# Wolfeboro Waters
# 2019 Assessment Subcommittee Summary Report
# February 26, 2020

## Executive Summary

Lake Wentworth, Crescent Lake, and Rust Pond in Wolfeboro, NH each have been the subject of a watershed assessment and management plan that have recommended goals and priorities for mitigation activities. Actions have been taken to respond to the plan recommendations, many of which have been seeking to reduce the addition of more nutrients to these waters. These actions over the years are resulting in measurable improvements in water quality.

Mirror Lake also has been the subject of such a plan and actions have been taken in response to limit the addition of nutrients there. However, Mirror Lake continues to experience cyanobacteria blooms, likely the result of releases of large amounts of phosphorous to the water from the sediment on bottom of the lake during low oxygen conditions.

Lake Winnipesaukee in Wolfeboro, other than Winter Harbor, was the subject of much broader water quality testing in 2019 than in the past and the results were good.

Winter Harbor over the past few decades has experienced noticeable growth of algae, plants, gunk, and biofilm slime on its sand and rock bottom that are undoubtedly the result of increased amounts of nutrients being added to the harbor. While leakage from shoreline septic systems and releases from the bottom of the harbor during low oxygen conditions may contribute some of these nutrients, multiple lines of evidence suggest that sources of storm water runoff are by far the most important sources—sources that can be addressed to preserve and enhance its water quality.

A small and brief cyanobacteria, likely Anabaena/Dolichospermum bloom, occurred at the end of June 2019 in Winter Harbor. The bloom occurred during a period when total phosphorous levels in the water were between 8.7ug/L and 11.7 ug/L --above NHDES's recommended level of 8.0 ug/L.

Several different types of cyanobacteria have been identified in Winter Harbor water, most with the potential to produce and release cyanotoxins. The concentrations of these different types vary over time. When phycocyanin fluorescence data in concentrated water samples indicate the presence of significant amounts of cyanobacteria, often few are seen microscopically, suggesting the presence of tiny picocyanobacteria, which do not form traditional blooms, but which also can produce cyanotoxins. Future e-DNA analyses should enable us to better track the presence and concentrations of picocyanobacteria and the other types of cyanobacteria present.

The traditional water quality parameters that result from the UNH and NHDES voluntary sampling programs are valuable for assessing sources and additions of nutrients to the harbor and the risks of blooms and presence in the water column of many types of algae and cyanobacteria (e.g., Anabaena/Dolichospermum, Microcystis, and picocyanobacteria). However, they do not directly measure the risks or presence of the biological growth on the bottom sediment and rocks in Winter Harbor, nor of Gloeotrichia cyanobacteria that bloomed unexpectedly there in late August 2018--a type of cyanobacteria that lives much of its life cycle and benefits from the nutrients in the bottom sediments. Different approaches will be needed to measure what is happening on the lake bottom, to assess risks of future biological growth and blooms (including Gloeotrichia), and to track progress in reducing such risks.

Winter Harbor has water quality problems that need to be addressed, yet the results of the most common measures of water quality for it are similar to those for most of the rest of Wolfeboro's Waters. Therefore, we need to determine where what we learn in Winter Harbor applies elsewhere in Wolfeboro Waters and New England.

## Background

Wolfeboro is a beautiful town and its waters are priceless assets. They are a responsibility of all of us to keep natural and clean.

Good water quality has many different dimensions, including being clear (low turbidity), odorless, having low salinity, being neither acidic nor basic (neutral pH), and being well oxygenated. High quality waters have a minimum of toxic chemicals (e.g., oils, pesticides, PFAS, and arsenic) and of pathogens (usually measured by level of an indicator bacteria--E. coli).

High quality waters support a wide array of native plants, animals, and microorganisms living in and around the lakes. However, as concentrations of (non-toxic) nutrients increase (e.g. of phosphorous, nitrogen, and iron), waters go through an aging process characterized by major growth of plants, algae, and cyanobacteria. This process of transforming from lake to pond, pond to marsh, marsh to meadow, and meadow to dry land is called eutrophication. Eutrophication is a natural process that typically takes thousands of years. However, human activity that result in increased concentrations of nutrients in the waters can cause the process to advance rapidly (years or decades).

Freshwater scientists (limnologists) and environmental agencies classify waterbodies into three trophic categories oligotrophic (good), mesotrophic (threaten), and eutrophic (poor).

- *The prototypic oligotrophic lake is a large deep lake with crystal clear waters and a rocky or sandy shoreline. Both microorganism and rooted plant growth are sparse, and the lake can support a coldwater fishery.*
- *A eutrophic lake is typically shallow with a soft and mucky bottom. Rooted plant growth is abundant along the shore and out into the lake, and algal blooms are not unusual. Water clarity is not good and the water often has a tea color. If deep enough to thermally stratify (described below), the bottom waters can be devoid of oxygen.*
- *Mesotrophic is an intermediate trophic state with characteristics between the other two. (NH Department of Environmental Services)*

The focus of this subcommittee has been upon: Crescent Lake, Rust Pond, Sargents Pond, Lake Wentworth, and Lake Winnipesaukee. Upper Beach Pond, which is entirely within Wolfeboro, has been extensively monitored and protected over the years as the town's water supply and has not been studied by this subcommittee this year.

Crescent Lake, Rust Pond, Lake Wentworth, and Mirror Lake have lake associations, have had volunteer water sampling and analyses, have had watershed assessments, and have had actions taken to protect or enhance their water quality. The watershed assessments have classified Crescent Lake, Rust Pond, and Lake Wentworth as ogliotrophic. None of these lakes have had cyanobacteria blooms reported that resulted in NHDES Advisories. However, Mirror Lake is classified as mesotrophic and has experienced cyanobacteria blooms resulting in NHDES Advisories in 2007 and 2019.

Sargents Pond is a small, shallow water body with a limited water monitoring history. It has not had any cyanobacteria blooms the subject of NHDES advisories. Based upon these limited data, it is also classified mesotrophic. Sargents Pond drains into Lake Wentworth. The Lake Wentworth Watershed Association plan to coordinate future water sampling and follow up for Sargents Pond.

The Lake Winnipesaukee Association over the years has coordinated a volunteer water sampling program across the lake with analyses done by UNH. It has also overseen watershed assessments on several different sections (e.g., Meredith and Moultonborough) and has one ongoing assessment that covers Tuftonboro and now all of Winter Harbor.

There are numerous miles of Lake Winnipesaukee shoreline, coves, and conditions within Wolfeboro. Some areas have had significantly more water quality analyses done in the past than others. Some have had little or none. All the parts of Lake Winnipesaukee in Wolfeboro have been classified as ogliotrophic and none of the water quality measurements in the past in Wolfeboro raised significant concerns.

There are several Wolfeboro residences on Mirror Lake and the lake drains into Lake Winnipesaukee's Winter Harbor, but the waterbody is in Tuftonboro and there is an active association for Mirror Lake that for years has been organizing water sampling and has been seeking actions to mitigate sources of nutrients to the lake. Mirror Lake has been classified as having a being mesotrophic and having a moderate risk of algal and cyanobacteria blooms. This subcommittee has been tracking reports on the lake and shares information with, but defers to, the Town of Tuftonboro and to the Mirror Lake Protective Association on its issues.

So, with the exception of Sargents Pond, which has had very limited monitoring, the five lakes that Wolfeboro Waters has focused upon have water quality that is categorized as good.

However, despite its good/low risk ogliotrophic classification, the Wolfeboro end of Winter Harbor experienced a bloom of Gloeotrichia cyanobacteria severe enough to warrant NHDES issuing an advisory urging people to avoid contact with the it water on August 30, 2018 that remained in effect for three weeks. (See Appendix A for the NHDES announcements.)

