AERATION AS A LAKE MANAGEMENT TOOL AND ITS USE IN VERMONT

A Review of the Lake Management Literature

Compressed air diffuser installed in Little Lake St. Catherine, Wells (Photo Credit VT DEC)

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Introduction

Aeration, or artificial circulation, is a lake and reservoir management tool that has been used for over 60 years. First developed in the 1950's as a tool to prevent winter fish kills, aeration was later used as a method to manage the effects of eutrophication. In principal, aeration is used to raise the dissolved oxygen content throughout a lake over time. Increasing the dissolved oxygen content in a waterbody has been shown to provide some water quality benefits, particularly in managing heavy metal concentrations in drinking water reservoirs and decreasing the frequency of cyanobacteria blooms. Aeration is seen as an important tool in lake restoration efforts and there is increasing interest in using aeration to manage the symptoms of eutrophication and for other novel applications. However, the use of aeration has the potential to cause harmful side effects in natural waterbodies under certain conditions and likely provides only short-term water quality benefits (Nygrén 2017).

To date, in Vermont, three aeration systems have been authorized for use in public waterbodies. One compressed air diffuser system and two updraft pump systems (SolarBee), have been installed and operated in Vermont. One SolarBee circulation system was operated in Tinmouth Pond in Tinmouth to manage aquatic nuisance macrophytes and another was operated in St. Albans Bay in Lake Champlain to manage cyanobacteria blooms. At the time of this paper (January 2019), the SolarBee systems are no longer in use. The compressed air diffuser aeration system was installed and operated in Little Lake St. Catherine in Wells. Additionally, an aeration system is currently under consideration for installation in Lake Carmi in Franklin to prevent internal phosphorus loading to decrease the frequency and intensity of cyanobacteria blooms.

The purpose of this paper is to explore the scientific literature documenting the mechanisms in which aeration may improve water quality, identify potential adverse impacts from the use of aeration, describe how aeration has been used in Vermont and elsewhere, and discuss the use of aeration for experimental purposes in Vermont.

Aeration as a Lake Management Tool

Aeration Types (oxygenation vs. circulation) and Applicability

Reduced oxygen conditions in lakes, ponds, reservoirs, and other waterbodies can impair water quality and lead to excessive cyanobacteria/algae growth. In lakes, ponds, and reservoirs, respiration occurs naturally throughout the water column and may be most intense near the lakebed, where bacteria decompose settled organic particles, creating lower oxygen levels at the lakebed. During the summer months, in thermally stratified lakes, the bottom layer is separated from sources of oxygen and the naturally reduced oxygen concentrations in deeper water near the lakebed can be exacerbated. As respiration continues throughout the summer in the bottom layer, oxygen can become depleted. Once oxygen levels are depleted at the bottom layer of the waterbody, elements bound to the lakebed sediment, such as phosphorus, are released into the oxygen depleted water. As the waterbody naturally de-stratifies, these phosphorus enriched bottom waters mix within the entire water column, resulting in more available phosphorous for primary production. This seasonal thermal stratification and oxygen depletion is a natural process that can lead to cyanobacteria blooms. Seasonal oxygen depletion can be amplified by human activities that cause increased nutrient inputs into the waterbody. Beginning in the 1960's, aeration systems began to be designed to manage the symptoms of eutrophication by addressing low oxygen conditions in waterbodies (Wagner 2015).

There are two primary methods of aeration: circulation and oxygenation. Oxygenation pumps oxygen into the deeper water layer of a thermally stratified waterbody, without disrupting stratification. Circulation uses air to force the movement of water so that it interacts with the atmosphere, or to move more oxygenated surface layers of water into deeper locations. There are a variety of products and methods developed to meet the purpose of circulation and oxygenation. Figure 1 identifies some of the common aeration types, although other methods exist that are not included in this chart. Selecting an appropriate aeration system type is dependent on the physical and chemical characteristics of a waterbody. Watershed size, land use, waterbody depth, stratification, and lake trophic type need to be understood prior to assessing whether aeration is an appropriate tool or what type of aeration system design may be suitable to meet a particular management goal.

Methods of Aeration	Type	Description
Oxygenation	Hypolimnetic	Pure oxygen is released into submerged chambers, water moves through the chambers and oxygen is transferred to the water.
	Downflow Bubble Contact	Oxygen injection into water pumped downward in a chamber.
	Side Stream Super Saturation	Supersaturated oxygen solution created on shore under pressure and discharged to target area.
	Diffused Oxygen Release	Release of oxygen gas into a waterbody.
Circulation	Diffused Air Circulation (DAC) or Compressed Air Diffuser	Release of diffused bubble plume directly in the lake from the lake bed to force water to mix with the atmosphere.[1]
	Updraft Pump	Low velocity, axial flow pumps can be powered by wind or solar sources. Water is forced upward.
	Downdraft Pump	Low velocity, axial flow pumps can be powered by wind or solar sources. Water is forced downward.
	Surface Spray Systems	Surface aeration through spraying water through fountains.
	Layer Aeration	Circulation of specific depth layers. Mixing occurs in the middle of the water column to preserve stratification stability.

Figure 1. Main categories of aeration practices by aeration type.

[1] Lake management research has largely focused on coarse bubble diffusion. Fine bubble diffusion (also known as laminar flow aeration), adapted from the field of waste water treatment, is another option for replenishing oxygen in the hypolimnion. Case studies of fine bubble diffusion used to reduce the intensity and duration of cyanobacteria blooms indicate this approach can be effective and affordable (e.g. Jermalowicz-Jones, 2012).

As described in the scientific literature, aeration methods and technologies have been commonly applied to address water quality issues in drinking water/water supply reservoirs, sewage treatment plants, and stormwater ponds where oxygen depletion is a threat to water quality. Aeration techniques have been applied somewhat less frequently in natural or artificial lakes and ponds to respond to the effects of eutrophication or for the protection of fish habitat (Cooke et al. 2005).

In drinking water reservoirs and treatment facilities, aeration has been used to improve water quality parameters that affect treatment needs and costs. In these facilities, aeration systems are installed with a goal to homogenize water quality, reduce the release of iron and manganese from bottom sediments, reduce the accumulation of sulfides, ammonium and other compounds, and to equilibrate pH levels. In stratified lakes that experience oxygen depletion in deep water and in shallow ice-covered lakes, aeration systems have been installed to improve fish habitat.

When used to manage algae and cyanobacteria blooms, aeration systems function in three different ways, the success of which depends on the characteristics of the waterbody. The first mechanism is to reduce phytoplankton biomass by forcing deeper mixing depths that shorten the time that plankton cells are exposed to light, which limit photosynthesis and growth. The second mechanism is to disrupt the competitive advantage cyanobacteria gain through buoyancy control and promotes conditions that are more favorable for diatoms and green. The third mechanism is to prevent internal loading of phosphorus at the lakebed by raising oxygen concentration at the sediment layer, which prevents the release of phosphorus bound to lakebed sediments.

In recent years, aeration has been marketed to lake managers as a tool that could potentially manage aquatic plants and accumulated organic material on a lake bottom, also referred to as “muck.” The proposed mechanism for muck control through aeration is to increase oxygen at the lakebed to encourage decomposition of organic sediments. Although there is a market for installing aeration systems for these uses and some experimental installations are in place in Vermont, the scientific literature does not support or recommend the use of aeration as a tool for managing muck or aquatic plants (Osgood 2015, Wagner 2015).

Assessment of Potential Benefits and Drawbacks of Aeration

Potential Benefits and Limitations

Increasing lake dissolved oxygen concentrations has been shown to improve water quality parameters and aquatic organism habitat. There are limitations to what the different types of aeration systems can accomplish due to physical, chemical, and biological factors of the waterbody and its watershed. In a literature review of aeration techniques used in reservoirs, the evaluation of oxygenation and/or circulation case studies indicated almost 90% of systems provided some measurable benefits, but only about half of the studies met the water quality goals identified for each project (Wagner 2015). Successful implementation of aeration requires an appropriate engineering design for the waterbody, adequate budget, and clear, well-defined goals that acknowledge the limitations of what can be expected to be accomplished by aeration systems.

Most circulation and oxygenation techniques are able, if designed properly, to prevent oxygen depletion (anoxia) in target areas, which has been shown to minimize the release of undesirable substances, (e.g. heavy metals, ammonia, and nutrients) from lakebed sediments, providing benefits to water quality.

Release of phosphorus and ammonium from sediments (internal loading) can also be prevented by oxygenation or circulation to address anoxic conditions. However, cyanobacteria/algae have alternate strategies for acquiring nutrients and their populations may not be completely controlled by the prevention of anoxic conditions (Wagner 2015). Additionally, evidence of long-term success of aeration in reversing the effects of eutrophication is sparse (Nygrén et al. 2017).

Oxygenation

Oxygenation has been shown to benefit water quality through reducing concentration of iron, manganese, and ammonium. Phosphorus reductions have been observed in some cases of oxygenation use, but the overall reductions are generally smaller than other methods, such as using phosphorus binding agents like alum or Phoslock (Cooke et al. 2005). Oxygenation has been documented to control algae and cyanobacteria if the main source of phosphorus comes from internal loading and if enough natural phosphorus binders are present. External loading is often the primary phosphorus source in a waterbody, especially in waterbodies with large watersheds. Oxygenation alone may not be able to overcome nutrient inputs from the watershed to impact the phosphorus availability in a waterbody. Oxygenation can create a zooplankton refuge in deep water by providing oxygen to greater depths, where the zooplankton may feed on algae or cyanobacteria and prevent blooms. Oxygenation has been shown to provide homogenization of water quality, including pH, which is a cost-saving benefit to water treatment plants, but may not be beneficial for maintaining the natural ecology of lakes and ponds.

Circulation

Circulation has been shown to improve dissolved oxygen content, ammonium concentration, epilimnetic pH, and trace metal concentrations (Iron and Manganese). In a literature review of dozens of circulation system studies, the impact of circulation on phosphorus concentration is mixed: in 65% of the studies, total phosphorus either increased or remained the same following aeration; water transparency worsened in 53% of the studies and improved in 21% of the studies (Cooke et al. 2005). There are several primary reasons that a circulation system may not sufficiently impact phosphorus to meet the expectations of a project. Unsuccessful responses may be due to the following (Bormans et al 2015):

- Inadequate sizing of aeration installation
- Chemical composition of sediments (iron concentrations impact phosphorus binding)
- Lack of control of external nutrient loading
- Lack of time for operation

Circulation can be used to reduce phytoplankton biomass by interfering with photosynthesis and growth conditions. Increased mixing depths created by aeration may limit light availability for individual cells carried deeper in the water column, decreasing photosynthesis. Low surface light and deep mixing from aeration can prevent photosynthesis in deep lakes, but not generally in shallow lakes. Circulation systems that aim to achieve complete lake mixing provide increased habitat for zooplankton to prevent algae and cyanobacteria blooms through increased grazing. Diatoms that would normally settle out of less turbulent waters in late spring or summer can remain in the water column to accumulate nutrients that might otherwise be used by cyanobacteria. A more turbulent environment, created by circulation, can shift the algae community to a more desirable composition that reduces cyanobacteria blooms. As noted above, however, circulation may also result in decreased transparency as continued mixing keeps turbulence-adapted phytoplankton like diatoms in suspension.

Complete circulation of a lake has contributed to reduced internal phosphorus loading and a corresponding reduction in algal/cyanobacteria biomass in some cases (Cooke et al. 2005). A reduction in internal phosphorus loading is likely to happen in specific conditions (e.g. phosphorus is held in iron-bound compounds in anoxic hypolimnetic sediments). Under other conditions, internal phosphorus loading may increase (e.g. if the iron-phosphorus ratio is low). Internal phosphorus loading is often high in unstratified (typically shallow), eutrophic lakes. Reductions in internal phosphorus loading may be limited after aeration in shallow lakes because circulation is already high in these lakes and stratification is less frequent.

