the TP concentration for the White Mountain Region is 8 ppb (NHDES, 2013).

Recent Median TP for Province Lake = 14.3 ppb

Figure 4. *Historical total phosphorus levels in Province Lake.*



As described in Section 4.1, NHDES uses a narrative nutrient criteria with a numeric translator, consisting of a "nutrient indicator" (phosphorus) and a "response indicator" (chlorophyll-a). The results from both the nutrient indicator and the response indicator are used to assess aquatic life uses (ALU) in NH Lakes. The median total phosphorus concentration of 14.3 ppb in Province Lake exceeds the NHDES aquatic life nutrient criteria pertaining to phosphorus for both oligotrophic and mesotrophic lakes (refer to Table 4).

The lack of data between 1979 and 1987, make it impossible to conclude that the lowest reading on record in 1979 (5 ppb in the epilimnion) is representative of in-lake TP concentrations in the 70's and early 80's, or if it is an outlier in the data. Therefore, it was included in the analysis. Comparing recent (2003-2012) vs. historic (1979-2002) data for only seasonal epilimentic samples indicates a decrease of 1.4 ppb (15.6 ppb historic vs. 14.3 recent) for TP in Province Lake.

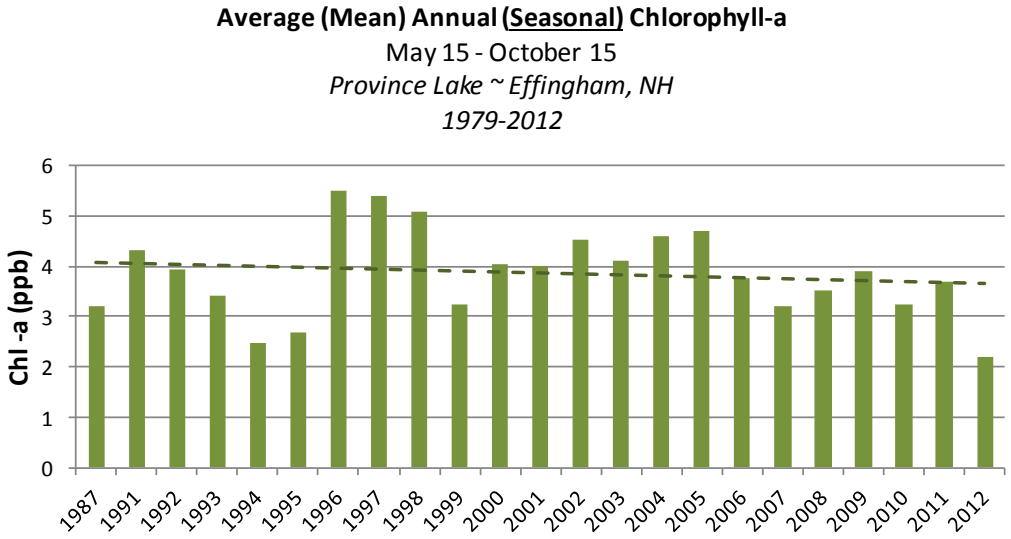
6.4 Chlorophyll-a (Chl-a) is a measurement of the green pigment used for photosynthesis, and found in all plants (including microscopic plants such as algae and cyanobacteria). Chl-a used as an estimate of algal abundance or lake productivity- higher Chl-a equates to a greater amount of algae in a lake. Chl-a concentrations are believed to be related to phosphorus concentrations, where increased concentrations of phosphorus result in increased algal growth.

Recent Median Chl-a Province Lake = 3.6 ppb

The median summer Chl-a concentration in New Hampshire lakes and ponds is 4.58 ppb, and slightly lower in the White Mountain Region at 3.11 ppb. Recent (2003-2012) and historical (1979-2002) median annual Chl-a concentrations of 3.6 ppb, are lower than the state average, but higher than the regional average by 0.5 ppb.

An unusually low reading in 1979 (0.78 mg/m3, ~ 1.1 ppb) was determined to be an outlier, and removed from the analysis. Chl-a reached a high point between 1996-1998 with concentrations greater than 5 ppb. Since 2006, average annual Chl-a concentrations have been below 4 ppb, with the lowest annual average in 2012 (2.2 ppb). A comparison of historical averages (2002 and earlier) vs. recent (2003-2012) averages shows a decrease of 0.36 ppb. Based on these factors, the Chl-a trend is appears to be decreasing (slightly improving) over time.

Figure 5. *Historical chlorophyll-a results for Province Lake.*



As described above, New Hampshire has a narrative nutrient criteria with a numeric translator, consisting of a "nutrient indicator" (phosphorus) and a "response indicator" (chlorophyll-a). The results from both the nutrient indicator and the response indicator are used to assess aquatic life uses (ALU) in NH Lakes. If Province Lake is classified as mesotrophic, then Chl-a levels in the lake are within the acceptable range (3.3 ppb - 5 ppb) based on these criteria. However, if the lake is classified as an oligotrophic lake, then the elevated Chl-a concentrations could be used to make support decisions, and the lake would likely be listed as impaired for aquatic life due to exceedance of the indicator threshold for both phosphorus and Chl-a. In the case of mesotrophic lakes where the phosphorus concentrations exceed the threshold, but are within the range for Chl-a, the lake would be considered fully supporting for aquatic life (Table 5).

In addition, Chl-a is used as a secondary nutrient response indicator for Primary Contact Recreation assessments along with cyanobacteria scums (cyano). They can cause a “not support” assessment, but, by themselves, cannot result in a “full support” designation (the primary indicator E. coli is needed for a “full support” assessment). The logic is that elevated Chl-a levels or the presence of cyano scums interfere with the aesthetic enjoyment of swimming and, in the case of cyano, may also pose a health hazard. Non-support for Chl-a is defined as concentrations greater than or equal to 15 ppb, far greater than Chl-a concentrations in Province Lake.

6.5. Phytoplankton and Cyanobacteria

Phytoplankton and cyanobacteria present in a lake can be used as an indicator of general lake water quality. There are many different types of phytoplankton including golden-brown algae and diatoms that are typically found in New Hampshire lakes. However, an abundance of cyanobacteria (blue/green algae) may indicate excessive phosphorus inputs in the lake, or that the lake ecology is out of balance. Cyanobacteria are bacterial microorganisms that photosynthesize and may accumulate to form surface water scums on lakes. While many species are found naturally occurring in all lakes across the world, there are eight known species common to New Hampshire lakes. These include: *Gloeotrichia, Merismopedia, Anabaena, Aphanizomenon, Oscillatoria, Coelospharium, Lyngba, and Microcystis* (NHDES, 2013). Certain cyanobacteria species produce toxins known as "cyanotoxins" that can adversely affect livestock, domestic animals and humans. *Microcystis and Oscillatoria* are best known for producing hepatotoxins known as microcystins, which affect liver function. *Oscillatoria and Lyngbya* produce dermatotoxins which cause skin rashes.

While cyanobacteria are naturally occurring in all lakes, their abundance can increase as lake nutrients increase. Other factors that result in bloom conditions include increased water temperature and sunlight. Cyanobacteria may overwinter on the lake bottom, moving up to the surface of the water and forming blooms in mid to late summer, or into fall (NHDES, 2009), as is the case for Province Lake over the past three years.