In response to this unpredicted cyanobacteria bloom and advisory, the Wolfeboro Board of Selectmen established the Cyanobacteria Task Force, now called Wolfeboro Waters, to assess the quality of the town's lakes and to coordinate community-wide efforts to preserve and enhance their quality, with a special focus on cyanobacteria and on Winter Harbor. This assessment committee is a subcommittee of the task force, and this is the first annual report summarizing its activities and findings in 2019 based upon the information and data available as of Jan 13, 2020.

In March 2019, Town of Wolfeboro voters approved warrant articles that included funding for:

- A town share of several engineering projects to reduce nutrient run-off flowing into Lake Wentworth
- A series of engineering projects to reduce nutrient run-off flowing from Partridge Drive across Whitegate Road to Winter Harbor
- A Wolfeboro share of funding of the ongoing Lake Winnipesaukee Association Watershed Assessment in Tuftonboro to have the assessment include all of Winter Harbor
- Funding for assessment and communications activities of the Wolfeboro Waters Task Force
- Funding for engineering options to address storm water runoff and sewage at Carry Beach.

## Assessment Subcommittee Activities in 2019

- The Assessment Subcommittee consists of two members with a scientific background, two town officials, the Executive Director of the Lake Winnipesaukee Association, and the Chair of the Tuftonboro Conservation Commission.
- The subcommittee developed a Cyanobacteria Identification and Reporting Protocol that was adopted by the Board of Selectmen in June 2019. (See Appendix B.) The protocol was used successfully one time on what proved not to be a cyanobacteria bloom adjacent to Sargents Pond.
- The subcommittee identified laboratories that can test cyanobacteria blooms for cyanotoxins and get us back results within a few days to a week—much faster than the nearly three months that it took in 2018.
- At least 30 new people were trained in water sample collection and processing by Bob Craycraft of UNH's Extension Service.
- Eighty people attended a USEPA and UNH training session on cyanobacteria bloom identification that was held on June 26, 2019 at the Brewster Pickney Boathouse.

- The only report of cyanobacteria bloom, one involving a mix of five different types of cyanobacteria, that resulted in a NHDES Advisory occurred in early August 2019 on Mirror Lake.
- The number of locations where water samples were collected and analyzed in 2019 covered most of Wolfeboro Waters (all but Sargents Pond) and were significantly greater in number in Lake Winnipesaukee than in the past.
- A refrigerator/freezer, a GoPro camera, a long-handled sampler, sample bottles, a vacuum pump, and two flasks were purchased to assist in water sample collection, processing, and taking underwater pictures.
- The Mill Street Meat Market volunteered to provide a convenient location for the shared sampling kits and supplies, as well as the refrigerator/freezer for collected samples.
- One site, in Johnsons Cove, was added to the water sampling and analyses being done in Winter Harbor and the frequency of sampling and the range of parameters measured there was expanded.
- A UNH graduate-level class in Limnology came to Winter Harbor at the beginning of October 2019 to collect a range of samples and measurements to be the basis of a case study on the water body. We expect to receive the writeup of the case study shortly.
- Numerous sources of nutrient runoff to Winter Harbor were identified and shared with the ongoing Watershed Assessment, which is using models to assess priorities for mitigation.
- The Bigelow Laboratory for Ocean Sciences in East Boothbay, ME was identified as having unique expertise and equipment to help identify and quantify cyanobacteria and cyanotoxins, including the use of DNA analysis. It hosts the National Center for Marine Algae and Microbiota and the Center on Single Cell Genomics and has expertise in analyzing sediment nutrients. We expect to take advantage of these unique capabilities in 2020 to identify and track the several specific types of cyanobacteria in our waters.

## Assessing Water Quality (Other than Cyanobacteria)

Most of the water quality monitoring of Wolfeboro Waters has been done using volunteers to collect samples and having the samples analyzed either by the University of New Hampshire's Extension Service (Lay Lakes Monitoring Program-LLMP) or the NH Department of Environmental Services (Volunteer Lake Assessment Program-VLAP). The two programs have similar objectives. Water samples are collected and processed and stored by volunteers following program guidelines and then the samples are analyzed in the UNH or NHDES lab using standardized methods. In addition, some measurements, such as temperature, pH, clarity, depth, and conductance are made directly in the lakes with the right equipment.

To assess the many different dimensions of water quality, a number of different parameters are measured. Some of these, such a clarity, are measured directly, while others are determined indirectly or by surrogates, such as using the concentration of *E. coli* bacteria as an indication of the level of human pathogens in the water. Most of the types of measures used to assess the quality of Wolfeboro Waters are described below, along with their interpretation.

**Salinity/Conductivity**: The salinity of water is an important determinant of the type of life that it can support. Most ocean/marine life require water with higher salinity. Freshwater life generally requires low salinity. Most often measuring conductivity is used as a surrogate for salinity--the lower the conductivity the better.

*Specific categories of good and bad levels cannot be constructed for conductivity, because variations in watershed geology can result in natural fluctuations in conductivity. However, values in NH lakes exceeding 100 uMhos/cm generally indicate human disturbance--NHDES/VLAP* Similarly, increasing conductivity over time can also suggest human disturbance. (UNH-LLMP considers less than 50 uMhos/cm to be minimal impact.)

**Clarity/Turbidity**: Water clarity is measured by determining the depth of water when a standardized black/white patterned disk (Secchi) can no longer be seen from the surface when looking through a tube that limits observation to the water column. Greater than 4.0 meters (~13 feet) is excellent, between 2.5 – 4.0 meters is fair, and less than 2.5 meters is poor. (UNH-LLMP)

**Color:** The (dissolved) color of water is determined on filtered water samples. A reading of fewer than 10 color units is uncolored, 10-20 units is slightly colored, 20-40 units is light tea colored, 40-80 units is tea colored, and more than 80 units is highly colored.

**pH (Acidity vs. Alkalinity)**: pH is a measure of acidity or alkalinity. A pH of 7 is neutral. The lower pH is below 7, the more acidic the water. The greater the pH above 7 the more alkaline/basic the water. A pH of 6.5 to 9.0 is optimum for fish growth and reproduction. A pH of less than 5.5 is considered suboptimal. (UNH-LLMP)

**Toxic Chemical Concentrations**: The lower the concentration of toxic chemicals the better. There are different standards based upon the specific chemical. With few suspected sources of toxic chemicals, few measurements have been done on our lakes, except Upper Beach Pond, which is a reservoir for Wolfeboro's drinking water. Note: groundwaters in our region have a much greater likelihood of having concentrations of toxic chemical (e.g. arsenic, MTBE, radon, and PFAS).

**Pathogen Concentration**: Clean water should have low concentrations of human pathogens, of which there are many. E. coli is a class of bacteria that is associated with the human intestines. Most, *E. coli* are harmless, but a few are infectious. NHDES measure *E. coli* levels at public beaches and uses their concentration as an indication of the presence of the full range of human pathogens. NHDES will issue a Beach Closure Advisory if either two or more samples collected at a beach exceed the state standard of 88 counts of *E. coli* per 100 milliliters (ml) of water or one sample exceeds 158 counts of *E. coli* per 100 ml of water.

**Temperature and Temperature/Depth Profiles**: The temperature of the water is measured because it is one of the factors that influences the makeup of plant, animal, and microorganisms that live comfortably in the lake, seasonally and over longer time periods.

Temperatures are also measured by depth in the water to provide a profile. If there is a location where the temperature of the water increases or decreases rapidly by depth (e.g. two-degree Fahrenheit/one-degree Centigrade per meter/three feet), the depth of that rapid transition is called a thermocline. Thermoclines represent a place where the water column is stratified into zones that mix very little. Thermoclines typically form in deeper waters during the summer when the waters near the surface become warmer than the waters near the bottom. Conversely, in the winter the surface waters exposed to the cold air may become significantly colder (and, indeed, freeze) compared to the liquid water toward the bottom of the lake.

When waters are stratified, scientists use the term epilimnion to refer to the surface-water region, hypolimnion to refer to the bottom-water region and metalimnion to the region between them around the thermocline. The depth of measurements and sample collection are important because there may be significant and important differences between what is happening in the surface waters versus the bottom waters.