Circulation has some documented limitations in its effectiveness and applicability. Lateral (horizontal distance from circulation unit) effects of circulation vary greatly depending on the depth of the waterbody and the presence of thermal gradients (Wagner 2015). There may be thermal resistance to mixing in deeper reservoirs, however, mixing shallow water using diffused air circulation systems may not have a wide lateral impact across the waterbody. In a shallow waterbody, bubbles from a diffused air circulation system reach the surface quicker and move less water. Lateral impacts from diffused air circulation are observed to be greater, the deeper the height of bubble release (Wagner 2015). Additionally, circulation systems are usually inadequate to counter heat input from long stretches of hot, sunny summer weather. Even if a waterbody is fully mixed, the overall rise in water temperature supports the occurrence of cyanobacteria blooms. Circulation can reduce the frequency of cyanobacteria or algae blooms, but rarely eliminates them (Wagner 2015). Aeration has been used successfully to manage cyanobacteria or algae blooms, but this outcome is less likely in shallow lakes since light is rarely a limiting factor for cyanobacteria or algae growth and internal loading is more difficult to control, due to the lack of stratification (Illinois EPA 1997 and Welch and Cooke 1995).

Aeration to Address Lake Bottom Sediments

Some aeration system manufacturers have promoted circulation as a management tool to reduce accumulation of organic-rich sediments in mesotrophic and eutrophic lakes. Productive lakes tend to build up sediments more rapidly than nutrient poor oligotrophic lakes. Littoral area sedimentation can increase from macrophyte establishment because aquatic plant beds can trap sediment and increase local organic loads. The mechanism for the reduction in organic-rich sediments from aeration is thought to occur through increasing oxygen concentrations at the lake bottom, thereby increasing the rate of aerobic decomposition of bottom sediments. In the literature review conducted for this report, no literature was found in which aeration was used as a tool to address lakebed organic sediment accumulation. While introduction of oxygen to the sediments may promote digestion of some organic compounds, such as cellulose (A. Horne, personal communication), there does not appear to be strong evidence to support the use of aeration as a tool to manage the accumulation of organic sediments.

In a study of how long-term aeration of lakes affects organic sediment accumulation rates, 10 lakes in Minnesota were selected for a sediment core study. Five of the lakes selected were aerated through artificial circulation for a minimum of 8 years, 5 lakes were never aerated. Historic patterns of sediment accumulation and composition were qualitatively similar in aerated and non-aerated lakes. After analysis of the sediment cores, each of the 10 lakes exhibited a sharp rise in sediment accumulation rates following settlement and urbanization. One of the non-aerated lakes exhibited a decline in sedimentation rates attributed to a dairy farm ceasing operation on the lake shore (Engstrom and Wright 2002.) The trends in the organic sedimentary content within and among lakes during the study period provided no evidence that aeration enhanced the oxidation or reduction of organic matter. In addition to proposed impacts to organic sediment accumulation, aeration has been marketed as a tool to reduce the abundance of rooted macrophytes. However, no such trends were evident in any of the aerated lakes (Engstrom and Wright 2002).

In a more recent 2015 study in Lake Apopka, a shallow (mean depth of about 5.2 feet), eutrophic lake in Florida, 96 aerators were installed in a 250-acre area of the lake for the purpose of decreasing organic sediment accumulation. Two applications of 1,000 pounds of microbes and 400 gallons of enzymes were added for bioaugmentation to speed up the decomposition process. It was anticipated that the installation of an aeration system would lead to increased water clarity, increased dissolved oxygen concentration, reduction of cyanobacteria, reduction of the decomposed organic muck layer on the lake bed, and a reduction of nutrient concentrations in the water column and the sediments. In an independent review of the experimental installation, University of Florida researchers saw no detectable differences in water chemistry between treatment areas and control samples. Ammonia, total phosphorus (TP), total nitrogen (TN), total chlorophyll, Secchi depths, and turbidity were all similar between sampling groups and across monthly sampling. Most metrics showed little to no changes in muck levels (less than 6 inches in depth change was observed between sample and control sites). The researchers noted that in-lake sediment fluid dynamics are not well understood and that changes in sediment depths could not be attributed to the decomposition of sediments (Slagal and Allen 2016).

In 2017, the Harris Chain of Lakes Restoration Council, the governing body overseeing the restoration of Lake Apopka and other geographically related lakes, made an official recommendation in their 2017 Annual Report to the Florida Legislature to no longer support aeration projects as part of the overall restoration efforts. The Council determined that aeration to control sediment accumulation did not work to expectations, and that the aerators were likely transporting flocculant sediments around the lakebed, rather than oxidizing the sediments. The Annual Report identified other watershed and fishery management strategies to achieve restoration goals (Harris Chain of Lakes Annual Report 2017).

Potential Adverse Impacts

Due to the expanding interest in using aeration as a water quality management/lake restoration tool in Vermont, it is important to understand whether there are potential risks or drawbacks to implementing aeration. It is well documented in the scientific literature where the use of aeration does not meet management goals, and in some cases, the aeration system exacerbates the effects of eutrophication.

Several "worst-case-scenarios" were described in a literature review by Cooke et al. (2005), including decreased water quality parameters following aeration:

- Crystal Lake, Minnesota (increased internal phosphorus (P), TP, TN, and chlorophyll)
- East Sydney Lake, New York (increased internal P and entrainment of P into the photic zone; no decrease in algal blooms and no increase in transparency)
- Silver Lake, Ohio (increased internal P and entrainment of P into the photic zone; no decrease in algal blooms and no increase in transparency)
- Lake Wilcox, Ontario, Canada (presence of algal blooms promoted by aeration from entrainment of P in the water column)

Although these worst-case scenarios are an exception to the expected response, they highlight potential unintended adverse impacts from aeration. Some of the main mechanisms for these potential adverse impacts are as follows (Cooke et al. 2005, Niemesto et al. 2016, Dinsmore and Prepas 1997, and Mallin et al. 2016):

- If nutrients are limiting productivity in the epilimnion, then aeration may increase particulate phosphorus, which can be mineralized to a usable form.
- Dissolved phosphorus may be transferred to the photic zone from deeper areas of the waterbody.
- Transparency may decrease due to increased algal/cyanobacteria biomass and silt.
- Increase in cyanobacteria due to changes in CO_2 and pH or to a decrease in zooplankton grazing intensity due to a change in habitat.
- Temperature increases.
- Alteration to macroinvertebrate communities, impacting food webs.
- Unmixed, anoxic zone persists near the sediment-water interface below circulation installations where heavy metals can continue to be released from the lakebed.
- Hypolimnetic aeration may increase nutrient recycling and primary productivity; increased temperatures and turbidity may reduce the stability of the water column, increasing nutrient cycling, thereby resulting in more organic material settling on sediments.
- In shallow lakes, circulation systems may make bottom-associated nutrients more available to the phytoplankton in the water column, increasing algal blooms.
- Changing a lentic environment (still water) to one that is at least partially lotic (rapidly moving water) would change the habitat of the fish community and place stresses and impacts on fish and other aquatic organisms that rely on still waters.
- Unknown impacts on phytoplankton, zooplankton and all other primary food sources that larval and juvenile fish species rely on in their early life stages.

Under-sizing of aeration equipment, operational problems, and inappropriate application of aeration may minimize the effectiveness of the project or even degrade existing water quality.

Aeration in the Context of Management Goals

Aeration is a tool that has been used for decades to manage the symptoms of eutrophication and to enhance fish habitat, however the scientific literature shows that its success is variable, and that there may be adverse impacts on natural lake functions (Wagner 2015, Cooke et al. 2005, Nygrén et al. 2017). It is important for lake managers to choose the appropriate tool for lake restoration that can meet water quality goals and to understand the cause of any water quality problems. If aeration is considered for use in natural systems, it should be considered as a shorter-term component of a longer-term watershed management strategy to meet water quality goals.

Many aeration projects show initial improvements, such as an increase in water clarity or a decrease in average phosphorus concentration, but over time, there is high variability in these parameters and a low likelihood that improvements will be sustained into the future (Tomasko et al. 2013). Wagner’s literature review summarizes several aeration case studies in which the projects do not achieve long-term management goals, despite early improvements to water quality. The lack of long-term improvements is most likely due to continued watershed inputs (Wagner 2015). When watershed improvements are not made in tandem with an in-lake treatment, watershed inputs can overwhelm the in-lake treatment, reducing its efficacy.

The use of aeration in a natural lake system has the potential result in unintended adverse impacts to water quality and fish and wildlife habitat; therefore, its use in natural lake ecosystems should be considered with caution. The long-term impacts caused by using aeration in a system that is not experiencing anoxia or cyanobacteria blooms are uncertain. When exploring aeration as a lake management tool, lake managers should consider the following:

- Understanding the sources and causes of the water quality issues in the waterbody (watershed inputs).
- Reviewing several aeration methods to determine which are best suited to address identified problems in the waterbody and watershed inputs.
- Developing clear management goals that reflect expectations of what an aeration system can achieve over time while recognizing the limitations of the system.
- Creation of a watershed management plan to address the sources and causes of water quality impairment.

Reviewing In-Lake Management Proposals in Vermont

The Vermont Department of Environmental Conservation's (VT DEC) Watershed Management Division is responsible for protecting, maintaining, enhancing, and restoring the quality of Vermont's surface water resources. Inherent in this effort is the support of both healthy ecosystems and public uses in and on Vermont's 800 lakes and ponds. Decisions on how best to support resilient ecosystems and public uses are made based on science-based management and policies and the review of projects in and near lakes in terms of state regulations and permits.

Regulatory Considerations

The Lakes and Ponds Management and Protection Program, which is housed within the Watershed Management Division of the VT DEC, has jurisdiction over activities that create new cleared area or new impervious surface area within 250 feet from mean water level of public waters 10 acres in size or greater, under the Shoreland Protection Act (10 V.S.A Chapter 49A, §1441–1449), activities that encroach on public waters (lake encroachment), regulated under the Management of Lakes and Ponds (29 V.S.A. Chapter 11), and activities to control aquatic nuisance species, regulated under Aquatic Nuisance Control (10 V.S.A. Chapter 50, §1455). Aeration installations have the potential to fall under the jurisdiction of one or more of these regulations. Generally, aeration projects are reviewed and regulated as lake encroachments, although two previous aeration projects in Vermont were authorized under Aquatic Nuisance Control permits. Air compressors in the protected shoreland area that are required for an aeration system are regulated under the Shoreland Protection Act.

A lake encroachment is defined by the statute as the placement of any material or structure in any lakes and ponds which are public waters, or the alteration of the lands underlying any public waters, or the placement of any structure beyond the shoreline delineated by mean water level. Proposed lake encroachment projects are evaluated for their impacts on the public good and the public trust. Projects are reviewed for potential impacts to water quality, fish and wildlife habitat, aquatic vegetation, and navigational and recreational concerns. A permitted project in a public waterbody must not adversely affect the public good or the public trust.

An Aquatic Nuisance Control permit is required for activities used to control nuisance aquatic plants, insects, or other aquatic life in Vermont's waterbodies. Examples of permitted projects include use of pesticides, copper-based algaecides, bottom barriers, powered mechanical devices, and structural and biological controls. Projects permitted under Aquatic Nuisance Control must demonstrate that there is acceptable risk to the non-target environment, there is negligible risk to public health, and there is either benefit to or no undue adverse effect upon the public good. Proposed pesticide projects must also demonstrate that there are no reasonable non-chemical alternatives and that a long-range management plan has been developed which incorporates a schedule of pesticide minimization.

The VT DEC does not support the use of small-scale aeration devices including fountains, bubblers, hydraulic jets, and small aerators that attach to docks. These items are often used to protect docks from ice and are also marketed as solutions for managing aquatic plants and accumulated organic sediment. Unless the use of small-scale aeration is necessary for an encroachment that promotes the public good, the VT DEC does not authorize bubblers/aerators for individual, private use because they have been identified as encroachments that may adversely affect the public good and are not consistent with the Public Trust Doctrine.

Applying the Surface Water Management Strategy to Aeration

The Watershed Management Division has developed the Vermont Surface Water Management Strategy to guide the management of pollutants and stressors that affect the uses and values of Vermont's surface waters. The Strategy presents the Division's goals, objectives and approaches for the protection and management of Vermont's surface waters and supports watershed management decisions that ensure efficient, predictable, consistent and coordinated management actions.