Cyanobacteria are a concern in Province Lake for many reasons, including lake aesthetics, concern about declining water clarity and the associated economic effects to the area, and most importantly, the potential affects to wildlife, domestic animals and human health. Cyanotoxins are released into the water when cells die or are consumed by organisms higher in the food chain. Ingesting lake water and/or recreating on a lake with high levels of cyanobacteria can result in both acute and chronic illnesses (NHDES, 2013b) that target the liver, kidney, the central nervous system and skin.

NHDES will post a beach advisory if potential toxin-producing cyanobacterial scum is present at the beach and cell dominance is greater than 50% of the total cell count (DES, 2013b). In 2009, the standard was revised to be based on a total cell count of all phytoplankton species (70,000 cells/mL or greater). The total phytoplankton cell count guideline is not intended as a direct measure of cyanobacteria

abundance, but is intended to indicate conditions in which excessive cyanobacteria levels could either exist or rapidly develop.

Blooms of cyanobacteria were reported to NHDES for the past four years (2010 - 2013). Samples were tested for toxic cyanobacteria in 2010, twice in 2012 (September & November), and again in June and July 2013. A summary of these findings is provided below:

September 1-15, 2010: Bloom conditions were reported. Bloom was examined and confirmed. DES issued a press release warning lake residents to avoid areas of the lake with green scums visible.

- On 9/2/10, a sample was collected and the cell count was 243,772 cells/mL of Anabaena.
- On 9/14/10, another sample contained less than 100 cells/ml of cyanobacteria.
- The cyanobacteria lake warning was issued on 9/3/10 and removed on 9/15/10. Toxin analysis was not completed on these samples.

September 23-October 15, 2011: Bloom conditions reported, but no lake warning issued. The NHDES swimming beach inspection program runs from Memorial Day through Labor Day. Because the bloom occurred after staff reductions in the fall, no samples were collected or analyzed.

September 2012: Bloom conditions reported.

- Samples collected on 9/6/12 contained 1,267,614 cells/mL and was all Anabaena & Microcystis. The sample was analyzed for microcystin, but it contained less than the detectable limit, 0.4 ppb.
- A sample collected 9/7/12 was only 13% Anabaena at 6,704 cells/mL. No lake warning was issued.

November 2012: Samples were collected by the Acton Wakefield Watersheds Alliance on 11/19/12. Samples were delivered to Jim Haney at UNH for analysis, and later analyzed for concentrations and toxins. There were no detectable microcystins, or β-Methylamino-L-alanine (BMAA, a neurotoxin) in the samples. No testing was conducted for anatoxins.

June 2013: A cyanobacteria bloom was reported on June 21, 2013 near the boat ramp on Bonnyman Road. The bloom was reportedly whitish and yellow small clumps at the surface and below the water's surface. A cyanobacteria advisory was issued by NHDES. Two samples were collected by the Acton-Wakefield Watersheds Alliance (AWWA), and found to be below the 70,000 cells/mL that would prompt a lake-wide warning. Follow-up analysis indicated that the samples were anabaena. The advisory was lifted on June 28, 2013.

July - November 2013: The Province Lake Association reported five more cyanobacteria blooms on Province Lake between July and November 2013. This includes a bloom on July 11, 2013 that was reported all around the lake and resulted in a cyanobacteria advisory and signage postage at various

locations around the lake. On August 27, 2013, a bloom was reported near Sunset and Bonnyman Rd. but no warning was issued. Similarly, two blooms occurred in October (10/9 in the Lake Shore Dr. area, and 10/31 along Point Rd.), neither of which resulted in a warning due to low cell counts. The final report was on November 4, 2013 along Point Rd.- again, no advisory was needed.

Based on the recent accounts and testing of cyanobacteria described above, Province Lake is considered non-supporting for primary contact recreation due to cyanobacteria. Another way of describing non-supporting cyano scums is: *"The surface water contains color, foam, debris, scum, slicks, odors and/or surface floating solids in significant amounts and for durations that significantly interfere with the primary contact recreational use, and they are not naturally occurring."*

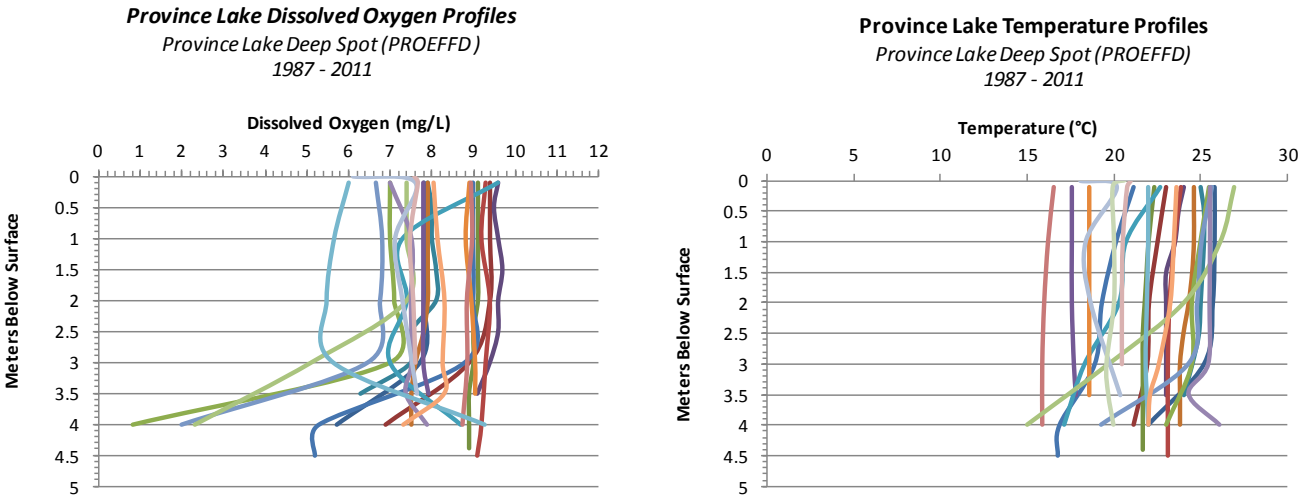
The increased frequency of blooms in Province Lake is alarming, from just one report in the fall of 2010 and 2011, three reports in the late summer and fall of 2012, and six reports beginning in early summer through late fall of 2013. Because cyanobacteria are indicative of excess nutrients, immediate action is needed to reduce the amount of nutrients, especially phosphorus that is entering the lake. Additional historical information from the 1960's and 1970's indicate that the cyanobacteria blooms occurring in Province Lake today are not new to Province Lake, and that management strategies can work to prevent future occurrences (refer to Section 6.10 for more information).

6.6 Dissolved Oxygen (DO) is the concentration of oxygen dissolved in the water, and is vital to fish, algae, macrophytes, and chemical reactions that support lake functioning. Too little oxygen (known as anoxia) severely reduces the diversity and abundance of aquatic communities. DO levels in lake water are influenced by a number of factors, including water temperature, concentration of algae and other plants in the water, and the amount of nutrients and organic matter flowing into the lake as runoff from the watershed.

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). In deep, stratified lakes, changes in DO and temperature are more dramatic with high oxygen near the surface and virtually no oxygen near the bottom, compared with non-stratified lakes like Province Lake where water is continually mixed through the water column. DO levels below 5 ppm can stress fish and other bottom-dwelling organisms including amphibians, and over time reduce habitat for sensitive cold water fish species.