Typically, stratified waters will mix as the temperature of the surface waters cool or warm to close to the temperature of the bottom waters. This mixing is called turnover. The exact time of turnover in the autumn or the spring may also be influenced by major wind events as the temperature differences decrease.

**Dissolved Oxygen**: The amount of dissolved oxygen in the water is important. Fish need oxygen to survive. If an area of a waterbody develops stratification (usually deeper waters) and if there is organic matter on the bottom of the lake, bacterial action on that organic matter may consume enough oxygen (that cannot be restored by mixing with the oxygen-rich waters above) to lower or completely deplete the dissolved oxygen on the bottom. Fish need oxygen levels of at least 4-5 ug/L. While warm water fish may be able to adapt by swimming in the warmer oxygenated water closer to the surface, it is a problem for colder water fish. If the oxygen level becomes totally depleted, the chemistry of the sediment and water can change (e.g., to increase significantly total phosphorous levels). UNH-LLMP classifies oxygen levels of 5 mg/L or more to be excellent, 2.0-5.0 mg/L to be fair (mesotrophic), and below 2.0 mg/L to be poor (eutrophic).

**Total Phosphorous**: Phosphorous is one of several nutrients in our waters. Phosphorous is not toxic. Phosphorous is measured because it is believed its concentration controls the amount of biological growth, including plants, algae, and cyanobacteria, because all the other essential nutrients for their growth are already present in higher concentrations than needed. In this case, more phosphorous, more growth. The lower, the better. The NHDES-VLAP classifies total phosphorous concentrations (TP):

- 1-10 ug/L Low (good)
- 11-20 ug/L Average
- 21-40 ug/L High
- >40 ug/L Excessive

The UNH-LLMP classifies total phosphorous concentrations (TP):

- < 8 ug/L Excellent (ogliotrophic)
- 8 -12 ug/L Fair (mesotrophic)
- 12-28.0 ug/L Poor (eutrophic)

**Algal Growth (Chlorophyll-a)**: A fluorometer that measures the fluorescence of light at one particular wavelength is used to measure the concentration of chlorophyll-a, a protein associated with green algae. The greater the fluorescence the higher the algal concentration. The UNH-LLMP classifies chlorophyll-a concentrations:

- < 3.3 ug/L Excellent
- 3.3 -5.0 ug/L Fair
- >12 ug/L Poor

## Assessing Cyanobacteria

There are a wide variety of different types of cyanobacteria and while cyanobacteria have existed for billions of years and are found in waters, soils, even ice from the Equator to the poles. So, cyanobacteria have presumably been in our waters and soils long before humans lived here. However, blooms of potentially toxin producing cyanobacteria only started being reported in New Hampshire in the 1960s and 1970s. In 2019, NHDES issued 35 advisories warning of cyanobacteria blooms in New Hampshire, including Mirror Lake, Half Moon Lake in Alton, and in Marsh and Jones Ponds in New Durham. These advisories were for blooms of a wide variety of different cyanobacteria, none of which was the same as the Gloeotrichia bloom the previous summer in Winter Harbor.

The NHDES "Fact Sheet on Cyanobacteria in New Hampshire Waters" {https://www.des.nh.gov/organization/commissioner/pip/factsheets/wmb/documents/wmb-10.pdf} and UNH's "A Quick Guide to the Common Cyanobacteria in New England" {http://cfb.unh.edu/CyanoKey/QuickList.html} provide some basic information on an increasing concern in freshwater lakes in New England.

What makes cyanobacteria of concern is that many different types, but not all types, can produce and release cyanotoxins (toxic chemicals) that can poison humans and animals. Sometimes those that can produce a toxin do make and release the toxin and yet at other times no toxin is produced.

There are several different classes of cyanotoxins associated with different types of cyanobacteria. Some cyanobacteria produce more than one type of cyanotoxin.

Unfortunately, what causes cyanobacteria to produce and release one or more cyanotoxins is not yet well understood. So, when there is a bloom of one or more cyanobacteria on or in the water known to be capable of producing and releasing cyanotoxins, it is not possible to predict how toxic it may be and how rapidly it may change depending upon the conditions of the water and the bloom.

While it takes cyanobacteria to produce and release cyanotoxins into the water, depending upon the toxin released and the temperature of the water and other environmental conditions, those toxins may persist days, or even weeks, after the cyanobacteria blooms have disappeared. So, the level of cyanotoxins in the water associated with high concentrations of cyanobacteria must be determined analytically.

The subcommittee identified three different laboratories capable of giving us (and NHDES) a determination of the concentrations of specific cyanotoxins of concern, at different costs, and with different turnaround times in 2019. Recently, NHDES has established a new Hazardous Algal Bloom and Cyanobacteria Program that will be able to analyze select cyanotoxins in 2020 in a timely fashion for free. In addition, the Bigelow Laboratory for Ocean Sciences in East Boothbay, Maine has receive a five-year grant from the National Science Foundation that are enabling them to expand their ability to analyze common cyanotoxins quickly.

The World Health Organization (WHO) and now recently USEPA have listing of low, medium, and high risks for the most common cyanotoxins based upon cell concentrations. The Massachusetts Department of Health has a publication establishing standards for state advisories based on these WHO and EPA assessments. New Hampshire has adopted standards based on Massachusetts' interpretations to guide the issuance of its advisories.

The risks from cyanotoxins increase as the concentrations of potential toxin-producing cyanobacteria go up. Each different type of cyanobacteria has its own unique requirements of sunlight, temperature, nutrients, and other conditions for optimal growth, as do the many types of algae plants, and other organisms in our waters. Unfortunately, these requirements are not well understood either. So, while more nutrients, such as high concentrations of total phosphorous in the water certainly increase the risks of cyanobacteria blooms (as well as algal blooms and plant proliferation), it is difficult to predict future concentrations of specific cyanobacteria. Moreover cyanobacteria blooms can appear (float to the surface) and disappear (sink) within hours.

Measurements, such as phycocyanin fluorescence, can help determine and monitor the presence and early increases in concentrations of cyanobacteria that can leading to subsequent blooms. However, ultimately the identification and the determination of the makeup of cyanobacteria surface blooms are done microscopically, typically after they have occurred.

Wolfeboro Waters is participating in the Cyanobacteria Monitoring Collaborative that is led by U.S. Environmental Protection Agency Region I (New England) and UNH (www.cyanos.org). It consists of cyanobloom identification and reporting using the bloomWatch App, a CyanoScope microscope capable of taking digital picture with reporting to the iNaturalist.org database for identification confirmation, monitoring cyanobacteria concentrations over time using a Fluoroquik Fluorometer to measure phycocyanin levels that are associated with cyanobacteria in the same way that chlorophyll-a is associated with green algaes

We are gathering numerous fluorometer measurements of different types of samples to obtain phycocyanin levels. In addition, UNH has been running our samples through two different types of fluorometers to correlate the measurement of phycocyanin between the two. Thus far, we are to use the measurements to infer the relative concentration of cyanobacteria in different samples, but not determine their concentration or that of any cyanotoxins.

In addition to the methods described above, the Cyanobacteria Monitoring Collaborative kit contains a tow net that can be dragged through the water to concentrate potential bloom-forming cyanobacteria in water and a ZAPPR (Zooplankton and Phytoplankton Phototaxis Response method)(tm) that can further concentrate a sample and separate cyanobacteria from zooplankton (small animals such as amoebas and euglena) in the water. These concentrated samples are helpful for microscopic identification.

Next year, with the assistance of the Bigelow Laboratory for Ocean Sciences in East Boothbay, Maine and the new NHDES program focused on cyanobacteria, we hope to be able to greatly expand our ability to determine what types of cyanobacteria are present and to track the concentration of the most important ones.