The focus of the Strategy is broader than individual pollutants, emphasizing the importance of managing waters in a watershed context. The Division prioritizes management and remediation activities upstream of rivers, streams, lakes, ponds, and wetlands. The Strategy recognizes that full protection and restoration of surface waters can only be accomplished when upstream and upland stressors are reduced to levels which support biological, physical and chemical integrity in receiving waters. Under this policy, in most cases, in-lake management approaches are considered in Vermont's waters only when sufficient progress has been made on land immediately adjacent to the resource or deeper in the watershed. Data should also indicate that impacted waters are in the recovery phase, so they may better respond to implementation of an in-lake management strategy. Preventative methods, consisting of the reduction of nutrient inputs from watershed sources is the most effective long-term solution to addressing eutrophication in waterbodies (Bormans et al. 2015). However, there are some scenarios in which in-lake methods can accelerate the recovery process and work as a compliment to efforts in the watershed to reduce external loading (Bormans et al. 2015).

The Division works to emphasize the importance of implementing best management practices within the watershed to address identified sources and causes of water quality degradation. The Division's Tactical Basin Plans identify and prioritize remediation projects or activities for specific waters based on monitoring and assessment data and identify appropriate funding sources to complete the work. In accordance with the Surface Water Management Strategy and the Tactical Basin Planning Process, in-lake treatments like aeration are only considered after significant progress to control sources of nutrients and sediment entering the waterbody has been made within the watershed. In-lake treatments are considered in context of their appropriate application to the management goal.

The Use of Updraft Pump Aeration Systems in Vermont

Updraft pump (UDP) aeration systems can be powered through conventional electricity, wind, or solar, but solar powered systems have gained popularity in the last two decades. In these systems, water is pulled upward by surface pumps as well as propelled downward. The upward movement of water is similar to that induced by compressed air. A tube is set at the desired depth and water is pulled upward through the tube at a relatively low velocity, releasing the water at the surface to flow radially outward. Some updraft pump (UDP) systems are used to prevent stratification, while others mix only surface water and tend to sharpen the separation between upper and lower water layers. Two UDP systems were authorized for operation in Vermont lakes (Lake Champlain and Tinmouth Pond) under Aquatic Nuisance Control Permits. Both waterbodies used updraft pump systems (UDP) manufactured by SolarBee.

Peer-reviewed, published data on the performance of UDP systems is scarce, despite the large number of systems in place. According to case studies, UDP systems were not found to provide cyanobacteria control in cases where only a subsection of the waterbody was circulated, in shallow waterbodies (less than 3.3 feet), or where the photic zone extends below the thermocline and the UDP system is set up to mix only the upper water layer (Wagner 2015). The potential to control cyanobacteria/algae with UDP systems is limited when the depth to which algae are circulated is still in the photic zone since algae located in deeper areas can be expected to rise later in the summer. A study of an UDP system installed in a small reservoir in Virginia, found that the UDP unit had no impact on water more than 33 feet (10 m) from the unit. It was concluded that the device lacked the power to mix a significant portion of the reservoir under the test conditions (Upadhyay et al. 2013).

Tinmouth Pond, Tinmouth

Tinmouth Pond (Chipman Lake) in Tinmouth is a shallow, 79-acre lake assessed in the Vermont Lakes Scorecard as “poor” for the presence of aquatic invasive species and for shoreland and lake habitat. Tinmouth Pond is assessed as “stressed” for phosphorus and as having a “moderately disturbed” watershed. Under an Aquatic Nuisance Control Permit issued in 2006, the Town of Tinmouth was authorized to install an updraft pump system to address nuisance populations of Eurasian watermilfoil (*Myriophyllum spicatum*). The use of SolarBees to control Eurasian watermilfoil (EWM) is not something that is supported in the scientific literature. The permit was issued noting the lack of scientific evidence to support the use of SolarBees to control EWM and with recognition that there was little risk of impact to the non-target macrophytes.

The permit to operate the SolarBee units in Tinmouth Pond expired January 8, 2018. The Town of Tinmouth applied to renew their Aquatic Nuisance Control permit on August 31, 2017. Because there is no evidence to support the use of artificial circulation/aeration systems for the control of macrophyte populations in the scientific literature, nor from the installation in Tinmouth Pond, and because the Town updated its permit renewal application to request the use of SolarBees for in-lake nutrient management, the project could not be evaluated through Aquatic Nuisance Control permitting. Evaluating the use of SolarBees for in-lake nutrient management falls under the jurisdiction of Lake Encroachment permitting. The Town of Tinmouth, at the request of the VT DEC, submitted a Lake Encroachment permit application for the authorization of the use of two SolarBee units in Tinmouth Pond on February 20,

2018. The VT DEC reviewed the proposed SolarBee reauthorization project in relation to its impacts to the public good and the public trust and determined that the VT DEC could not support the reauthorization of two SolarBee units in Tinmouth Pond.

The Town of Tinmouth (the applicant) stated that Tinmouth Pond experienced improved water quality over time from the operation of the SolarBees. However, The VT DEC data do not show an improvement to water quality. According to the 2017 Lake Score Card water quality trend analyses, since 1997, Tinmouth Pond has statistically significant increasing summer Lay Monitoring total phosphorus (TP), while summer chlorophyll-a (algae and cyanobacteria) remains low and stable. Spring total phosphorus is stable from 1994 through 2011, though it has only been sampled six times since 1995 and only once since 2005. There is insufficient data to calculate a trend for Secchi depth (water clarity) because the Secchi disk typically hits the bottom of the lake at the sample site (around 3 meters), except in 2017 when it never hit bottom (Figures 2 and 3).

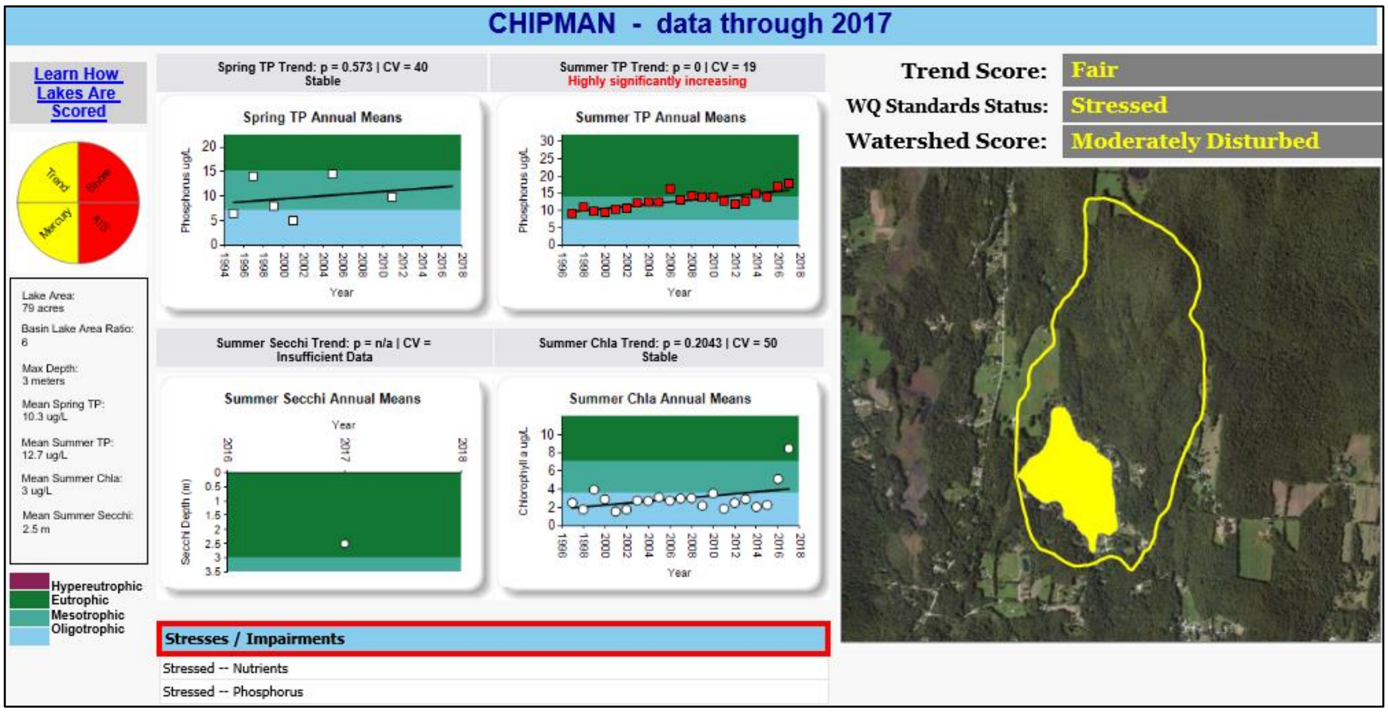

Figure 2. Tinmouth Pond (Chipman Lake) Score Card Trends and Status Report

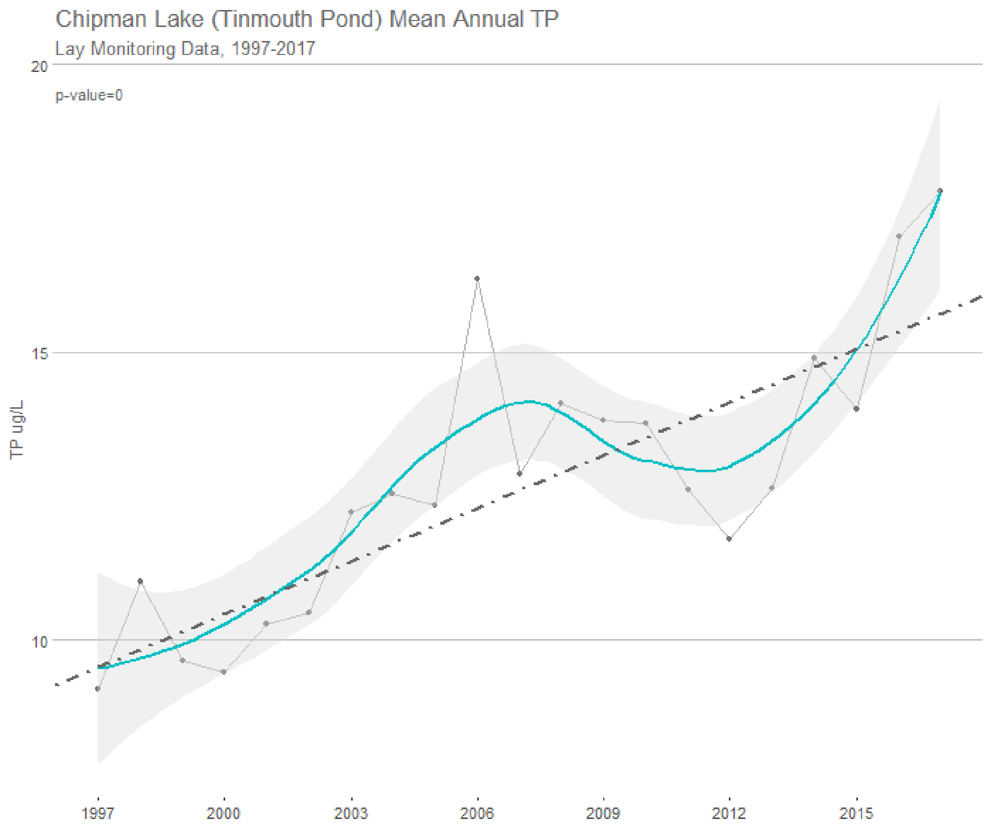

Figure 3. Tinmouth Pond Lay Monitoring Program mean annual total phosphorus (TP) data trends (VT DEC)

Installation and operation of SolarBees in Tinmouth Pond since 2006 has not resulted in water quality improvements, as the data indicate an increasing total phosphorus trend. Based on the increasing phosphorus trends, as well as evidence of potential adverse impacts from aeration noted in the scientific literature, the potential negative impacts to water quality within the waterbody generated from the use of SolarBees outweigh any proposed benefits to water quality identified by the applicant.

A direct correlation between the use of the SolarBees and the increasing phosphorus data trend could not be made, but anecdotal evidence supported a hypothesis that in 2017 the uptake tubes on the SolarBees were set in a position too close to the lakebed, causing the units to suck up and redistribute lake bottom sediments across the lake, increasing phosphorus and decreasing water clarity, creating conditions in which the Secchi disk did not touch the lake bottom.