Dissolved oxygen and temperature profiles for Province Lake have been collected over the course of twenty-one years between 1987 and 2011. Results are consistent with a non-stratified lake, showing little change in temperature or oxygen from the surface to the bottom of the lake (Figure 6). Only a few instances of low dissolved oxygen (< 5 ppm) occurred in 1998, 2003 and 2005. A single reading of 3.2 ppm was recorded on 8/8/79 at 4.5 m. In general, temperature in Province Lake ranges from 18-26 degrees Celsius, and dissolved oxygen levels range from approximately 7 ppm to 9.5 ppm.

Figure 6. *Dissolved oxygen and temperature profiles for Province Lake.*



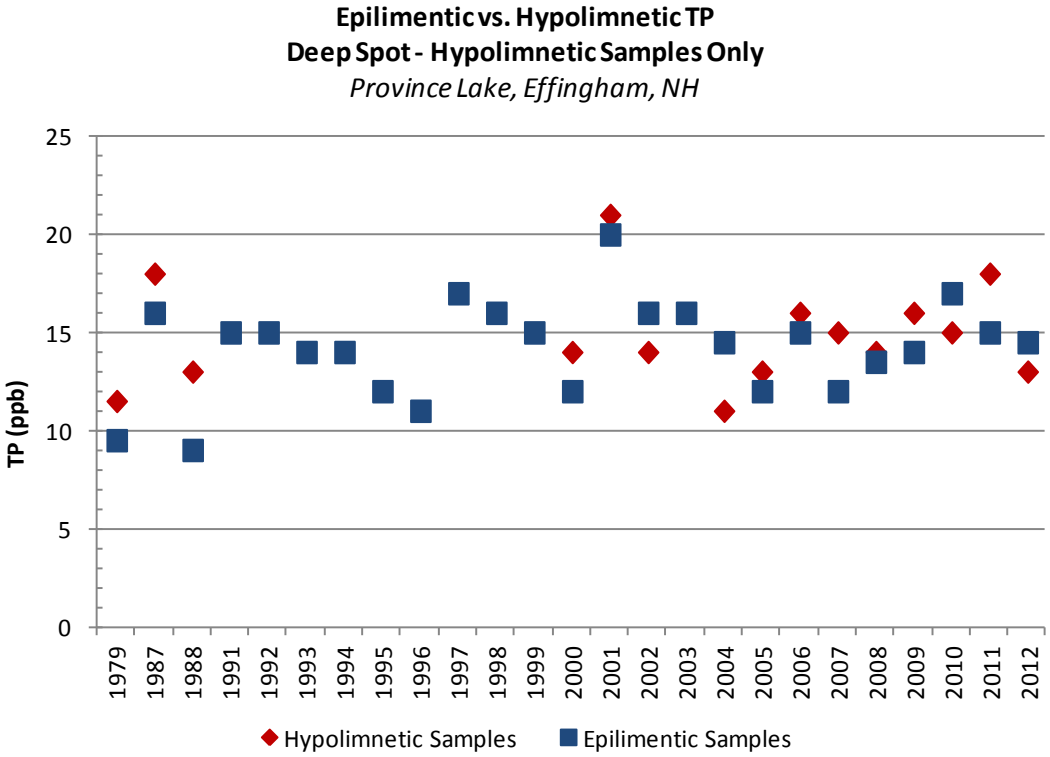
Internal phosphorus loading is a process in which phosphorus is released from bottom sediments as a result of low levels of dissolved oxygen at the bottom of the lake. The consistently high levels of dissolved oxygen throughout the profile are not cause for internal loading due to low levels of dissolved oxygen, however phosphorus-laden bottom waters can be redistributed in the water column during fall turnover, which can stimulate additional algal growth and/or cyanobacteria growth and result in an algal bloom in the fall.

As discussed previously, Province Lake is a shallow lake with heavy boat traffic during the summer months. Local stakeholders have voiced concern about resuspension of phosphorus-laden sediment as a result of boat propellers, especially in shallow coves. No data exists to estimate/quantify internal loading caused by sediment disturbance from boat traffic. Further study of this possibility is recommended, and could be accomplished by monitoring the lake water column both before (Thursday afternoon), during, and after (Monday afternoon) heavy boat traffic weekends, or on holiday weekends. Phosphorus concentrations, turbidity, and Secchi disk transparency would provide valuable data to help answer the question of man-made mixing/internal loading as a result of boat traffic in the lake. While the increase in nutrients is especially important to Province Lake in order to reduce the potential for ongoing cyanobacteria blooms, there are many other negative effects of boating on the lake including increased turbidity, decreased water clarity, metal and gasoline inputs, shoreline erosion, effects on rooted aquatic plants, invertebrates, fish, waterfowl and other aquatic wildlife.

A comparison of phosphorus samples collected in the upper portion of the water column vs. samples collected near the bottom of the lake, indicates that phosphorus concentrations at the bottom of the lake are less than 1 ppb higher on average than samples collected on the same day at the same time at the surface. There is no statistical difference between TP in the upper vs. lower profile. In 30% of cases, samples collected lower in the profile had a lower TP concentration than in the epilimnion (Figure 7). The high levels of dissolved oxygen throughout the profile, coupled with the TP results shown in Figure 7

indicate that the lake is well oxygenated, well mixed, and not highly susceptible to internal loading as a result of low levels of dissolved oxygen. However, any phosphorus that settles in the sediments may be easily resuspended into the water column as a result of the shallow depth and boating activity, providing a source of food for algae.

Figure 7. *Comparison of hypolimnetic vs. epilimentic TP for Province Lake.*



6.7 Additional Parameters

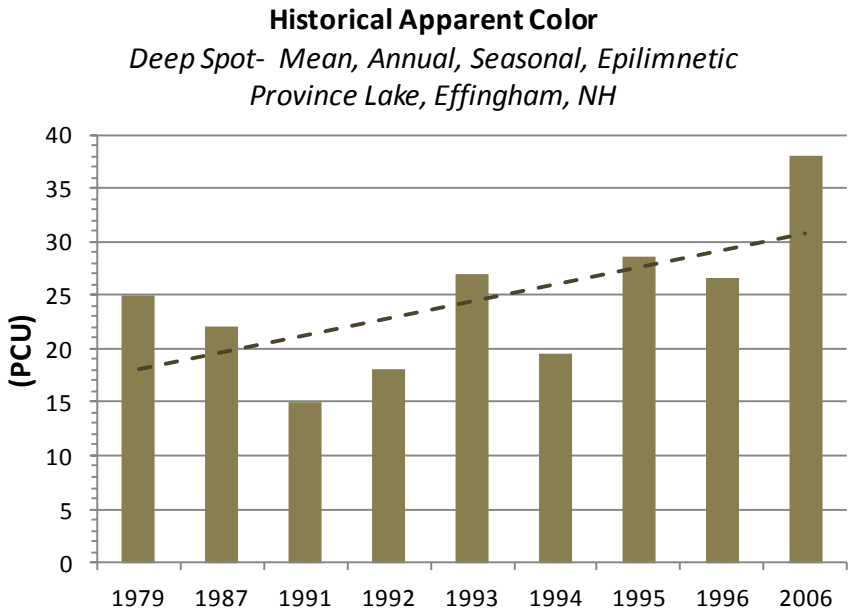
In addition to the above parameters, color and pH are important parameters to measure.

6.7.1 Color

Color is the influence of suspended and dissolved particles in the water as measured as apparent color in Platinum Cobalt Units (PCU). A variety of sources contribute to the types and amount of suspended material in lake water, including weathered geologic material, vegetation cover, and land use activity.