As some cyanobacteria spend important parts of their life cycle in lake-bottom sediments, including Gloeotrichia, the type that bloomed in Winter Harbor in 2018, we hope to expand sediment sampling and analyses in the future. The only sediment data that we have thus far are three samples that the Bigelow Lab collected in Winter Harbor and analyzed during the 2018 bloom.

## The Quality of Wolfeboro Waters

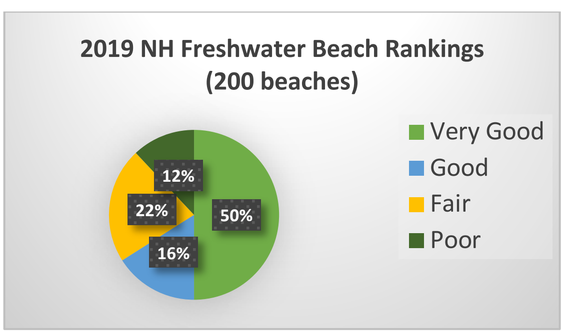
This report only highlights noteworthy new information, trends, and issues. (The separate section - below -on Winter Harbor, which has been of particular concern to Wolfeboro since the cyanobacteria bloom and NHDES Advisory in late summer 2018, is more detailed.) The Lake Winnipesaukee Association has volunteered to provide the LLMP and VLAP monitoring data for all of Wolfeboro Waters, by sampling site on its map-based gateway.
{http://winnipesaukeegateway.org/monitoring-the-lake/monitoring-sites-map/}

**Wolfeboro's Public Beaches:** Wolfeboro has four public beaches that a monitored by NHDES. Three samples are collected multiple times during summer months and tested for the presence and concentration of *E. Coli* bacteria. NHDES will issue a Beach Closure Advisory if either two or more of the samples collected at a beach exceed the state standard of 88 counts of *E. coli* per 100 milliliters (ml) of water or if one sample exceeds 158 counts of *E. coli* per 100 ml of water. Advisories stay in effect until subsequent test results are acceptable.

Statewide NHDES monitors and classifies public beaches into four different categories.

- Very Good = least 98% of samples are clean
- Good = 90-97% of samples are clean
- Fair = 70-89% of samples are clean
- Poor <70% of samples are clean

Statewide there are approximately 200 freshwater beaches that NHDES monitors, 50% of them are found to be very good.



The most recent NHDES classifications of Wolfeboro's four public beaches are

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|---|---|---|
| Albee Beach (Lake Wentworth) | Very Good 2019 | Good 2003-2019 |
| Brewster Beach (Lake Winnipesaukee) | Fair 2019 | Good 2003-2019 |
| Carry Beach (Lake Winnipesaukee/Winter Harbor) | Fair 2018 | Very Good 2003-2018 |
| Lake Wentworth State Park | Fair 2019 | Fair 2003-2019 |

NHDES issued one beach advisory at Brewster Beach in 2019, one at Lake Wentworth State Park in 2019, and one at Carry Beach in 2018, based upon excess concentrations of *E. coli*.

These *E. coli* coliform bacteria readings represent almost certainly local conditions at the beaches and not lake-wide pathogen pollution, especially given how quickly each advisory ended (2-5 days).

*Fecal contamination (E. coli) can come from many sources, including swimmers, wildlife, nearby septic systems, storm drains, and farm runoff. To health protect your health and that of your beach, discourage the feeding of wildlife, such as seagulls, and geese. (NHDES)*

**Lake Wentworth and Crescent Lakes:** Lake Wentworth and Crescent Lake are discussed together, as they are not only hydrologically linked, but they have often been studied together, and they are both a focus of the Wentworth Watershed Association.

A comprehensive watershed assessment and management was prepared for Lake Wentworth and Crescent Lake in 2012.
{https://www.des.nh.gov/organization/divisions/water/wmb/was/documents/lake-wentworth-crescent-lake-wolfe.pdf }&
{https://www.des.nh.gov/organization/divisions/water/wmb/was/documents/lake-wentworth-crescent-lake-wolfe-appendices.pdf }

This plan summarized all the data going back to 1975 in Lake Wentworth and 1984 in Crescent Lake, identified noteworthy issues concerning the water quality of the two lakes, and has served as the guide for ongoing mitigation actions to preserve and enhance the lakes. The Wentworth Watershed Association has taken the lead in continuing to assess the conditions and trends in water quality of the two lakes and in organizing the numerous actions that have been taken and are being taken to protect and improve the water quality of the two lakes. {https://wentworthwatershed.org}

The 2012 assessment identified Lake Wentworth as impaired due to

- low pH (less than the minimum standard of 6.5),
- low dissolved oxygen, and
- the presence of exotic milfoil (variable milfoil) in the bays near Heath, Hersey, and Willey Brooks.
- It also set a goal of reducing total phosphorous levels in the surface waters 15 % by 2030 from 6.7 ug/L to 5.7 ug/L.

The 2012 assessment identified Crescent Lake as impaired due to

- extensive milfoil.
- It also set a goal of reducing total phosphorous levels in the surface waters 15 % by 2030 from 7.9 ug/L to 6.7 ug/L.

Our lakes naturally have little buffering capacity (e.g., limestone). Therefore, they are vulnerable to acid rain coming from outside our local area and state. So, there are limited local options to address Lake Wentworth's low pH. Fortunately, its average pH was only slightly below 6.5. Also, fortunately, environmental regulations and switches away from coal-fired power plants have reduced the amounts of acidic sulfur dioxide in the air resulting that when transported cause local acid rain.

There has been an extensive effort by the Town of Wolfeboro and the Wentworth Watershed Association to address the milfoil in the two lakes and Back/Front Bay in Lake Winnipesaukee. The efforts have been keeping the invasive plant levels down. While some believe that total elimination will be impossible, the Lake Sunapee Association claims that an infestation in their lake has been completely eradicated.

The watershed assessment found that Lake Wentworth waters stratify in place over summers, but Crescent Lake does not. Three monitoring sites have been being used to track dissolved oxygen profiles in the lake: Site 2 Triggs, 1 Fullers, and Governor's Deep. {See Appendix C} Over late Summer 2009, the dissolved oxygen level at

- Site 2 Triggs went down to a little below 5 ug/L, fair/mesotrophic (UNH classification) at about 49 feet deep (15 meters),
- 1 Fullers went down to a little below 1 ug/L, poor/eutrophic at about 79 feet deep (24 meters), and
- Governor's Deep was completely depleted, poor/eutrophic, by 56 feet (17m) deep in late August and by 46 feet (14m) deep in early September.

As such oxygen depletion is caused by bacteria consuming organic material already on the bottom of the lake, late summer oxygen levels near the bottom of Lake Wentworth are not likely to improve until a significant portion of such organic matter has been consumed. The most important actions that can be taken to help this along is to reduce further inputs of organic matter to the lake, which are being pursued.

The most recent data for Lake Wentworth over Summer 2018, the dissolved oxygen level at

- Site 2 Triggs was not measured,
- 1 Fullers went down to 4.2 ug/L, fair/mesotrophic at about 79 feet deep (24 meters), and
- Governor's Deep went down to 4.2 ug/L, fair/mesotrophic, by 56 feet (17m) deep in late August and by 46 feet (14m) deep in early September.

Such dissolved oxygen profiles can vary from year to year, so it takes several years to determine trends. However, if these more recent results are representative of the future, dissolved oxygen levels in Lake Wentworth may be improving.

The 2012 assessment recognized that for Crescent Lake to achieve its goal to reduce total phosphorous levels will require reductions in the levels of Lake Wentworth that feed into it.