During the permit application review process, the proposed authorization of two SolarBee units in Tinmouth Pond to manage nutrients, was determined to adversely impact the public good through the following:

- The use of SolarBees was found to be excessive for the stated purpose
- The continued use may potentially result in long-term impacts to water quality
- The continued use may cause potential disturbances to fish and wildlife habitat
- The use of SolarBees was inconsistent with the natural surroundings

Based on these findings, the proposed project would have resulted in a negative cumulative impact to Tinmouth Pond, adversely affecting the public good. Therefore, the VT DEC was required to deny the application in accordance with 29V.S.A. §405.

St. Albans Bay, Lake Champlain, St. Albans

St. Albans Bay in Lake Champlain is in the northeastern portion of Lake Champlain and has a history of excessive phosphorus levels and algae blooms dominated by cyanobacteria. There have been significant efforts made in the past to reduce phosphorus loading to St. Albans Bay from point and nonpoint sources in the bay's watershed. However, water quality in St. Albans Bay has not improved, largely because of on-going phosphorus loading from the Bay's watershed and from internal loading within the sediments. The Town and the St. Albans Area Watershed Association were permitted to install updraft pump circulation systems to control algae blooms under an Aquatic Nuisance Control permit in 2006.

Three SolarBee units were installed in St. Albans Bay in 2007, authorized under Aquatic Nuisance Control permitting. Assessment following one season of operation found that chlorophyll-a and Secchi transparency were not improved in the study area and that those metrics were more deteriorated than in most other areas of the bay. This is explained by the prevailing wind direction along the Bay, creating poor water quality conditions nearest shore and the UDP units, suggesting that influence of the UDP circulators may have been overwhelmed by water movement from outside the zone of expected influence. Algae/cyanobacteria usually accumulate near the shoreline at the end of the wind line, and the circulators were unable to prevent this common phenomenon from occurring in this bay. The UDP circulators did not result in reduced cyanobacteria dominance in the target area. Oxygen was >4 mg/L at all stations on all dates throughout the Bay, indicating strong mixing throughout the monitored portion of the bay. Nutrient and flow patterns showed no strong influence from the UDP systems between inside and outside of the UDP zone of influence (Wagner 2015). No discernible benefits were achieved from the installation of the UDP circulation units in St. Albans Bay. The units were removed after one season of operation, as they were not seen as an effective tool for managing cyanobacteria blooms in St. Albans Bay (Smeltzer et al. 2008).

Diffused Air Circulation in Little Lake St. Catherine, Wells

Little Lake St. Catherine is a 162-acre shallow waterbody located at the southern end of a three-lake chain formed through glacial scour. Little Lake is surrounded and underlain by poorly drained wetland soils. These soils drive the productivity and expectations for the lake and basin. Historical records indicate that Little Lake was impounded to an unknown height prior to 1784. Around 1900, a new impoundment was constructed that held seven feet of head, as evidenced by information contained in the Vermont Dam Inventory. The northern and southern littoral zones of the lake are presently fringed by wetland complexes (see Figure 4). Both zones are mapped Class 2 wetlands and likely produce a significant quantity of organic material that may migrate into the lake. Natural Resources Conservation Service maps indicate hydric wetland soils are present throughout the area surrounding Little Lake. Little Lake contains diverse aquatic habitat and serves as an important "fish nursery" for the entire three-lake system. Data from the Vermont Lakes Score Card assess Little Lake as "poor" for the presence of aquatic invasive species, "stressed" for shoreland habitat, and rates the watershed as "moderately disturbed." Little Lake does meet State water quality standards and the water quality trend is rated as "good" and is considered stable. Residents have expressed concern about increasing organic sediment accumulation and macrophyte growth within Little Lake.

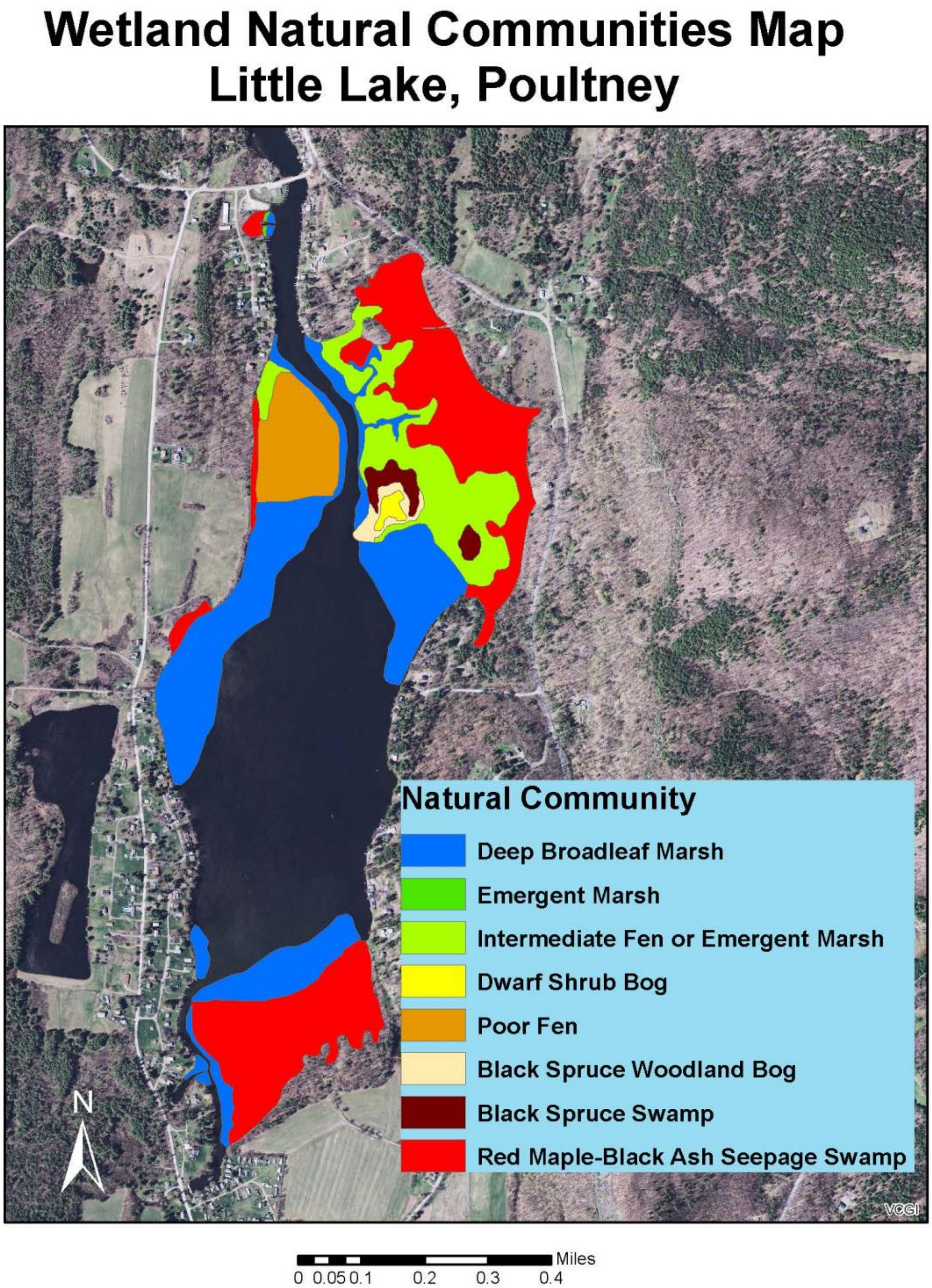

Figure 4. Wetland natural communities in Little Lake mapped by VT DEC

To address their concerns about increasing organic sediment accumulation, the Lake St. Catherine Conservation Fund (LSCCF) proposed to install a diffused air circulation (DAC) system throughout the lake. In 2011, a DAC system for the east side of the lake was authorized under a Lake Encroachment permit and later expanded and reauthorized in 2013. In 2015, the project was authorized to expand to the west side of the lake under another Lake Encroachment permit (Figure 5). The units in Little Lake were installed for the purpose of reducing organic sediment accumulation on the lakebed and approved under Lake Encroachment permitting as an environmental research project, which is a consideration of the public trust. This installation was viewed as a research project because there is a lack of evidence in the scientific literature that supports the use of aeration as a tool to reduce organic sediment accumulation.

Figure 5. Map showing DAC diffuser locations (labeled as Diffuser 1-11 on the east side and ws 1-15 on the west side), VT DEC monitoring locations (DEC Station 1 and 2), and LSCCF monitoring locations (DFWI Site 1-4, and NE, SE, SW, and NW).

Diffused air circulation systems create rising air bubbles from a perforated pipe or through engineered diffuser assemblies to induce water flow and circulation. The system in Little Lake is comprised of diffuser assemblies connected by airlines to an onshore compressor. The primary purpose of diffused bubbles is to move water upward so that it reaches the surface and interacts with the atmosphere, adding more oxygen to the water (Wagner 2015).

In 2017, the LSCCF expressed interest in expanding the current system to other locations in the lake. Some of the proposed locations for the additional aerators were located within Class 2 wetlands or wetland buffers. Class 2 wetlands, which have a 50-ft buffer, are protected under the Vermont Wetland Rules (VWR). Any activity that is not an allowed use designated in §6 of the VWR will require a State Wetland Permit. To approve a Wetland Permit application for impacts of aeration in Little Lake, the applicant would need to demonstrate that there are no undue adverse impacts to the wetland and its functions and values. State Wetland Ecologists noted that using aeration to physically alter a wetland by reducing its size and introducing oxygen to the system may be considered an adverse impact. Staff from the Division’s Wetlands Program also expressed concerns about potential adverse impacts on mapped rare, threatened and endangered plant species or their habitat in the area. The Wetlands Program recommends a strategy of avoidance and minimization of wetland impacts to meet the goal of "no net loss" of wetlands and their functions and values.

The VT DEC has continued to emphasize and support the use of watershed management around Little Lake and the greater Lake St. Catherine system to address water quality concerns. In 2016, the VT DEC worked with a variety of state and local partners including the Towns of Wells and Poultney, The Lake St. Catherine Conservation Fund, The Lake St. Catherine Association, the Poultney-Mettowee Natural Resources Conservation District (PMNRCD), the Rutland Regional Planning Commission, and the South Lake Basin Coordinator to form an implementation team to explore and implement watershed management solutions. The group met several times throughout 2016 and 2017. The PMNRCD has received State of Vermont Ecosystem Restoration Program funding to assess the Lake St. Catherine watershed and identify implementation projects to improve water quality by reducing nutrient and sediment inputs. The PMNRCD wrapped up collecting field data in 2018 and is currently working on developing priority projects to address water quality issues in the Lake St. Catherine and Little Lake watersheds.

Little Lake St. Catherine Data

The authorization of the operation of the entire DAC installation expired at the end of the 2018 season. Any reauthorization and expansion of the project must be reviewed and reauthorized under Lake Encroachment permitting. Data concerning water quality, aquatic plants, and descriptions of the physical characteristics of Little Lake have been collected for decades by the VT DEC, volunteers, and other observers. Additionally, monitoring of the DAC project in Little Lake has been conducted by the Lake St. Catherine Conservation Fund (LSCCF) and by the VT DEC. The data allow for a review of the conditions prior to the circulation project and can provide some insight into any impacts of the installation.

Dissolved Oxygen

LSCCF provided dissolved oxygen data for 2012, 2013 (on 7/21), and in 2015. The site locations and sample depths for the 2012 and 2013 data were not provided, so this data cannot be used for analysis. The 2015 data is complete. The 2015 data indicate that no anoxia was present at any depth (Figure 6). In general, concern about anoxic conditions begin when the dissolved oxygen saturation is close to 0%; all Little Lake measurements are above 40%.