Color data is limited for Province Lake, with only nine years of monitoring data between 1979 and 2007. The single sample collected in 2007 was from February, and was not included in the seasonal analysis (Figure 8). Results of the analysis indicate that color increased in the lake over the historic sampling period. In Maine, lakes with greater than 25 SPU are considered colored. When lakes are highly colored, the best indication of algal growth is Chl-a. Current data is needed to determine if this trend has continued to the present. An increase in color affects light penetration and transparency, and may result in increased levels of phosphorus and favor cyanobacteria growth.

Figure 8. Apparent color in *Province Lake.*



Increased color in lakes can also affect water temperature. Lakes with high color can warm up more quickly in the spring since sunlight reaches shallower depths. This also can affect what type and when plankton are present in the water. If nutrients such as phosphorus remain constant, warmer lake temperature (driven by increased color) can benefit blue-green algae and increasing their levels of productivity. Climate change can also affect color. Large storm events/storm surges like we saw with Hurricane Irene in August 2011 and 2012 with Hurricane Irene and Hurricane Sandy in October 2012 may result in irregular pulses of color and nutrients from wetlands as a result of flushing. Province Lake has several large wetlands that flow into the lake, and therefore may be contributing to this color change.

6.7.2 pH

pH is the standard measure of the acidity or alkalinity of a solution on a scale of 0 (acidic) to 14 (basic). Most aquatic species require a pH between 6.5 and 8. As the pH of a lake declines, particularly below 6, the reproductive capacity of fish populations can be greatly impacted as the availability of nutrients and metals changes. pH is influenced by bedrock, acid rain deposition, wastewater discharge, and natural carbon dioxide fluctuations. A waterbody is considered impaired in New Hampshire for aquatic life when the pH falls below 6.5 or above 8.0. The median epilimnetic pH for lakes in New Hampshire is 6.6, while the average pH for the White Mountain Region is slightly higher at 6.69.

pH in Province Lake = 6.7

The average pH for Province Lake is 6.7, which is on the low end of the adequate range for many aquatic species. The pH trend shows an insignificant decrease (-0.04) over the historical sampling period. pH fell below 6.5 in Province lake a total of 13 times since 1996, seven of which occurred since 2006. Province Lake was therefore listed as impaired for pH in 2012 due to numerous pH measurements that fell below 6.5. Fortunately, there were no pH exceedances observed in the lake in 2011 or 2012.

6.8 Assimilative Capacity Analysis

The assimilative capacity of a lake is its ability to resist the effects of landscape disturbance without water quality impairment. For purposes of this plan, phosphorus was determined to have the greatest direct impact on the water quality in Province Lake. A lake receives natural inputs of phosphorus in the form of runoff from its watershed. This phosphorus will be taken up by aquatic life within the lake, settle out in the bottom sediments, or flow out of the lake into 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, and precipitation runoff coefficient. If a lake is receiving more phosphorus from the watershed than it can assimilate, then water quality will decline over time, and algal or cyanobacteria blooms will become more frequent.

The median total phosphorus concentration of Province Lake, at the deepest sampling location, was used to calculate the total, reserve, and remaining assimilative capacity using procedures described in the Standard Operating Procedures for Assimilative Capacity Analysis for New Hampshire Waters (Table 9; NHDES, 2008). Tier 2 waters, or high quality waterbodies, have one or more water quality parameters that exceed the water quality threshold 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. An impaired water is one in which the water quality of one or more parameters is worse than the threshold; they have a negative assimilative capacity and require reductions in pollutant loading in order to restore the waterbody to meet the standard.

Table 9. *Assimilative capacity analysis results for Province Lake.*

Lake	Station	Existing Median TP (ppb)	TP WQ Threshold (ppb)	AC Threshold (ppb)	Remaining AC (ppb)	Analysis Results
Province Lake	Deep Spot	14.3	8.0 (olig.)	7.2	-7.1	Exceeds Threshold
	(PROVEFFD)	14.3	12.0 (meso.)	10.8	-3.5	Exceeds Threshold

Based on the NHDES assimilative capacity analysis, Province Lake exceeds the water quality threshold (for both oligotrophic and mesotrophic lakes). This is because there is no remaining reserve assimilative capacity (not a Tier 2 or Tier 1 waterbody). A reduction of at least 3.5 ppb (~25% reduction from current TP) of phosphorus is needed in Province Lake to meet the mesotrophic water quality threshold for total

phosphorus. However, the response indicator, Chl-a will ultimately determine if the lake will be listed as impaired for aquatic life use. If Chl-a is also not supporting in Province Lake, then the lake would be considered impaired for aquatic life use. Based on the results of the Chl-a analysis, and direct comparison to the decision matrix for Aquatic Life Use assessment determinations (Table 5), Province Lake would be considered "impaired" under the oligotrophic classification, and "Potentially Non-Supporting" under the mesotrophic classification.

The watershed management plan will include establishment of water quality goals, guided by the water quality analysis and forthcoming watershed load modeling that will link watershed loading conditions with in-lake total phosphorus concentrations to predict the effect of existing watershed development on future water quality in Province Lake. The loading model makes predictions about chlorophyll-a concentrations and Secchi disk transparency. 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 will be used to determine how much phosphorus it takes to increase or decrease total phosphorus concentrations in the lake by 1 ppb- and therefore can be extrapolated to estimate the number of kilograms (or pounds) of phosphorus that needs to be prevented from entering the lake in order to improve water quality.

6.9 Other Stations

Since 1991, two major tributaries that flow into Province Lake have been monitored consistently for total phosphorus (TP). These stations include the Rt. 153 Inlet (PROEFFR) located on the South River on the eastern side of the lake in Wakefield, NH, and the Island Inlet Station (PROEFFI) located on an unnamed tributary on Bonneyman Rd in Wakefield, NH on the southwest side of the lake (Figure 2). In addition to TP, turbidity has been collected at these stations since 1997, and color was collected between 1991 - 1996. For purposes of this analysis, TP and turbidity were analyzed to determine what trends, if any exist, and to determine average TP for these important tributaries to help inform the land use model.

Table 10. *Results for major tributary stations at Province Lake.*

Station	Average TP (ppb)	Avg. Turbidity (NTU)
Rt. 153 (PROEFFR)	32.7	0.77
Island Inlet (PROEFFI)	34.7	1.76

Results of this analysis indicate that the Island Inlet contributes higher concentrations of TP and higher sediment loads as indicated by the higher turbidity (Table 10). Turbidity ranged from 0.14 to 5.0 NTU at the Island Inlet Station compared to 0.33 - 2.70 NTU at the Rt. 153 station. A comparison of TP and

turbidity for both stations is provided in Figures 9 and 10 (below). The TP trend indicates a decreasing trend (lower TP over time), where as turbidity appears to be increasing over time at the Island Inlet site. Watershed reconnaissance should be considered for the land area and immediate stream corridor draining to this station to determine if a local perturbation is causing the increasing turbidity. Decreasing the phosphorus load from land uses upstream of Province Lake will go a long way toward reducing the overall in-lake TP concentration.