The most recently available complete data for total phosphorous levels in the two lakes are from 2018. They indicate

- a 2018 Crescent Lake average total phosphorous concentration of 7.5 ug/L, a slight reduction from the 2012 level of 7.9 ug/L {https://extension.unh.edu/resources/files/Resource007721_Rep11309.pdf} and
- a 2018 Lake Wentworth average total phosphorous concentration of 5.3 ug/L, which if sustained in the future, would represent achievement of the goal of a 15% reduction called for in the watershed assessment. {https://extension.unh.edu/resources/files/Resource007722_Rep11310.pdf}, {https://extension.unh.edu/resources/files/Resource007723_Rep11311.pdf}, and {https://extension.unh.edu/resources/files/Resource007724_Rep11312.pdf}

Again, total phosphorous concentration measurements, like many water quality parameters have a lot of noise or variability. So, it takes several years to determine trends. However, Lake Wentworth having an average total phosphorous level of 5.3 ug/L in 2018, a reduction of 1.4 ug/L compared to 2009 is preferable to having an average in 2018 that was considerably higher than 2009.

**Rust Pond:** The Rust Pond Association, {www.rustpond.org}, founded in 1950, has been overseeing the level and purity of Rust Pond. It was a founding member of the NHDES Voluntary Lake

Assessment Program and has 30 years of water quality measurements on the pond. Rust Pond was the first of Wolfeboro Waters to have a watershed assessment and management plan, which was completed Winter 2007.
(https://www.des.nh.gov/organization/commissioner/pip/publications/wd/documents/des-r-wd-07-24.pdf )

The assessment plan reported total phosphorous (TP) concentrations in the surface waters (epilimnion) and near the thermocline (metalimnion) to be 9 ug/L and in the bottom waters (hypolimnion) to be 12 ug/L. These are considered average, but the plan identified the North Inlet Tributary to the pond as having high TP levels (32.9 ug/L) and recommended measures to reduce that input of phosphorous to the lake, as well as to reduce phosphorous inputs from a variety of other sources.

The assessment also determined that dissolved oxygen levels in the bottom 2-3 meters (6-10 feet) of the pond in late summer were zero and identified a number of actions that could be taken to limit the amount of organic material flowing into the pond.

The most recently available water quality data from VLAP for Rust Pond in 2017 {http://pmisk.org/rustpond/rust-wolfeboro_2018.pdf} indicate total phosphorous (TP) concentrations in the surface waters (epilimnion) to be 6 ug/L and near the thermocline (metalimnion) to be 7 ug/L and in the bottom waters (hypolimnion) to be 11 ug/L and that there is a significant trend over time toward lower concentrations. On the other hand, North Inlet TP levels were higher and of concern at 45ug/L.

In addition, limited data suggest that dissolved oxygen levels in 2018 were "encouragingly" better than in 2007.

The 2018 VLAP report flagged pH (Acidity) and Conductivity/Chloride as being within desirable levels but trending upward significantly, an undesirable direction. VLAP recommends reducing the application of road salt and checking the North End Inlet for possible new sources.

**Sargents Pond**: There are no watershed assessments nor any recent water quality data for Sargents Pond. As the pond is in its watershed, the Lake Wentworth Watershed Association plans on obtaining samples in the future as part of the UNH LLMP. It is categorized as mesotrophic, however, that is based upon little data. The Lake Wentworth Watershed Association hopes to get volunteer samplers to collect samples in 2020.

**Mirror Lake**: The Mirror Lake Protective Association {https://www.mirrorlakenh.org/}, founded in 1991, is overseeing water sampling in the lake, working with the UNH Extension LLMP program on monitoring the lake and with NHDES VLAP program monitoring tributaries into the lake. A Mirror Lake watershed assessment and management plan was completed in May 2012.
{http://www.mirrorlakenh.org/wp-content/uploads/2012/06/MirrorLakeWMP_Final_05222012web.pdf }

In 2008, Mirror Lake was included on a list of New Hampshire Threatened or Impaired water bodies due to recurring blooms of potential toxin-producing cyanobacteria. (The first reported bloom was in 2007.) As a result, the watershed assessment and management plan focused on phosphorous levels in the lake and their sources. In 2012, Mirror Lake was classified as mesotrophic and had a median concentration of total phosphorous in its surface waters of 10.0 ug/L. However, that median was increasing 0.7 ug/L every decade.

In response to the bloom and the management plan several actions were taken to reduce the amount of nutrients flowing into Mirror Lake, including stopping the Town of Wolfeboro's municipal spray irrigation that was up the watershed. The fact that phosphorous levels in the center of the lake and along its shores suggest that most additions of nutrients from runoff have been addressed.

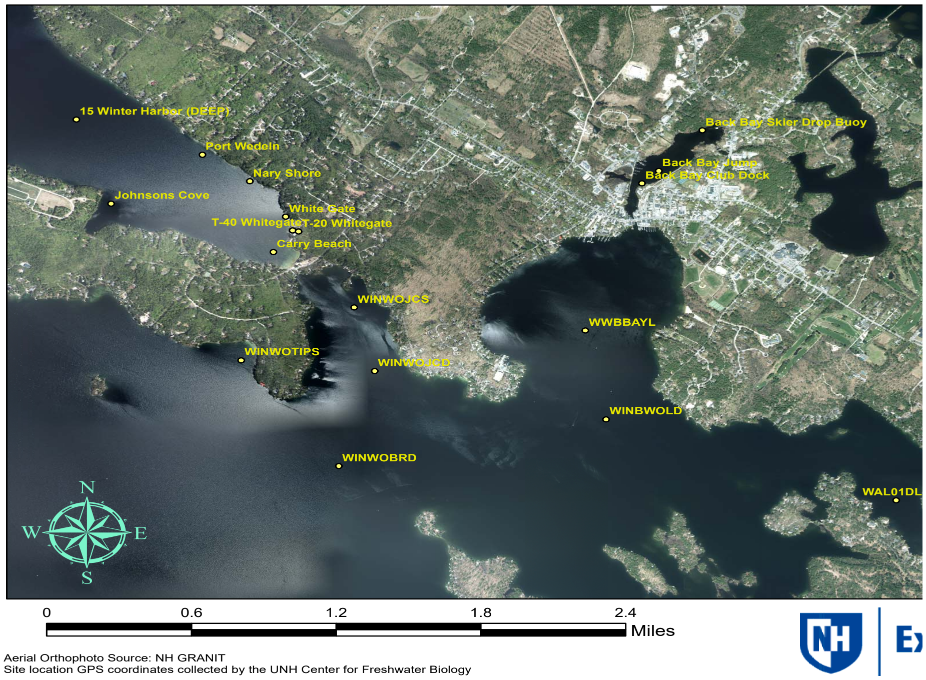
On August 7, 2019, there was a NHDES issued a Cyanobacteria Advisory because samples collected the day before contained as much as 1.3 million cells per milliliter of five different types of cyanobacteria: Woronichnia, Microcystis, and three varieties of Anabaena/Dolichospermum. The advisory lasted until August 20, 2019. {https://www.des.nh.gov/media/pr/2019/20190807-cyanobacteria-tuftonboro.htm} and {https://www.des.nh.gov/media/pr/2019/20190820-cyanobacteria-tuftonboro.htm}

The UNH LLMP 2018 program summary reported total phosphorous levels in the surface water by the 3 Deep Point collection site was 8.5 ug/L and, while the level has oscillated, it has shown a variable decline since 2012. It also reported that dissolved oxygen was totally depleted (eutrophic) in the bottom 6 meters of the lake at 3 Deep Point for much of the summer. Thus, the phosphorous and organic matter already on the bottom of the lake is a significant source of the total phosphorous in the water above. {https://extension.unh.edu/resources/files/Resource007719_Rep11306.pdf} {https://www.des.nh.gov/organization/divisions/water/wmb/vlap/annual_reports/2016/documents/mirror-tuftonboro.pdf}

**Lake Winnipesaukee (except Winter Harbor):** Lake Winnipesaukee is the largest lake in New Hampshire containing many coves, islands, and inlets across multiple towns. The Lake Winnipesaukee Association (LWA) is the non-profit organization that is leading efforts to coordinate the assessment of water quality around the lake and to develop management plans to protect and enhance the lake. (www.winnipesaukee.org). In addition, LWA has a gateway with a map of the Lake Winnipesaukee watershed that includes all of Wolfeboro Waters and says it will provide access to all the individual monitoring results in the future. {www.winnipesaukeegateway.org}

In recent years, LWA has been leading efforts to conduct assessment and management plans for different sections of the lake. It has completed some, addressing Center Harbor and Moultonborough. It currently is undertaking one that addresses Tuftonboro and, with the support of the Town of Wolfeboro voters in March 2019, the Wolfeboro portion of Winter Harbor. This assessment and management plan is expected to be completed in the summer of 2020. The data collected by this Assessment Subcommittee in the Winter Harbor are available to the LWA and the engineer firm that it hired to prepare this plan.