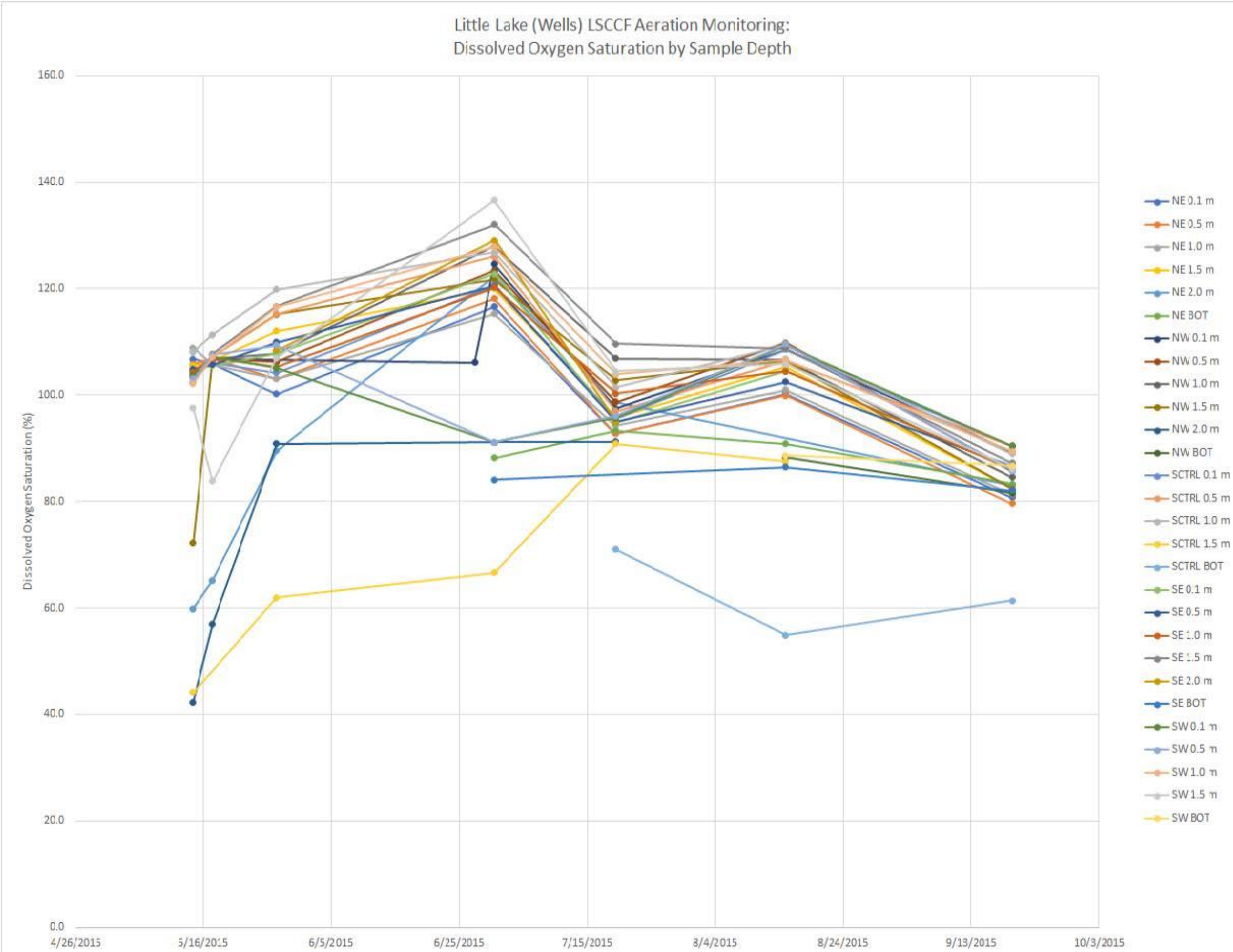

Figure 6. 2015 dissolved oxygen saturation by sample depth (sampled by LSCCF)

Phosphorus and Nitrogen

LSCCF collected and reported data for total phosphorus (TP), dissolved phosphorus (DP), and Total Nitrogen (TN) in 2013. Only TP data were provided for 2014, 2015, and late 2017 (September and October). The DEC's Lay Monitoring Program has collected summer TP data at DEC Station 1 annually since 2009. DEC also collected spring TP and TN data at DEC Station 1 in 2009, 2012, 2016, and 2017. All the data show high variability, but Lay Monitoring TP data were consistently lower than LSCCF TP data collected from 2013 through 2015 (Figure 7). DEC's summer Lay Monitoring TP data analyses do not indicate an increasing phosphorus trend (Figure 8). Overall phosphorus concentration trends analyzed from both DEC's summer Lay Monitoring data and Spring Phosphorus Monitoring data are considered to be stable and meeting water quality standards.

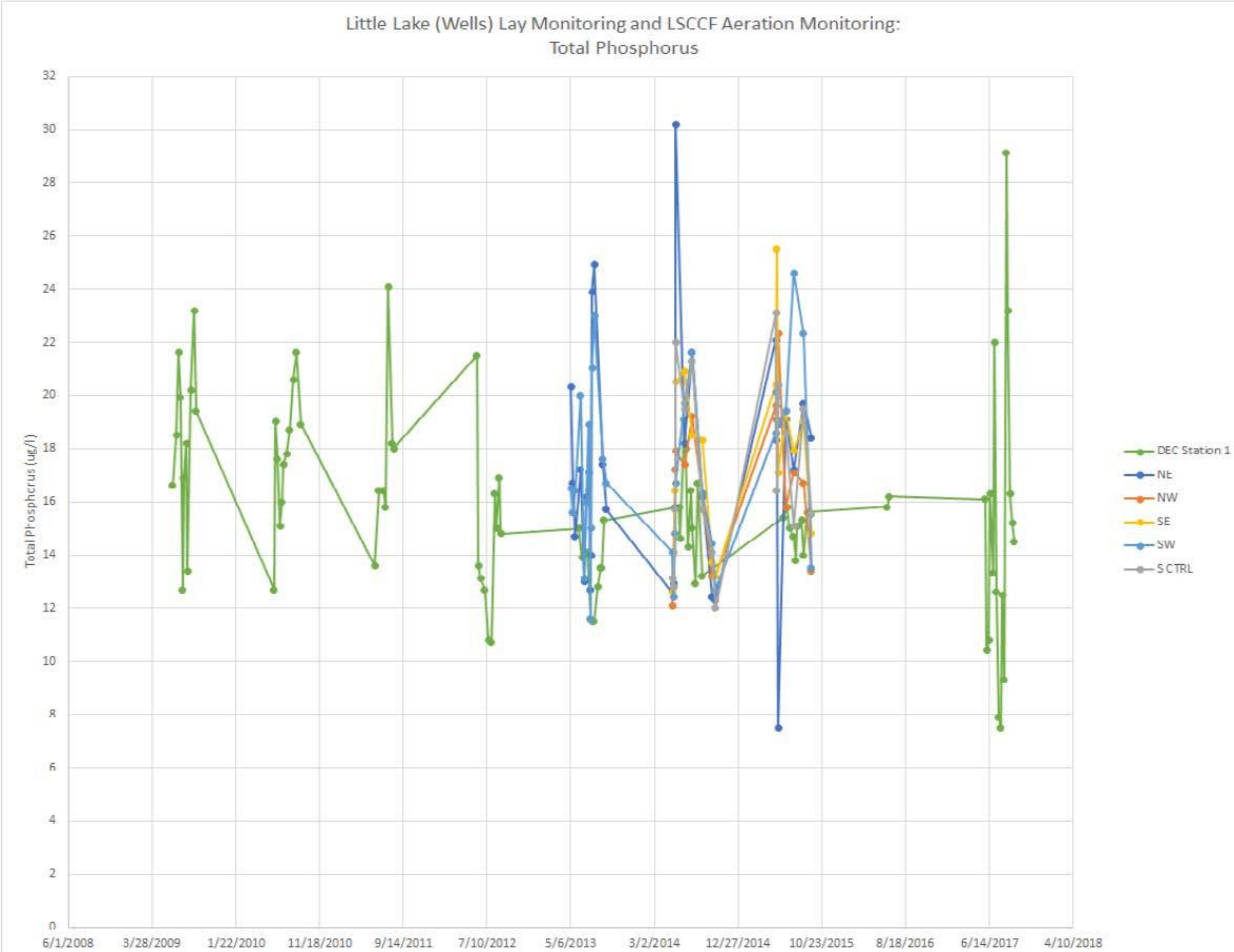

Figure 7. Total phosphorus collected by LSCCF at 5 stations and by DEC at DEC Station 1

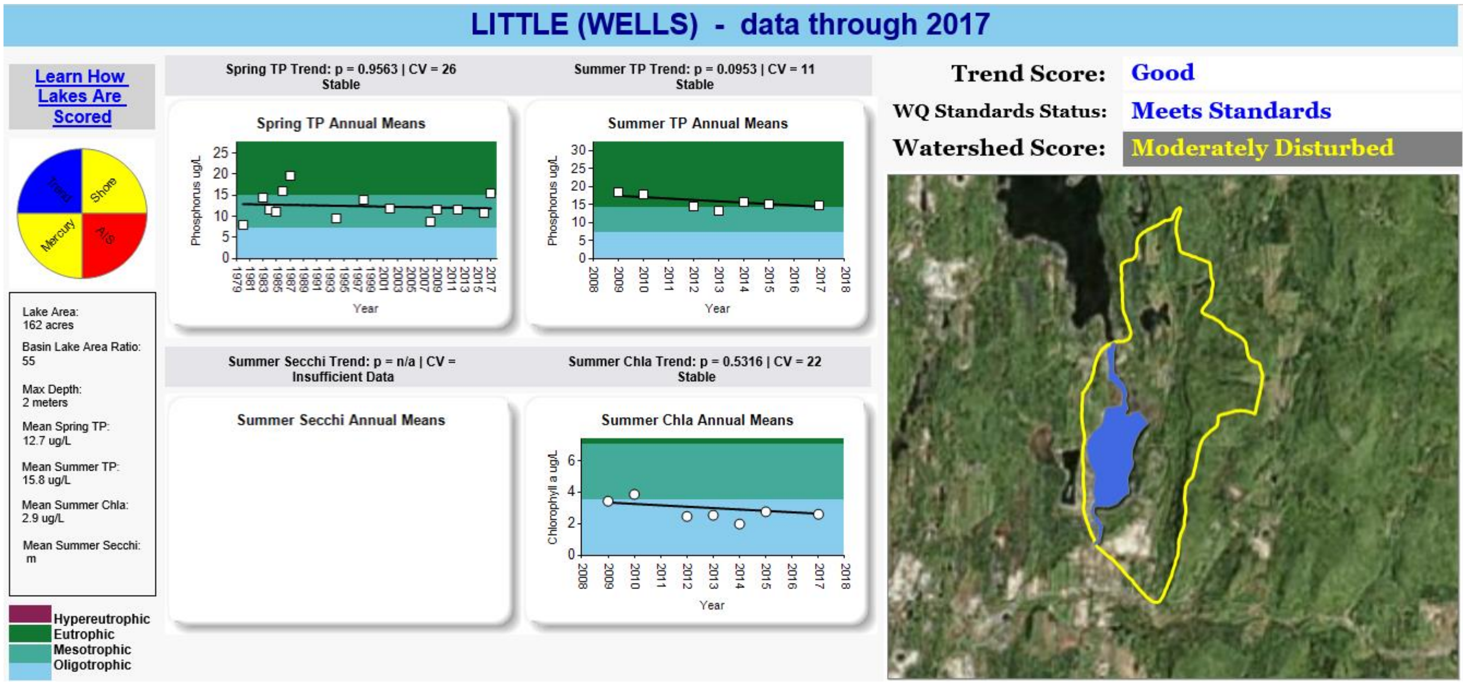

Figure 8. Little Lake Score Card Trends and Status Report

Chlorophyll-a

LSCCF collected chlorophyll-a data in 2013 and late 2017 (Sep/Oct). The Lay Monitoring Program has collected summer chlorophyll-a data at DEC Station 1 annually since 2009. All data show some variability with no apparent increasing trends, but Lay Monitoring data were less variable than LSCCF data in 2013 (Figure 9).