Figure 9. *Comparison of annual TP at primary tributary monitoring stations at Province Lake.*

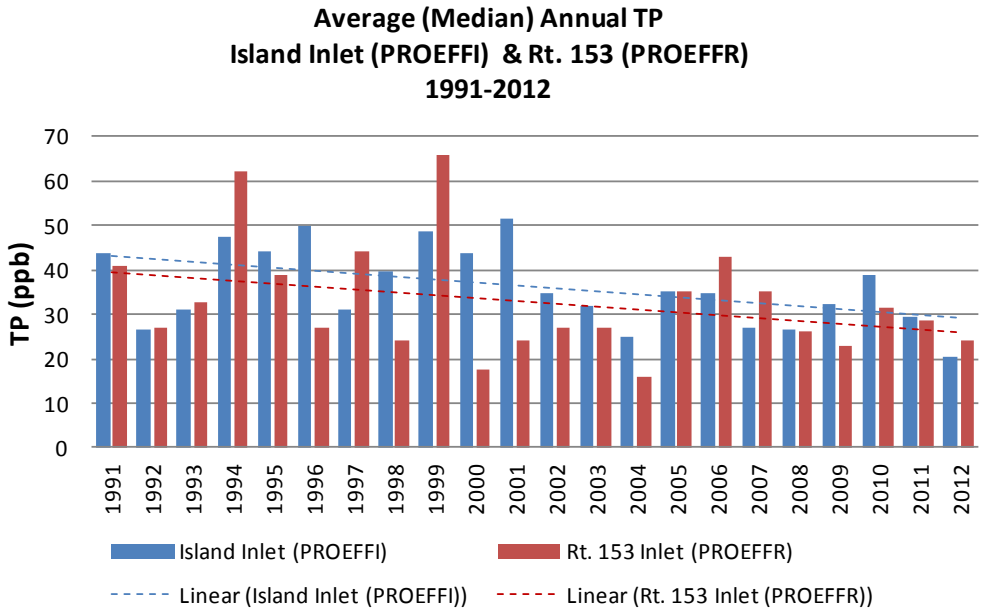
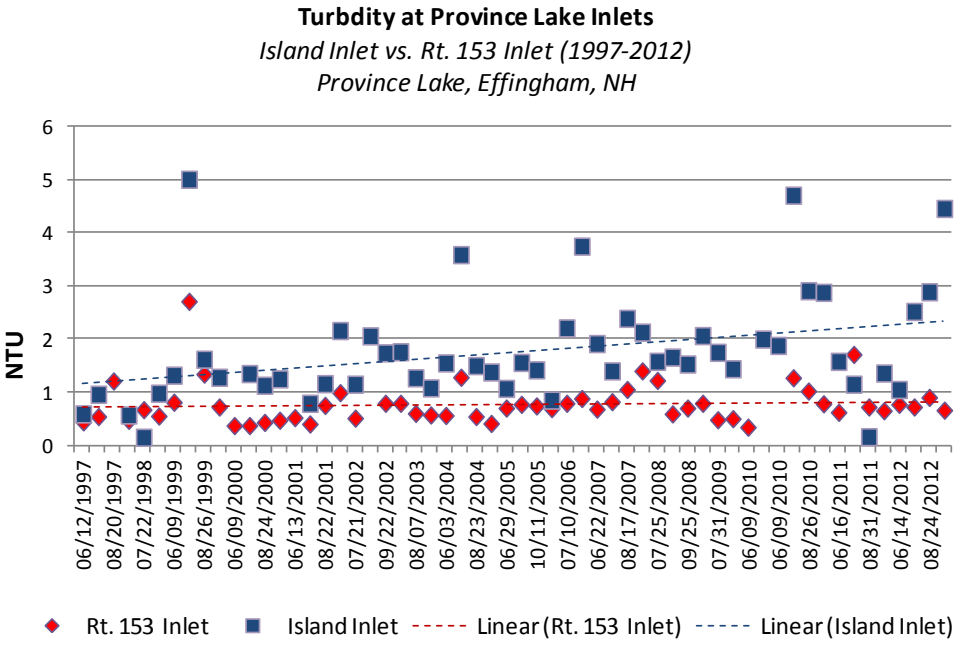


Figure 10. *Comparison of turbidity at primary tributary monitoring stations at Province Lake.*



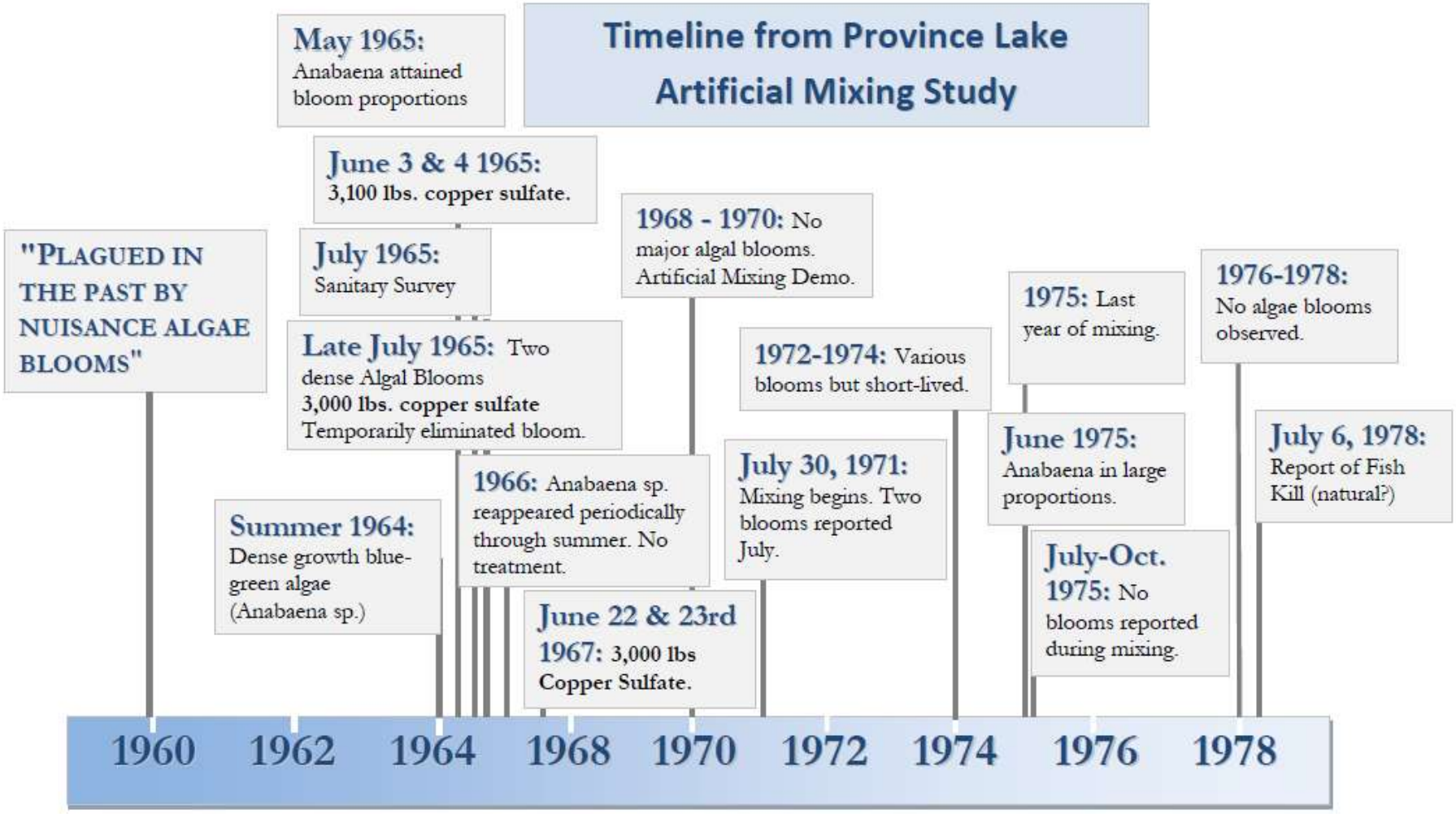
6.10 Other Historic Data

On July 10, 2013, the Province Lake Watershed Planning Steering Committee met to discuss the water quality analysis and to set an interim water quality goal for Province Lake. At that meeting, several committee members discussed other historical data that might be linked to annual and long-term trends presented by FB Environmental (FBE). The first is an artificial mixing study that was completed by the New Hampshire Water Supply and Pollution Control Commission (NHWSPCC, 1979), and the second is data from the New Hampshire Fish and Game Department which includes data from 1937 and 1956 (In: NHWSPCC, 1979).