**Figure 8. Lake Winnipesaukee**
**Wolfeboro, NH**
**2019 sampling locations**




Over the years there has been water sampling done in conjunction with UNH LLMP for a number of sites in Lake Winnipesaukee in Wolfeboro, but no systematic multi-year monitoring at its sites and summary reports prepared, except for Winter Harbor starting in 2017 (which is discussed in a separate section below). On the other hand, looking over the historical data, there were no major issues or concerns that were apparent.

In 2019, the Assessment Subcommittee sought to expand sample collection across the various sections of Lake Winnipesaukee in Wolfeboro to get some baseline data, to identify any issues or areas of concern, and to guide the design of future conditions and trends monitoring. Sampling sites were added in Wolfeboro Bay, Back/Front Bay, Jockeys Cove, Delings Cove, Tips Cove, and the Broads. (See Figure 8 above)

The 2019 final data from the UNH LLMP program was received in early January 2020. An extract of the key data is provided in Appendix D None of the measurements of total phosphorous are in excess of 8.0 ug/L nor any chlorophyll-a measurements in excess of 3.3 ug/L. Water clarity as measured using Secchi disks was good at all the deeper water sites. So, all of the measurements thus far indicate good (ogliotrophic) conditions.

## Winter Harbor

Winter Harbor has been given a special focus of assessment as it is the only part of Wolfeboro Waters that has been the subject of a NHDES Cyanobacteria Advisory, other than Mirror Lake. On

August 30, 2018, NHDES issued a Cyanobacteria Advisory urging people to avoid contact with the water at the Wolfeboro (southern) end of Winter Harbor. The public Carry Beach is at that end of Winter Harbor.

Prior to that cyanobloom, the Lake Winnipesaukee Association had received a grant from NHDES to conduct a watershed assessment and management plan for Lake Winnipesaukee in Tuftonboro. The northern part of Winter Harbor is in Tuftonboro. So, some assessment and management recommendations were contemplated for Winter Harbor. In March 2019, voters in Wolfeboro approved a warrant article that included funding for the watershed assessment to cover the whole of Winter Harbor fully. That watershed plan is currently underway with its completion planned for Summer 2020. The Assessment Subcommittee of Wolfeboro Waters has been helping to provide requested data and information to assist the development of the watershed plan.

**Background:** Winter Harbor is a Y-shaped bay with a single outlet to the center of the lake (The Broads). The southern arm of the harbor (approximately 650 acres{Underwood Technical Memorandum to David Ford October 4, 2019}) is the Wolfeboro end. Most of the southeastern shoreline on the northern arm is also in Wolfeboro of the southern arm of the harbor. The prevailing winds blow down the Wolfeboro-end of the harbor. There is little flow out that end, so anything added in the water at that end has a long residence time.

There is a deep hole, less than ¼ mile long and ¼ mile wide in the middle of the Wolfeboro end of the harbor. It has been used as a sampling site and is about 24 meters (80 feet) deep. Most of the rest of the harbor is 13 meters (43 feet) deep or less.

The Wolfeboro-end of the harbor is at the bottom of relatively steep terrain on both sides, with the Carry Public Beach at the end on an isthmus between the mainland and Wolfeboro Neck (a peninsula). The soil on the hills have low water retention qualities.

Until the 1960s, much of the Winter Harbor shoreline was taken up by several summer camps for children. Four summer cottages were built along Whitegate Road in the early 1950s, where Camp Ashbrook had existed. At that time there were only about one or two dozen other summer cottages scattered along the shore. Few of these were year-round residences. The Wolfeboro Neck shoreline of Winter Harbor consisted primarily of Camp Wyanoke and the Wolfeboro Airport (including an authorized seaplane strip in the harbor). As the children's camps closed, their lands were divided and more summer cottages and then larger houses have been built along the shoreline.

Camp Wyanoke on Wolfeboro Neck was the last of the youth summer camps to close in 1975. (Wolfeboro Neck is peninsula with two hills separating Winter Harbor and The Broads. Camp Wyanoke was on the first hill.) The Bentley Family sold the Wyanoke Camp property, which was subsequently developed with a number of larger homes as Wyanoke Harbors. Water coming off the Wyanoke Harbors hills flows primarily toward Carry Beach on one side and toward Johnsons Cove, an inlet on Winter Harbor. Most of the Wyanoke Harbor properties were landscaped to minimize direct runoff into the lake. The top of the second hill had the Wolfeboro Airport on it and a few houses along the shore of Winter Harbor and the Broads. The former airport is currently a hay field.

Starting after the youth camp era, the large wooded areas up the hill on the mainland side leading up to North Main Street started to get developed, with increasing numbers of year-round houses, lawns, roads, gullies, and culverts that resulted in ever increasing amounts of water flowing off the land, down the hill, across the shoreline properties below, and into the lake (e.g., Cricket Hill Estates, Wolfeboro Commons, and Port Wedeln). Stormwater streams developed and increased their flow over the years, where none had existed before. Some of the shoreline owners complained about flooding, washed out driveways and roads, and the amount of silt and water entering the lake.

What was a sandy and rocky bottom of a crystal-clear lake in the 1950s over the years have increasing become covered by plants, algae and other plant-type growth. During summers large algae-like masses have grown, floated in the shallow waters, and landed on the beaches.


During summers large algae-like masses have grown, floated in the shallow waters, and landed on the beaches. Green growth is now seen on the edges of the ice near the stormwater streams and on bottom of the lake at ice out. Rocks that one swims to to stand upon are now covered with a slippery, slimy growth.


Concern about this growing set of problems and observable degradation of the quality of the water was expressed to Town of Wolfeboro officials who visited and verified the concerns. In 2017, the Public Works Department contracted with Underwood Engineering to study the stormwater runoff coming from Partridge Drive and the rest of Cricket Hill Estates and flowing through the culverts across the town roads in the development and to identify some BMP (Best Management Practice) options to mitigate the problems.

In 2018, the Town applied for a NHDES grant to help fund the BMPs that were identified. However, that grant request was not approved, presumably because the state was funding a Lake Winnipesaukee Association Assessment and Management Plan that would include Winter Harbor and that would recommend priorities for mitigation. That plan is currently underway.

**Water quality monitoring history**: A limited amount of water quality monitoring was done in the Wolfeboro end of Winter Harbor until 2017. The deep-water hole was used for a few weekly measurements in 2009 and once for more a wider range of measurements and analyses in 2016. Carry Beach was monitored for *E. Coli* as part of the NHDES Beach Advisory Program.

Starting in 2017, four other sampling sites (besides the Deep water site) were identified (ones off the shores of Port Wedeln, Nary Shore, Whitegate Road, and Carry Beach) and multiple samples were collected, processed, and sent for analyses as part of the UNH Extension LLMP program. These were looking at the traditional parameters covered by the LLMP program. That sampling approach continued through the summer of 2018 until a bloom of Gloeotrichia was observed.

The bloom was reported to NHDES, which confirmed it and issued an Advisory for the Wolfeboro end of the harbor on August 30, 2018 advising people and pets to avoid contact with the water. That advisory lasted three weeks, until September 21, 2018 (See Appendix A).