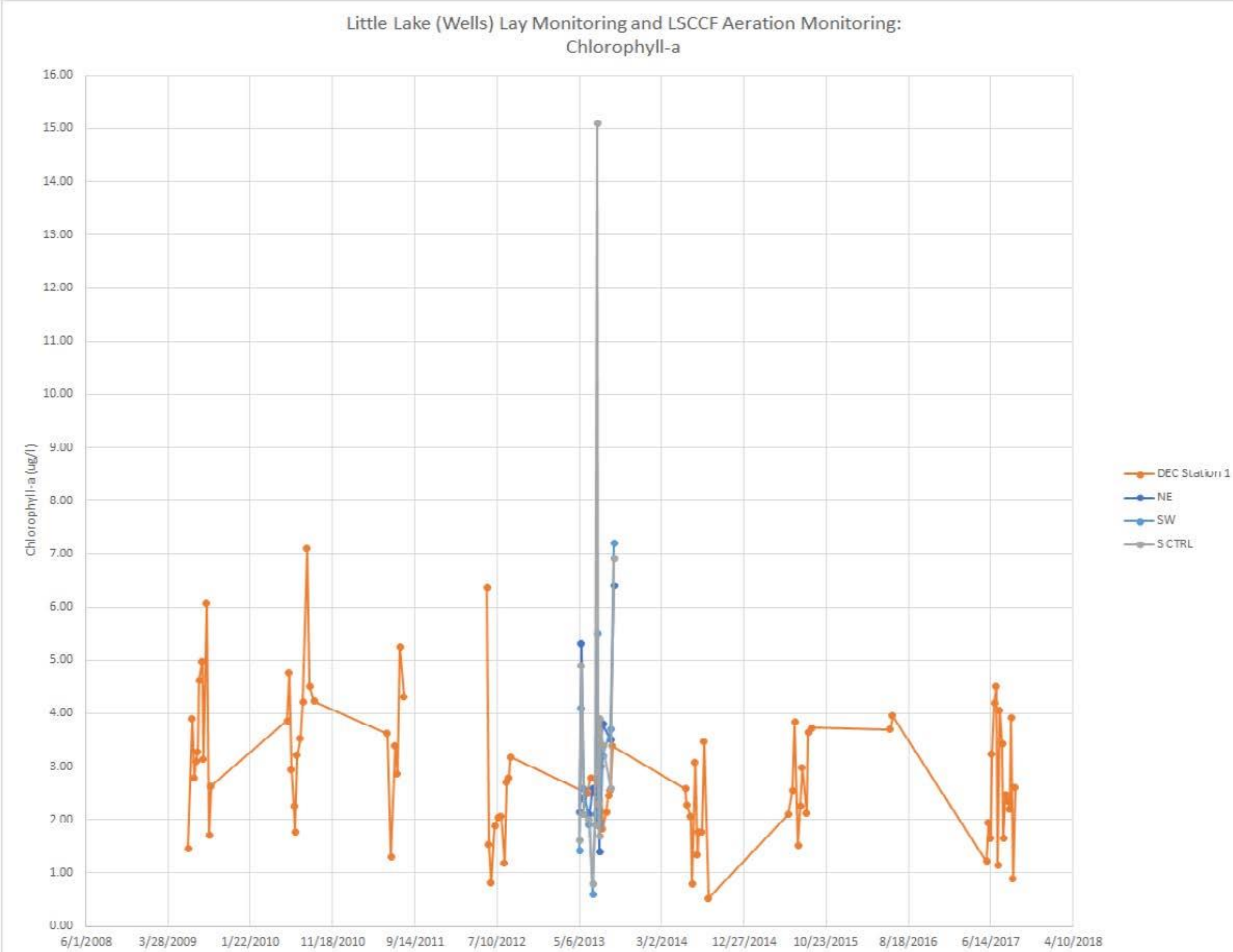

Figure 9. Chlorophyll-a monitoring data from LSCCF and VT DEC

Depth

Depth data was collected by LSCCF and the DEC; depth data varied greatly between the two groups. LSCCF provided depth data for 2012-2017 measured adjacent to diffusers as well as at four nearby water quality sites and two control sites. The LSCCF measured depth by pressing a pole attached to a square board down into the flocculant sediment (all data are calibrated to dam benchmark water level). This methodology is described in the 2011 Lake Encroachment Permit Application:

> *Depth measurements will be taken, once pre-implementation and once each month thereafter, at 12 locations evenly spaced around the lake using a surveyor's transit from an on-shore benchmark location. We will use 2 soft bottom-locating techniques. First: A 12" square board attached to a metal pole (marked off in a scale of inches and feet) will be lowered until it rests, with its own weight, on the soft bottom. A reading will be recorded both via the surveyor's transit and the length of submerged pole. Second: A 12" square board attached to a metal pole (marked off in a scale of inches and feet) will be lowered until it can be seen to just be touching the soft bottom sediment. Additional readings will be recorded.*

Depth data collected by LSCCF using the using the pole and board method indicate overall depth increases (decreases in organic sediment accumulation) varying from 1.4 to 5.0 feet adjacent to diffusers and depth increases ranging from 3.1 to 4.8 feet at nearby water quality monitoring sites. Depths at the north and south control sites remained unchanged at about 5 feet. Depth data on east side diffusers that comprised the initial installation in 2012 show minimal changes in 2017 (Figure 10).

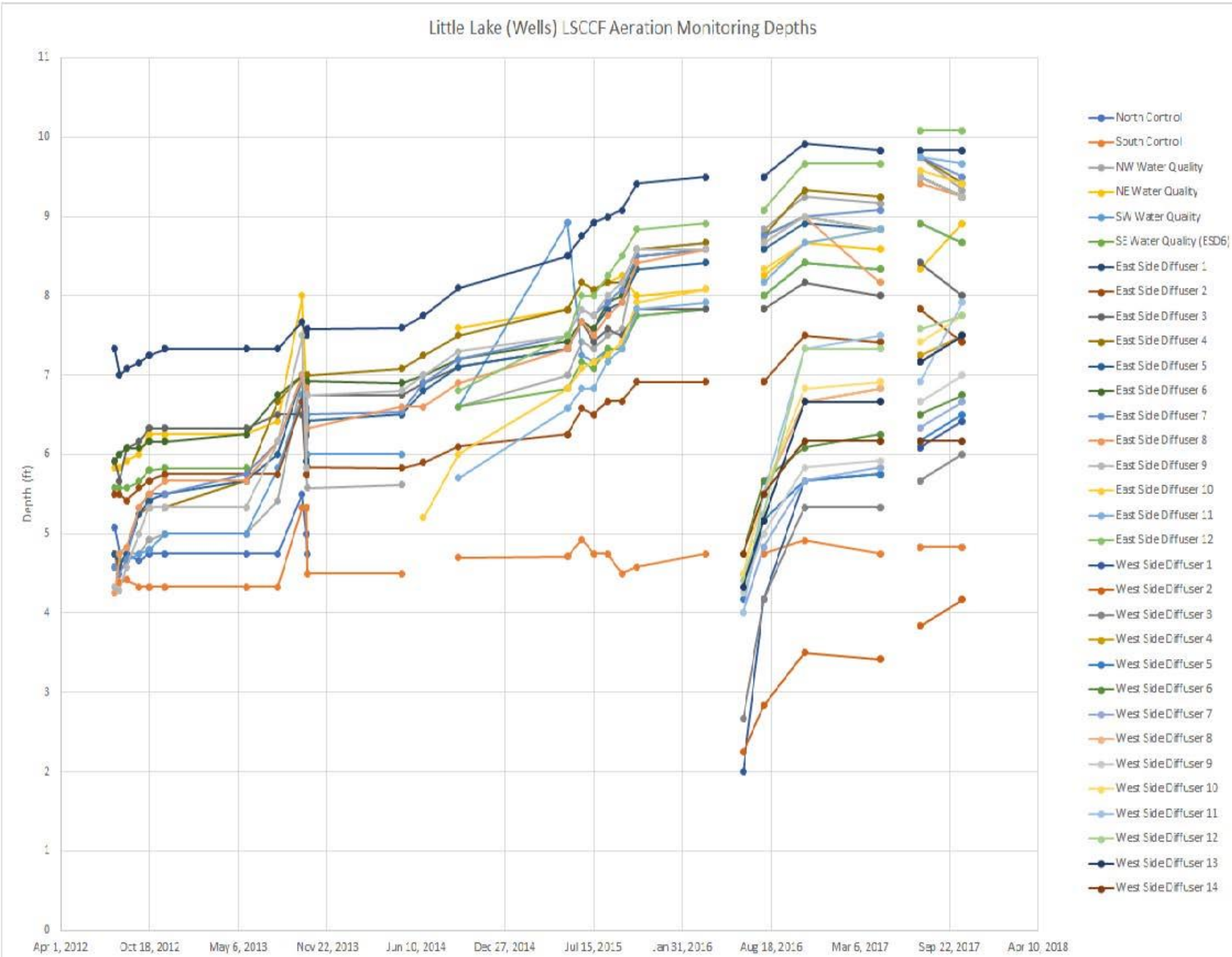

Figure 10. Depth data recorded by LSCCF using the pole and bucket board method

The Vermont Lakes Lay Monitoring Program collects Secchi depth data throughout the summer, which is equal to lake depth in Little Lake. Because of the water clarity conditions, the Secchi depth reading is taken from the lake bed. Secchi depth has been collected at DEC Station 1 intermittently since 1966 and from DEC Station 2 since 2009 (Figure 11). LSCCF also recorded Secchi depth data in 2015. Secchi depth readings have not increased over time (Figure 12). Measurements collected using a Secchi disk provide an alternate and potentially consistent long-term look at lake depth based on measurements of the disc to the lake surface-water interface. However, Secchi depth readings are not calibrated to dam height, so annual fluctuations in precipitation may impact Secchi depth readings.