Following this meeting, FBE reviewed data from the artificial mixing report and with assistance from NHDES, combined the data into a spreadsheet that could be used with the existing water quality analysis. Results from this assessment were presented to the steering committee on November 6, 2013 at UNH. Data from the two sources described above were not used in the final water quality analysis because they have not been flagged as final in the NHDES Environmental Monitoring Database (EMD) as required in the Province Lake modeling SSPP (FBE, 2013). However, at the request of the committee, FBE came up with several conclusions as well as a timeline showing activities on Province Lake between 1965-1978 (Figure 11).

1) Province lake data from 1965, 1967 and 1968 show an extremely wide range of total phosphorus values, and demonstrates that Province Lake has experienced "nuisance algae blooms" in the not so distant past, which included cyanobacteria (Anabaena sp.), similar to what is being documented in Province Lake today.
2) Significant copper sulfate applications in 1965 and 1967 (3 applications at 3,000 lbs. each), resulted in wide variability in water quality results during this time period (TP values 8 to >250 ppb). In addition, there is a lack of information about the specific dates that samples were collected during this time period. Therefore, these data are not recommended for addition to the water quality analysis, but should be used for informational purposes only.
3) Artificial mixing occurred between July 1971 and 1975. Available water quality data is from 1975-1978. When combined with the EMD data, results from the four years in the 1970's were not significantly different than the rest of the data collected on Province Lake from 1979-2012. Therefore, NHDES could potentially use this data in the EMD after it has been through a QA/QC process.
4) Monitoring data from the NH Fish & Game Department was limited to one Secchi disk transparency (SDT) reading (June 1937 and July 1956). SDT readings were at 3 meters for both dates. NHDES could choose to add this data to the EMD for Province Lake. Adding these data into the trend analysis for Province Lake did not change the historical water clarity results, but does indicate that water clarity was slightly better in the 30's and 50's (3.0 m vs. 2.6 m average for last ten years).

***Figure 11**. Timeline from Province Lake Artificial Mixing Study.*



Adapted by FB Environmental Associates from NHWSPCC, 1979.

7. SUMMARY & RECOMMENDATIONS

7.1 Summary of Water Quality

The water quality analysis for Province Lake focused on three major parameters: transparency, chlorophyll-a, and total phosphorus (Figure 12), as well as dissolved oxygen, temperature and color. The analysis indicates that Province Lake is considered "not supporting" based on the aquatic life use indicator threshold for total phosphorus, and that overall, water quality has declined over time. However, a closer look at the historic (1979 - 2002) and recent (2003-2012) water quality monitoring data indicates that this trend has been gradual, and in some cases, the historical water quality was higher than the recent water quality (Table 11).