While the bloom was observed to be worse toward Whitegate Road and Carry Beach in the Wolfeboro end of the harbor, the bloom extended up the harbor and Gloeotrichia colonies could be observed throughout the harbor and out in the Broads. The bloom was first observed on Aug 29, 2018 and continued to build on calm water days for a week. Then after nine days it disappeared.

While Gloeotrichia is capable of producing significant levels of cyanotoxins, NHDES determined by later in the fall, that bloom above did not release significant levels of microcystin toxins, a common type of cyanotoxin. A university lab collaborating with the Bigelow Lab found microcystin and another cyanotoxin (BMAA) associated with the bloom, but also at levels well below health concern.

Gloeotrichia is known to live most of the year in lake-bottom sediments. During the summer, it can form colonies of about 5,000 cells and float toward the surface to get sunlight and nitrogen from the air that it has the ability to fix—like peas. These colonies appear as yellow-green dots that are visible to the human eye.

While there were concerns about the observable deteriorating water quality in Winter Harbor in recent decades and while some residents along the shore thought that they had been seeing evidence of cyanobacteria, most of the water quality results through 2017 were classified as good. So, the bloom was not expected.

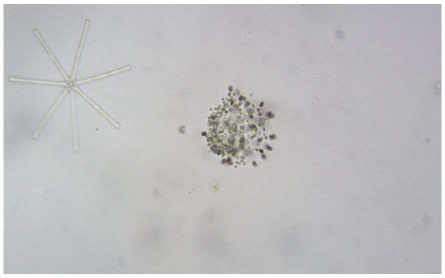
Samples of the water flowing into the lake from two nearby storm water streams were collected just before the bloom and another during the bloom. The total phosphorous concentrations from one of the streams was a very high 7,856.9 ug/L and 4,789.3 ug/L, as compared to a desired (and measured) lake water concentration of less than 8 ug/L.
(See {https://extension.unh.edu/resources/files/Resource007726_Rep11314.pdf} and Appendix E for Winter Harbor data).

After the bloom, we have been able to borrow and have been given equipment and supplies to be able to measure a broader array of parameters. Several additional people volunteered to collect water samples over the summer and others offered their boats to collect samples this fall at the Deep Water site after the water level went down in Lake Winnipesaukee. We collected water samples to determine total phosphorous levels into the Fall 2018, through Winter 2018-19, and at ice-out in Spring 2019, in an effort to reconcile what was being observed and what was being measured. We are continuing this year-round sampling this year.

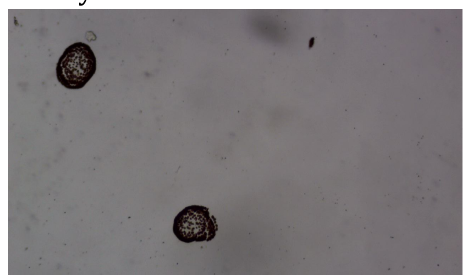
Over the past several years, we have gotten to know and have exchanged information with the water quality and cyanobacteria experts at NHDES, USEPA Region 1, UNH, the Bigelow Laboratory, and elsewhere and have been learning about ongoing activities, responsibilities, and expertise across New England.

**Findings:**

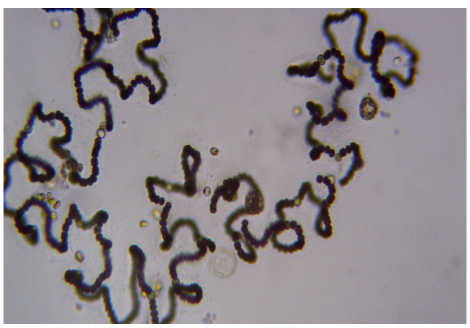
- Except for several high total phosphorous levels at Whitegate Road in 2019, the traditional water quality measures (i.e. total phosphorous concentration, Secchi Disk clarity, chlorophyll a concentration) during Summers 2017, 2018, and 2019 in Winter Harbor were generally good and not very much worse than for other Wolfeboro Waters. They have been higher before and after the summer. (See below.) Phosphorous levels during non-summer months were often above, sometimes significantly above, the NHDES recommended level of 8 ug/L.
- Several different types of cyanobacteria have been identified microscopically in Winter Harbor waters. Their concentrations vary significantly over time.

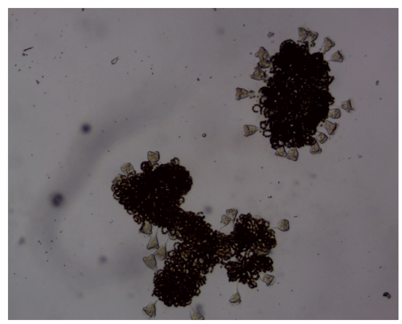


Microcystin (the star in the upper left is a diatom)

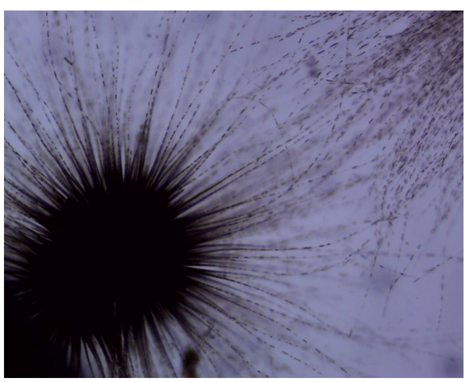


Coelosphaerium

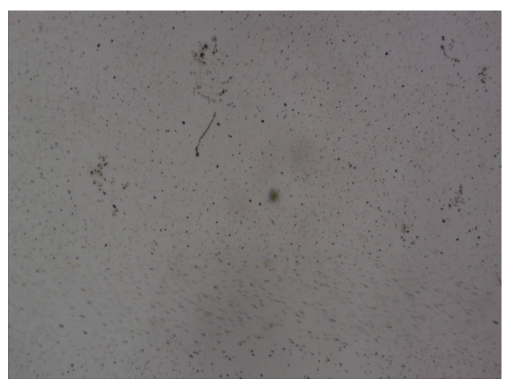




Two different types of Anabaena/Dolichospermum



Gloeotrichia



Likely picocyanobacteria (the tiny dots)

- In addition, much smaller picocyanobacteria (bottom right picture above) are likely present, as the concentration of larger cyanobacteria observed microscopically often do not seem high enough to yield the phycocyanin levels being measured in concentrated tow samples. While picocyanobacterial do not form large highly visible blooms, they are capable of producing significant amounts of cyanotoxin, if they reach high concentrations.
- There was a brief cyanobacteria bloom, likely of Anabaena/Dolichospermum, along the beach at 48 Whitegate Road on the afternoon of June 27, 2019. The bloom was a bright green strip 6 inches to a foot wide and about 50 feet long. A sample was collected and frozen

for fluorometry analysis later. The bloom was never seen again after that. When the sample was run through the Fluoroqik Fluorometer later, the phycocyanin read 14,424 ug/L--very high and 330 times higher than the chlorophyll a measurement, indicating that the green strip was definitely a cyanobacteria bloom. This bloom occurred during a period at the end of June and early July when the total phosphorous levels were above 8.0 ug/L. (Note: Carry Beach and Johnsons Cove sites also had total phosphorous levels above 8.0 ug/L on June 24, 2019, as did Johnsons Cove again on July 16.) So, total phosphorous levels in the nearby water column were predictive of an above normal risk of this type of cyanobacteria bloom and the Fluoroquik phycocyanin fluorescence measured the high concentration of cyanobacteria in the bloom.