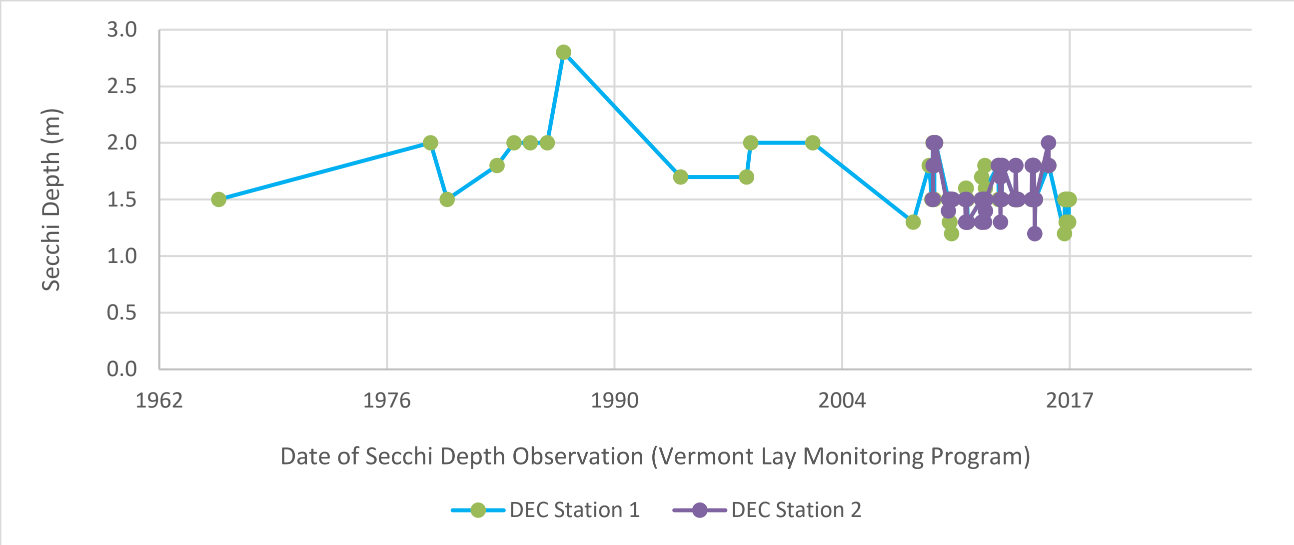

Figure 11. Secchi depth measurements collected by VT DEC Lay Monitoring Program

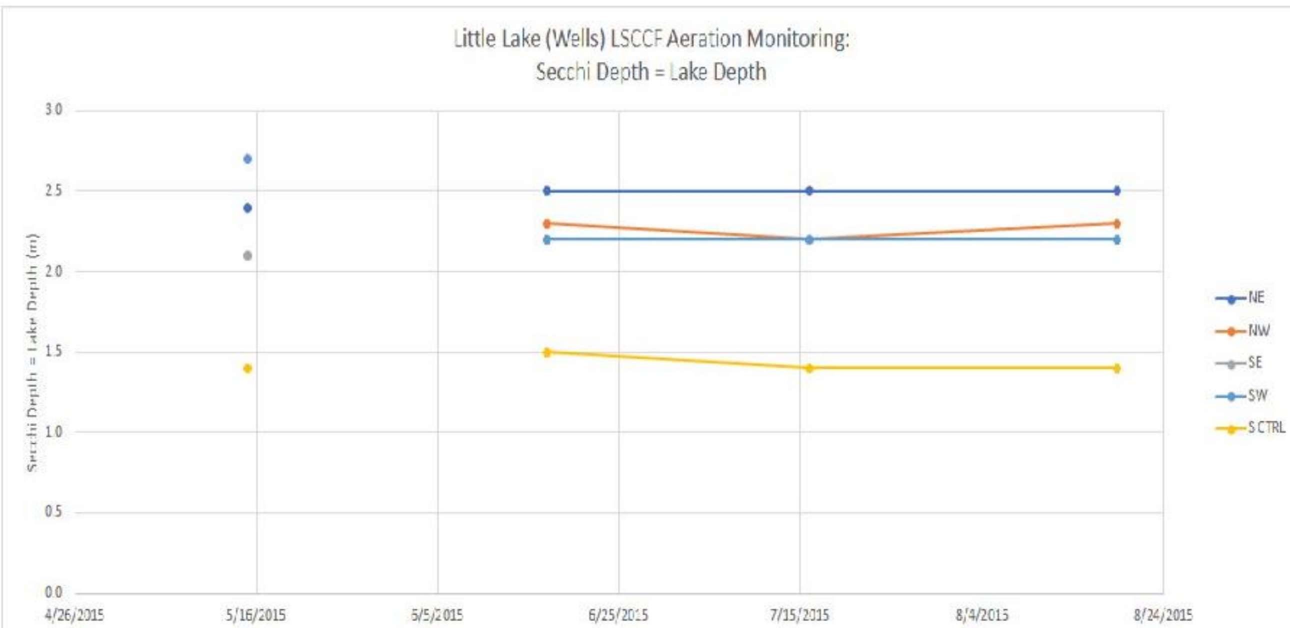

Figure 12. Secchi depth measurements provided by LSCCF

In 2017, the VT DEC recommended that LSCCF add sampling sites along transects between three diffusers and extending toward mid-lake to monitor the extent of the diffuser's potential impact on lake depths. Depth data collected by LSCCF between June and October show increases in depth at each transect site varying from 0.5 to 0.7 feet, but overall depths were shallower (from 1.0 to 2.4 feet) moving away from the diffusers and did not increase from summer to fall (Figure 13). These depth measurements were taken by the LSCCF using the pole and board method. During a sampling visit in summer 2017, DEC recommended LSCCF adopt the use of a sludge sampler ("Sludge Judge") they were testing to compare depth measurements between this measurement tool and the board and pole method. The sludge sampler may more accurately show the depth of settled solids. However, LSCCF provided no 2017 data using this method.

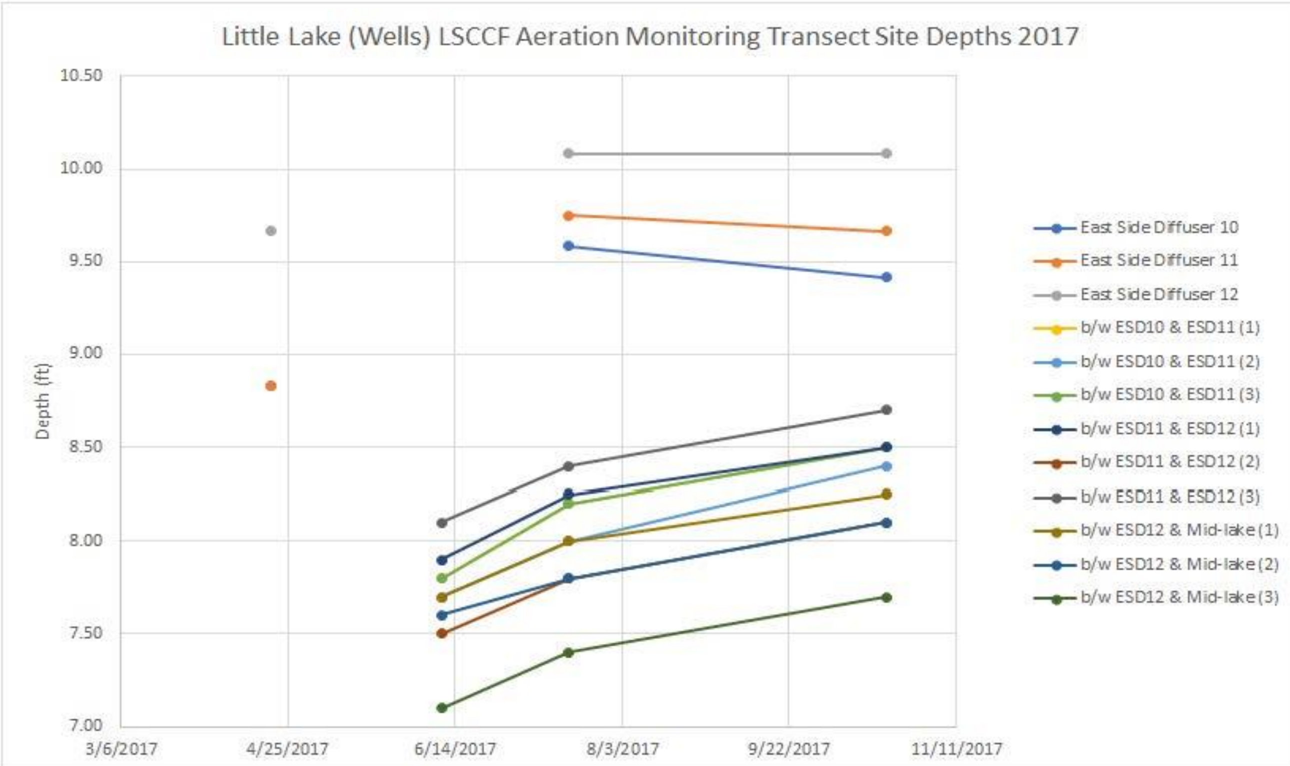

Figure 13. Depths measured by LSCCF along transects using the pole and board method

Depth Trends

Historical lake depth measurements have been recorded at Little Lake on several occasions by different organizations. A 1967 biological survey by Carl F. Baren of the Vermont Water Resources Board concluded that Little Lake had an average depth of 5 feet, as the average Secchi depth readings were 4 feet and 11 inches. Plant cover at the time of the survey was 70%. The Lake St. Catherine Association reports that a “Natural Resources Planning Study of Wells, VT” (Raymond Lobdell, 1975), indicated that Little Lake is a shallow lake of about 181 acres, with an average depth of two feet, a maximum depth of only four feet. That document indicates that the “lake bottom is covered by a thick layer of silt and organic matter." Bathymetric surveys were completed in 2001 by ReMetrix (Figure 14) and 2008 by the VT DEC, prior to the installation of the DAC system. A ReMetrix survey catalogued water depth to sediment at 43 locations, with depths ranging from just under 1 meter in areas nearest to shore, to between 1.4 and 2.1 meters (4.6 and 6.9 ft) in open water locations. In 2007, LSCCF members conducted a depth survey along single centrally located N-S and E-W transects, with results comparable to those produced by ReMetrix Inc. In 2008, the VT DEC conducted a survey of lake depths using GIS methods, also revealing depth measurements of between 1 and 1.8 meters (3.2 and 5.9 ft).

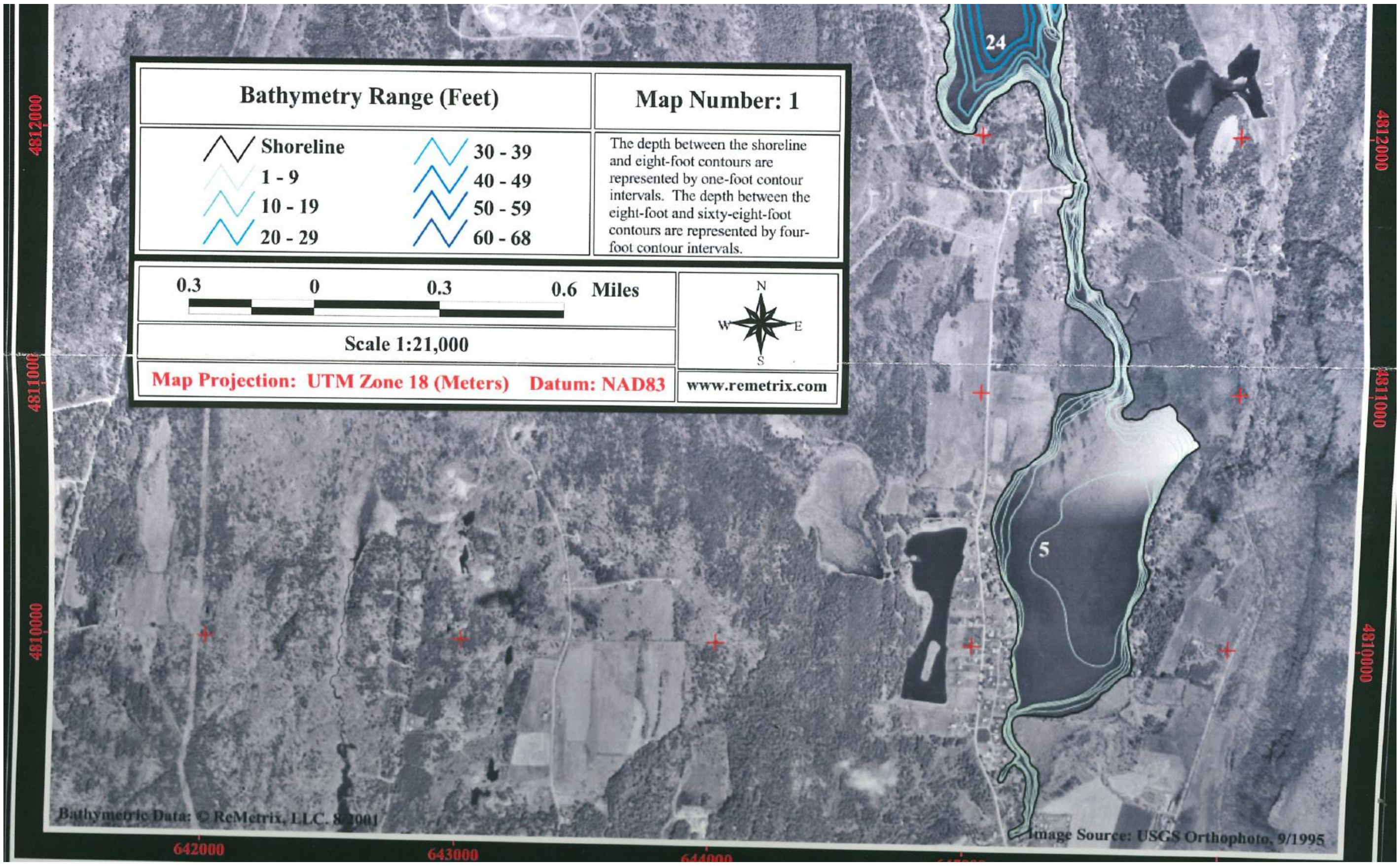

Figure 14. Little Lake Bathymetric Survey by Remetrix in 2001

In 2016, the VT DEC conducted a point-intercept plant and depth survey following the Wisconsin Department of Natural Resources' "rake-toss" methodology as described in Hauxwell et al. 2010. Maximum depths observed in this grid survey completed by the DEC were 5.5 feet (Figure 15). In 2018, the DEC measured lake depth again, using a BioBase sonar to measure depth to bottom (Figure 16). Figure 17 shows a zoomed in version of the BioBase sonar depth map, with the location of the diffusers. No discernable increase in overall lake depth has been observed in Little Lake between 2001 and 2018.