Figure 12. *TP, Chl-a and SDT trends in Province Lake.*

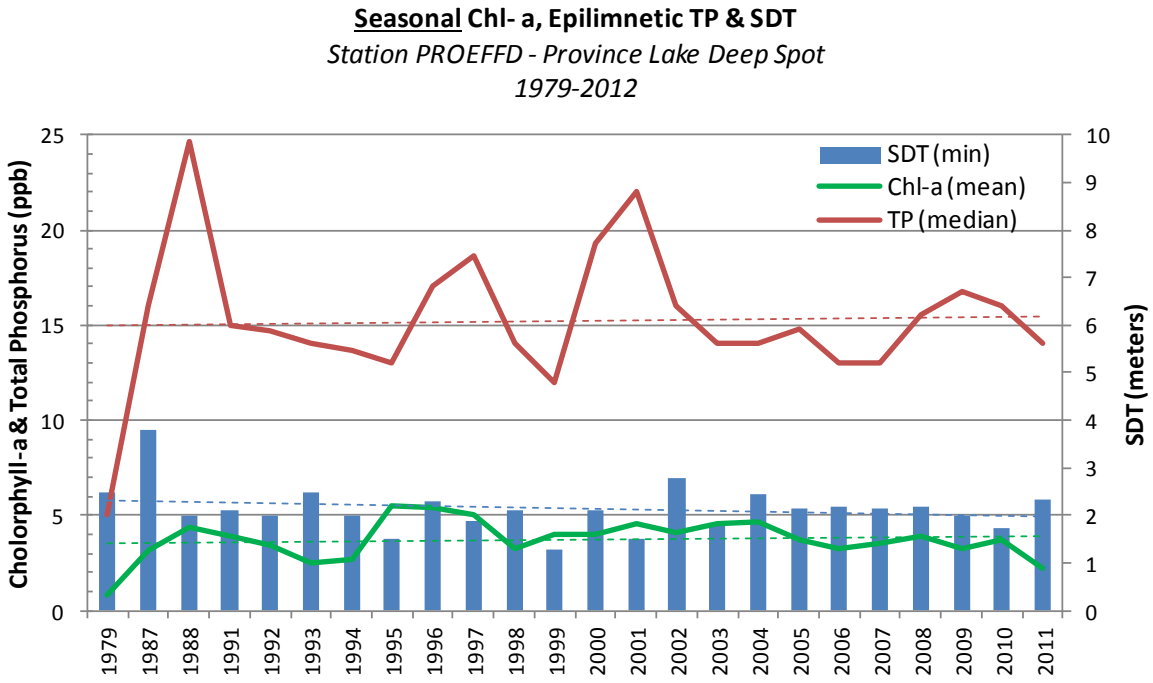


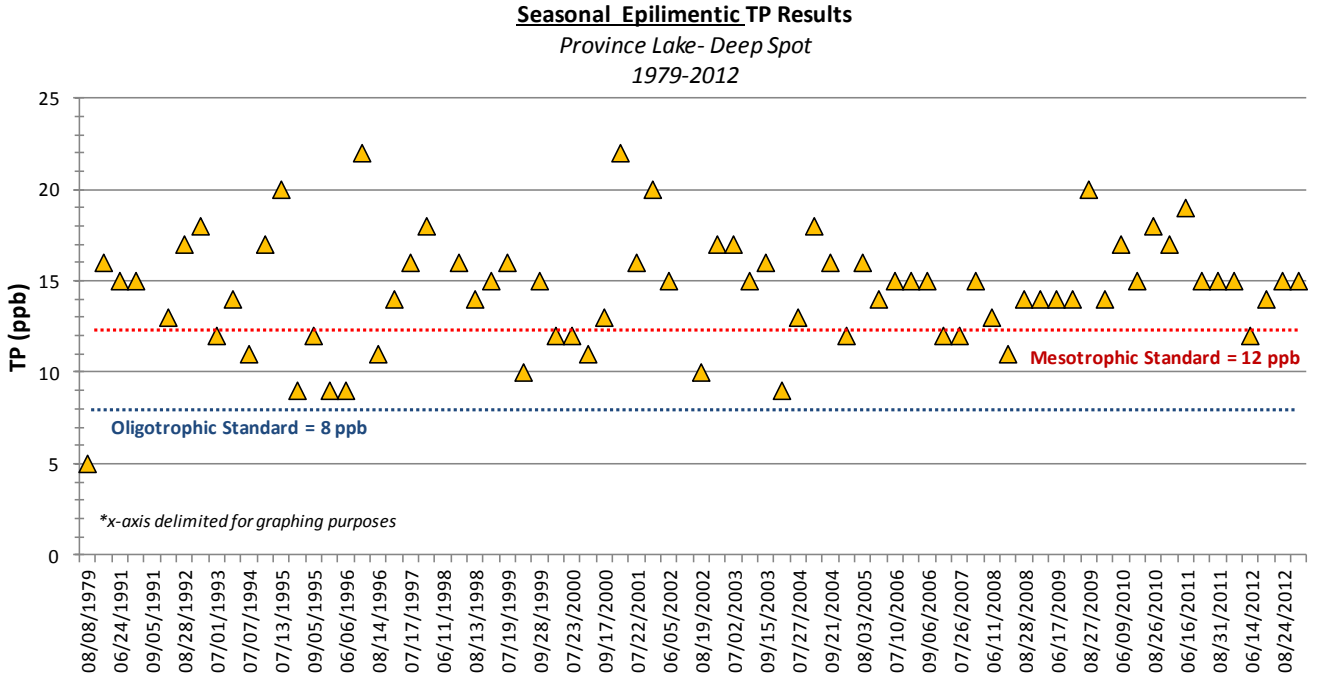
Table 11. *Summary of water quality values in Province Lake.*

WQ Parameter	Annual Average[1]	Historic (1979 - 2002)	Recent (2003 - 2012)	Change[2]
Mean Secchi (m)	*2.59	2.62	2.56	-0.06 (-)
Mean Chl_a (ppb)	3.7	3.99	3.63	-0.36 (+)
Median TP (ppb)	*14.3	15.64	14.25	-1.4 (+)
DO Trends	Good	n/a	n/a	n/a
Mean Color (PCU)	*24	n/a	n/a	n/a
pH	*6.7	6.73	6.69	-0.04 (-)

[1] *Seasonal Average;* [2] *(-) refers to declining water quality, (+) refers to improving water quality;*
** indicates declining trend over time*

With the exception of one data point from 1979, there is no record of any seasonal total phosphorus data below 8 ppb, the NHDES oligotrophic phosphorus threshold. However, there are many instances in which the seasonal epilimentic TP concentration met the mesotrophic TP threshold (Figure 13).

Figure 13. *Comparison of epilimnetic TP vs. TP threshold in Province Lake.*



Based on the decision matrix for aquatic life use assessment determinations in New Hampshire (Table 5), Province Lake is considered either potentially non-supporting for Aquatic Life Use under the mesotrophic classification, or impaired for Aquatic Life Use under the oligotrophic classification. This is due to elevated levels of chlorophyll-a that exceed the threshold for oligotrophic lakes (<3.3 ppb), in conjunction with a large phosphorus stressor that exceeds both the oligotrophic threshold (8.0 ppb) and the mesotrophic threshold (12 ppb).

7.2 Recommendations

There are a number of factors that have surfaced as a result of this water quality analysis that support a decision regarding the rationale for assigning the highest trophic state for Province Lake. Based on this analysis, it is recommended that:

- As described in Section 6.1, the trophic state for Province Lake has been listed as both oligotrophic and mesotrophic. A decision needs to be made by the water quality subcommittee as to which trophic state should be used for setting the water quality goal for the Province Lake Watershed Management Plan. Results of this analysis, which includes calculating the trophic state using the Carlson TSI assessment, and the NHDES trophic classification system, coupled with the 2006

NHDES trophic survey, consistent water quality trends over the historical monitoring period, and improvement in at least two major water quality parameters between the historic and recent monitoring period (Table 10), indicate that a trophic classification of mesotrophic for Province Lake would be justified and still be protective of water quality.

- To improve water quality in Province Lake so that total phosphorus is within the assimilative capacity for mesotrophic lakes in NH, the water quality goal should include a reduction of at least 3.5 ppb TP, a 25% reduction from the recent median, summer in-lake concentration (based on last 10 years). Reducing TP in Province Lake to 10.8 ppb will help reduce available phosphorus available to the phytoplankton such as blue-green algae including cyanobacteria.
- No data is currently available to quantify the effects of increased phosphorus loading from the sediments as a result of heavy boat traffic in Province Lake. This could be accomplished by monitoring the water column both before (Thursday afternoon), during, and after (Monday afternoon) heavy boat traffic weekends, or on holiday weekends. Phosphorus concentrations, turbidity, and Secchi disk transparency would provide valuable data to help answer the question of man-made mixing/internal loading as a result of boat traffic in the lake.
- Apparent color has not been measured in Province Lake consistently since 2007. The increase in color over the historical sampling period (1979 - 2007) indicates that color may be an important parameter in understanding why Province Lake is experiencing annual cyanobacteria blooms over the past three years.
- Examine the relationship between dissolved organic carbon (DOC) and metals as they relate to phosphorus cycling in the lake. This may include collecting DOC data in major wetlands that flow to the lake.
- Limited total nitrogen data exists for Province Lake. A close examination of TN:TP ratios may provide information relative to effects on phytoplankton communities, the source of nutrients flowing into the lake, and help answer the question of appropriate trophic classification.
- Work with NHDES and UNH to develop a cyanobacteria monitoring protocol; consistent analysis is needed for water samples collected during bloom conditions to better quantify cyanobacteria blooms and to determine the extent of harmful toxins.
- Conduct intensive tributary monitoring at new and existing stations in the watershed to better understand the effects of nutrient and sediment loading to the lake. Include both wet and dry weather sampling events and collect flow data to help further quantify nutrient loading from individual tributaries.
- Extend the VLAP monitoring period from mid-May through mid-October to collect information relative to fall cyanobacteria blooms. Current data collection (with one exception) begins in June

and is concluded at the end of September. Adding an additional one or two samples in spring and fall may prove informative over the long-term.

- Add VLAP Secchi disk transparency and dissolved oxygen measurements on a weekly or bi-weekly schedule to collect more information about water quality between major sampling events.
- Add weekend (or Monday) sampling to augment current weekday (Thursday) sampling.
- Continue gathering information about the effects of historical management practices such as plant dredging/weed harvesting, timber harvesting, and artificial mixing and copper sulfate additions, and how these might have affected trophic state classification, historical TP values.
- Set a reasonable, attainable, scientifically-sound water quality goal to help improve lake water quality and prevent reoccurrence of annual cyanobacteria blooms.