- On the other hand, the Fluoroqik phycocyanin result from the nearby water at Whitegate Road on June 24, 2019, as determined by UNH, was 2.50 ug/L. While this was the highest level measured by UNH over Summer 2019, it is not above its normal range. Therefore, either the range for what is considered above normal should be changed or these phycocyanin measurements would seem to be of value primarily for measuring samples taken where cyanobacteria are concentrated and less valuable with general water samples.
- Neither total phosphorous concentrations nor chlorophyll-a concentrations were effective in tracking the biological growth on the bottom of the lake nor the floating algal masses that have been observed in recent years. For example, despite massive presumably algal blooms floating in the water in Winter Harbor, chlorophyll a concentrations measured by fluorescence never were other than good.
- Similarly, these measures are not effective in tracking and predicting Gloeotrichia concentrations, as Gloeotrichia, unlike most other cyanobacteria lives most of the time in the sediment, rather than the water column. Total phosphorous concentration at Whitegate Road on September 9, 2018, during the Gloeotrichia bloom, was 4.4 ug/L --a very good level. In addition, there had been no precipitation during the several days leading up to the observation of the bloom.
- The finding above does not mean that such traditional measures are not valuable indicators of water quality, merely that they are not good measures for some of the specific problems that we have been observing. For example, the traditional measures help predict and track increasing concentrations of the many different types of cyanobacteria that live most of the time in the water column (as opposed to Gloeotrichia that lives most of the time in the sediment) and they are good indicators of nutrients flowing into and present in our lakes.
- The water stratifies in the deep water hole in Winter Harbor when the summer heat warms the surface waters significantly as compared to those at the bottom. The thermocline depth where there is a significant change in the water temperature is typically between 9.5m (31 feet) and 10.5m (34 feet) deep. There is expected to be little circulation between the upper and lower layers, so long as they remain stratified, including little exchange of oxygen.
- Colder water fish, such as salmon, like the cooler, deeper water. However, they need 4-5 ug/L of oxygen in the water to comfortably survive. Below the thermocline there is enough organic matter for bacteria to consume, using up oxygen in the process. Starting in mid-July, the oxygen levels starting from the very bottom of the lake, go below 5 ug/L. By mid-September the bottom 12 meters (40 feet) have oxygen levels below 5 ug/L.
- When the bacteria growth at the bottom consumes all the oxygen, the geochemistry changes. One important change is that ferric iron can be reduced to ferrous iron, which in turn can solubilize phosphorous that previously was tied up by a much less soluble ferric iron complex. Indeed, this happens in the deep water hole in Winter Harbor, where grab samples taken near the bottom showed total phosphorous levels in the lower level significantly higher than that of the surface layer.

- While all the measurements of water quality in Winter Harbor prior to 2018 were done during summer months, samples collected in the fall, winter, and spring at Whitegate Road found some higher total phosphorous levels in October and November 2018 (17.4 ug/L and 10.3ug/L) and April and May 2019 (8.6 ug/L and 8.7 ug/L) than are typical during the summer months.
- The lake has degraded noticeably in recent decades. The reasons for this degradation presumably have to do with climatic changes favoring biological activity and increased loadings of nutrients to the lake. Wolfeboro Waters are getting warmer over time and wind and precipitation events are getting more extreme. These can be expected to continue but are not within our control to change. On the other hand, many of the sources of additional nutrients to our lakes (e.g., land use, septic systems, direct discharges, fertilizer and chemical use, and storm water runoff, and fed waterfowl) we can take measures to reduce.
- Only small additions of total phosphorous to the surface waters of Winter Harbor are believed to be the result of mixing of the higher concentration total phosphorous in the bottom layer of the stratified water in the deep water hole with the upper layer across the rest of the harbor. The concentrations of total phosphorous at the bottom of the lake in the relatively small deep hole, where the waters were anoxic never reached above 34 ug/L. This would likely account for only a small and temporary increase in TP concentration across the whole harbor. Indeed, measurements of total phosphorous concentrations in the surface layer of water at the deep water site above the hole only changed from 5.4 ug/L to 6.7 ug/L between Oct 8, 2019 and October 19, 2019, when turnover occurred. Similarly, at Whitegate Road between October 9 and October 19, 2019 the total phosphorous level in the water only changed from 5.1 ug/L to 7.6 ug/L and returned to 5.6 ug/L in little over two weeks (by November 4, 2019). Note: these increases in TP concentration were preceded by more than 2 inches of rain in Wolfeboro on Oct 17 & 18, 2019. So, storm water runoff is likely contributed significantly to the increase in TP concentration over this time period.)
- In addition, concentrations of total phosphorous above 8.0 ug/L correlate with storm water runoff. For example, when measurements were taken simultaneously at multiple shoreline sampling sites and the deep water site in the center of the harbor, all the occurrences of TP concentrations 8.0 ug/L or above were at shoreline sites, while the concentrations at the deep water site were lower.
- Also, virtually all days with measurements of TP of 8.0 ug/L or greater at any winter Harbor site were preceded by significant rainfall within the prior four days (four out of five in excess of 1.25 inches and the fifth in 2009 over 0.4"). Also, on ten out of 12 occasions when measured TP concentrations were less that 4 ug/L, the prior four days had 0.21" or less of precipitation and six had 0.00". None of the latter four-day stretches had as much as 1" of rain (See the last column in Appendix E).
- TP was observed to be very high (e.g. >4,000 ug/L and >7,000 ug/L) in the stormwater runoff streams after significant precipitation—streams that did not exist decades ago.

**Future:** Our assessments to date have determined the status and trends of many important aspects of water quality in Wolfeboro Waters. They have also come to many useful conclusions about issues and possible ways to address them. However, several fundamental questions remain, for example:

- Winter Harbor has problems that need to be addressed, yet traditional water quality measures for the harbor are similar to most of the rest of Wolfeboro's Waters. Is Winter Harbor unique? If so, in what way? If not, how do we determine where else we have waters with similar problems that need to be addressed?
- What are the best measures of the risks of cyanobacteria blooms, especially those that produce significant levels of cyanotoxins? Which cyanobacteria concentrations track water column total phosphorous concentrations most closely?

- How local are the problems and, therefore, their potential solutions?
- Clearly reducing runoff of nutrients into our waters is the most important thing that we can do to prevent the degradation of and to enhance the quality of our waters. What are the most effective engineering, policy, and household measures to do so? Are there other important or easy measures that we can be taking to do so?
- What are the highest specific sources of runoff of nutrients into our waters that need to be addressed? Certain sources of runoff have been identified in the lakes that have already had watershed assessment and management plans, others are easily seen and are clearly of high priority to be addressed. In Winter Harbor, other sources currently are being modeled for priority setting purposes as part of the ongoing Lake Winnipesaukee Association watershed assessment and management plan.

In addition to expanding water sampling to cover Sargents Pond and to continue sampling the sites sampled in Summer 2019, we propose to address the questions above and to efficiently monitor important conditions and trends in the future by

- Using DNA to identify the types of cyanobacteria present, including picocyanobacterial, in our waters, to track changes in the concentrations of ones of concern, and to anticipate and verify future blooms.
- Comparing the levels of different cyanobacteria with total phosphorous, other nutrients nd parameters, and weather events.
- Identifying microorganisms seen microscopically in samples with elevated phycocyanin.
- Correlating phycocyanin fluorometer reading that we are getting with those from different labs and instruments.
- Attempting to use videos taken by drones to see how local biological growth is and to track changes over time
- Conducting biological and chemical sediment analyses
- Testing quickly to determine the presence and concentrations of any toxins associated with cyanobacteria blooms

Respectfully submitted,

Abigail Adams, M.D.
Wolfeboro and
Lake Winnipesaukee (Tuftonboro) Resident

Justin Chafee
Assistant Director, Wolfeboro Department of Parks and Recreation

Warren Muir, Ph.D.,
Chair, Wolfeboro Waters Assessment Subcommittee
Member, Wolfeboro Conservation Commission and
Winter Harbor (Wolfeboro) resident

Linda Murray
Co-chair, Wolfeboro Waters
Member, Wolfeboro Board of Selectmen and
Lake Wentworth resident

Pat Tarpey, MS
Executive Director, Lake Winnipesaukee Association

Steve Wingate
Chair, Tuftonboro Conservation Commission and
Winter Harbor (Tuftonboro) resident