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APPENDICES

Appendix A- Summary of Available Water Quality Data for Province Lake

Trophic Survey Data and Chemistry from NHDES		
Province Lake Deep Spot	***(PROEFFD)***	
Depth, DO, pH, Sp. Cond., TP, TKN, Alkalinity, Color, and Cl-		*1979, 1987, 1988, 2006, 2008*
SDT, NA+, K+, Chl-a, and Ca+		*1979, 1987 & 2006*
Magnesium		*1979 & 2006*
DO (% Saturation)		*1987 & 2006*
Nitrogen (NO2+NO3)		*1979, 1987 &1988*
Turbidity		*1979*
Coliform		*1987*
Sulfate		*1987, 1988, 2006 & 2007*
Bacteria Sample Sites (PROEFFC01, PROEFFC02)		
E. Coli		*2006*
VLAP Data from Sara Steiner, NHDES		
Province Lake Deep Spot	***(PROEFFD)***	
Depth, DO, pH, SDT, Sp. Cond., TP, and Chl-a		*1991-2012*
Apparent Color		*1991-1996 & 2006*
Alkalinity		*1991-2007*
Chloride		*2006, 2011, 2012*
Calcium, TKN, and Potassium		*2006 only*
Acid Neutralizing Capacity		*2008-2012*
Turbidity		*1997-2012*
Bacteria Sample Sites		
Bass Rock (PROEFFBR)	*E.Coli*	*1991*
Towle Farm (PROEFFTF)	*E.Coli*	*1991, 2005*
Boat Launch (PROEFFBL)	*E.Coli*	*2009*
Province Lake Generic (PROEFF-GEN)	*E.Coli*	*1991, 1992*
Island Inlet (PROEFFI)	*TP, Sp. Cond. and pH*	*1991-2012*
	E.Coli	*1995*
	Turbidity	*1997-2012*
	Apparent Color	*1991-1996*
Route 153 Inlet (PROEFFR)	*TP, Sp. Cond. and pH*	*1991-2012*
	E.Coli	*1992, 1993, 2006*
	Turbidity	*1997-2012*
	Apparent Color	*1991-1996*
	Chloride	*2011, 2012*
NH Fish Study Data from Walt Henderson, DES		
Province Lake Deep Spot	*Mercury*	2009

Prepared by FB Environmental Associates for the Province Lake Association, April 12, 2013

Appendix B- NHDES Water Quality Report Card for Province Lake

Welcome to New Hampshire's Watershed Report Cards built from the 2010, 305(b)/303(d)

Each Watershed Report Card covers a single 12 digit Hydrologic Unit Code (HUC12), on average a 34 square mile area. Each Watershed Report Card has three components;

1. REPORT CARD - A one page card that summarizes the overall use support for Aquatic Life, Primary Contact (i.e. Swimming), and Secondary Contact (i.e. Boating) Designated Uses on every Assessment Unit ID (AUID) within the HUC12.
2. HUC 12 MAP - A map of the watershed with abbreviated labels for each AUID within the HUC12. **New for 2010, all AUIDs have been rebuilt on 1:24,000 hydrography and the maps have been built on an 11"x17" format.**
3. ASSESSMENT DETAILS - Anywhere from one to forty pages with the detailed assessment information for each and every AUID in the Report Card and Map.

How are the Surface Water Quality Assessment determinations made?

All readily available data with reliable Quality Assurance/Quality Control is used in the biennial surface water quality assessments. For a full understanding of how the Surface Water Quality Standards (Env-Wq1700) are translated into surface water quality assessments we urge the reader to review the 2010 Consolidated Assessment and Listing Methodology (CALM) at http://des.nh.gov/organization/divisions/water/wmb/swqa/2010/documents/2010calm.pdf.

Where can I find more advanced mapping resources?

GIS shapefiles and google earth KML map files are accessible from http://des.nh.gov/organization/divisions/water/wmb/swqa/2010/index.htm.

How are assessments coded in the report card?

Assessment outcomes are displayed on a color scale as well as an alpha numeric scale that provides additional distinctions for the designated use and parameter level assessments as outlined in the table below.

		Severe Not Supporting, Severe	Poor Not Supporting, Marginal	Likely Bad Insufficient Information – Potentially Not Supporting	No Data No Data	Likely Good Insufficient Information – Potentially Full Supporting	Marginal Full Support, Marginal	Good Full Support, Good
CATEGORY	Description							
*Category 2	Meets standards						2-M or 2-OBS	2-G
Category 3	Insufficient Information			3-PNS	3-ND	3-PAS		
Category 4	Does not Meet Standards;							
4A	TMDL^ Completed	4A-P	4A-M or 4A-T					
4B	Other enforceable measure will correct the issue.	4B-P	4B-M or 4B-T					
4C	Non-pollutant (i.e. exotic weeds)	4C-P	4C-M					
Category 5	TMDL^ Needed	5-P	5-M or 5-T					

* "Category 1" only exists at the Assessment Unit Level.

^ TMDL stands for Total Maximum Daily Load studies (http://des.nh.gov/organization/divisions/water/wmb/tmdl/index.htm)

Appendix B- NHDES Water Quality Report Card for Province Lake Cont.

Assessment Unit ID NHLAK600020902-01 Size 965.6490 ACRES

Assessment Unit Name PROVINCE LAKE Beach N

Primary Town EFFINGHAM Assessment Unit Category*~ 5-M

2010, 305(b)/303(d) Parameters by Assessment Unit

Designated Use Description	*Desig. Use Category	Desig. Use Threat	Parameter Name	Parameter Threatened (Y/N)	Parameter Category*	TMDL Schedule	Expected To Attain Date	Source Name (Impairments only)
Aquatic Life	5-M		ALKALINITY, CARBONATE AS CACO3	N	3-PAS			
			CHLORIDE	N	3-PAS			
			CHLOROPHYLL-A	N	5-M	2023		Source Unknown
			DISSOLVED OXYGEN SATURATION	N	3-PNS			
			OXYGEN, DISSOLVED	N	3-PAS			
			PHOSPHORUS (TOTAL)	N	5-M	2023		Source Unknown
			pH	N	4A-M	2019		Atmospheric Deposition - Acidity
Drinking Water After Adequate Treatment	2-G		ESCHERICHIA COLI	N	3-PAS			
			POTASSIUM	N	3-PAS			
			SULFATES	N	3-PAS			
Fish Consumption	4A-M		Mercury	N	4A-M	2017		Atmospheric Deposition - Toxics
Primary Contact Recreation	2-G		CHLOROPHYLL-A	N	2-G			
			ESCHERICHIA COLI	N	2-G			
Secondary Contact Recreation	2-G		ESCHERICHIA COLI	N	2-G			
Wildlife	3-ND							

Severe	Poor	Likely Bad	No Data	Likely Good	Marginal	Good
Not Supporting, Severe	Not Supporting, Marginal	Insufficient Information – Potentially Not Supporting	No Data	Insufficient Information – Potentially Full Supporting	Full Support, Marginal	Full Support, Good

*DES Categories; 2-G = Supports Parameter well above criteria, 2-M = Supports Parameter marginally above criteria, 2-OBS = Exceeds WQ criteria but natural therefore not a WQ exceedence, 3-ND = Insufficient Information/No data, 3-PAS= Insufficient Information/Potentially Attaining Standard, 3-PNS= Insufficient Information/Potentially Not Attaining Standard, (4A=Impaired/TMDL Completed, 4B=Impaired/Other Measure will rectify Impairment, 4C=Impaired/Non-Pollutant, 5=Impaired/TMDL needed) M=Marginal Impairment, P=Severe Impairment, T=Threatened (http://des.nh.gov/organization/divisions/water/wmb/swqa/index.htm)

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Date: 8/25/10