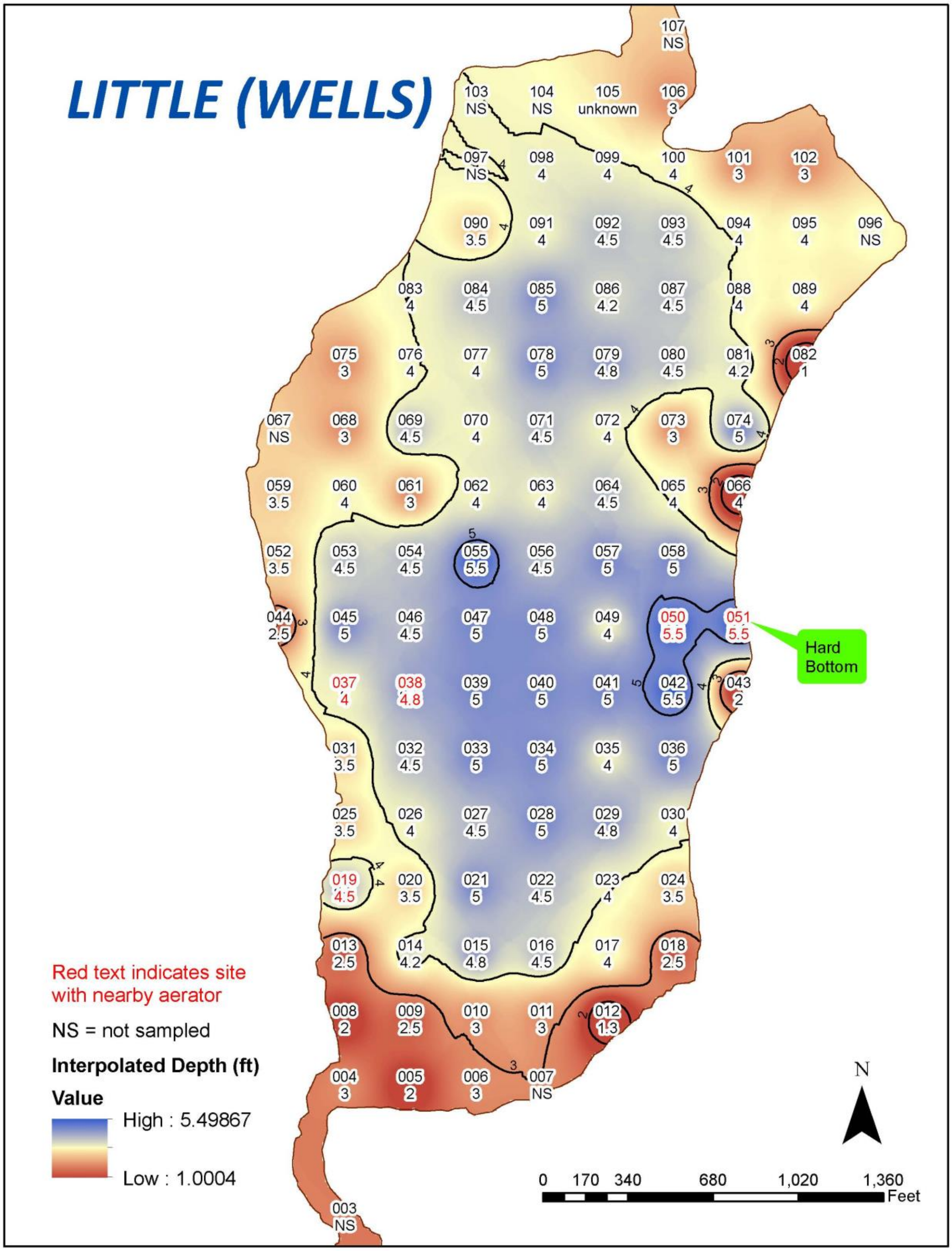

Figure 15. Depth map created by VT DEC using the WI DNR rake method (2016)

Little Lake - Wells, VT

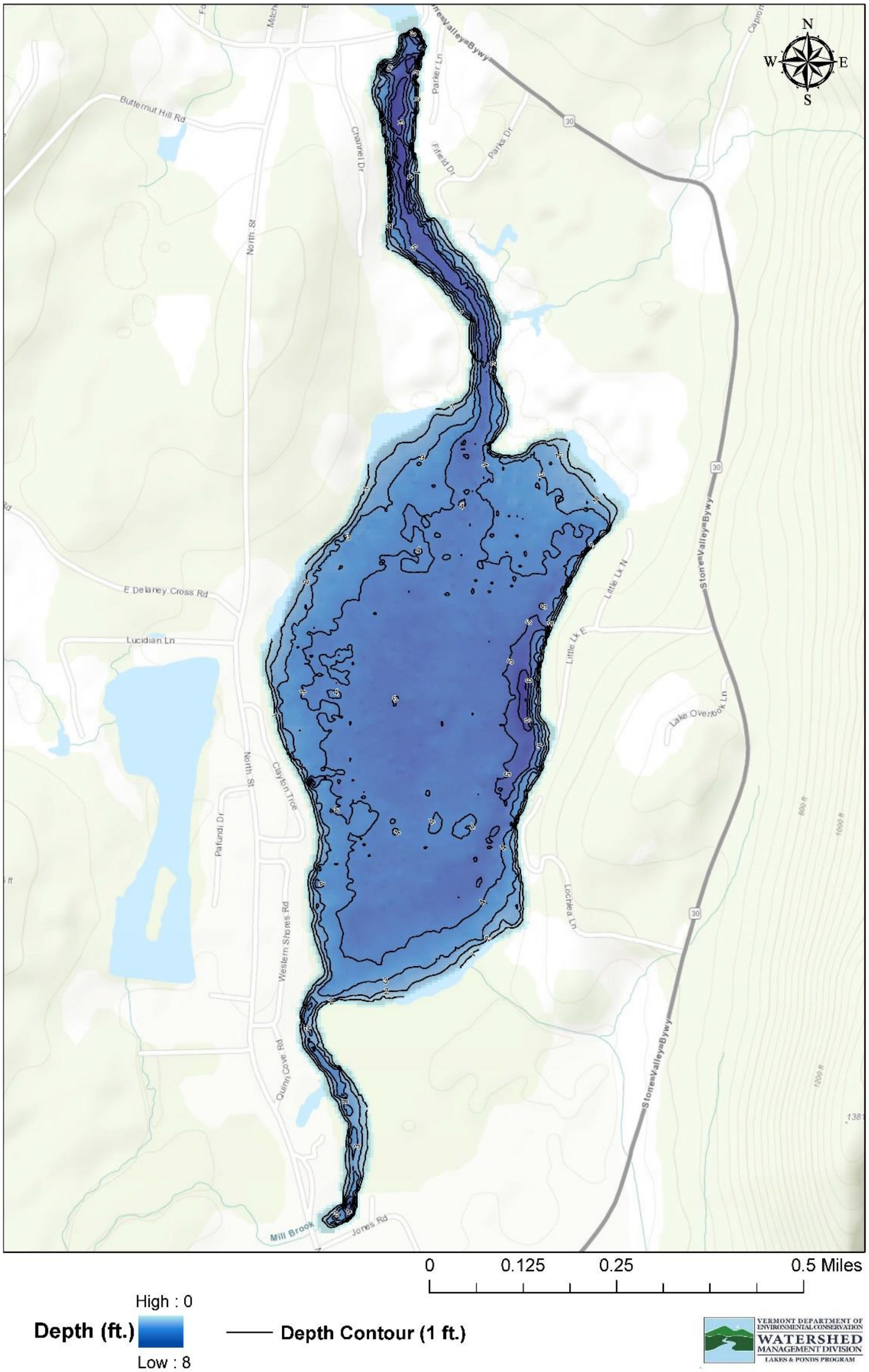

Figure 16. Little Lake Depth Map generated from BioBase mapping conducted by the VT DEC

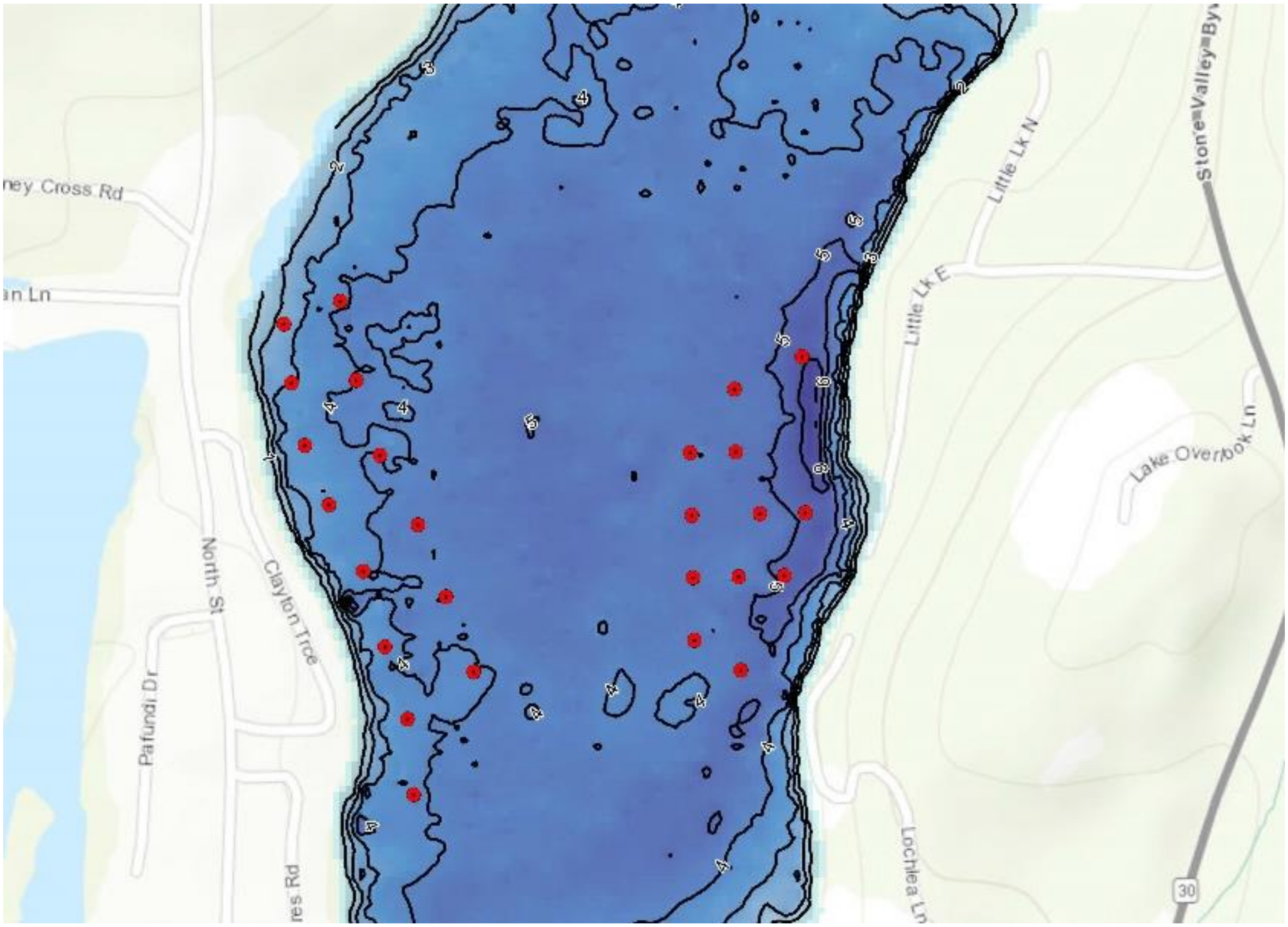

Figure 17. Little Lake Depth Map (zoomed in) showing location of diffusers generated from BioBase mapping conducted by the VT DEC

From the depth surveys conducted pre and post aeration installation by the VT DEC and others, there is no evidence to support that the use of the DAC system has altered the depth of Little Lake St. Catherine. Depths throughout Little Lake St. Catherine have remained relatively constant throughout the time depth sampling has occurred.

From historical characterizations and more recent data, it is evident that Little Lake has maintained the features of a shallow lake with a flocculant lakebed that supports dense plant cover. Representatives from the LSCCF have expressed considerable concern to the VT DEC regarding water depth, sediment thickness, and a worry that the lake is experiencing rapid lake shallowing. The available information does not suggest significant shallowing over time. The deepest locations observed in all surveys range from 5 to 6 feet of depth. Annual fluctuations in depth and plant cover are likely connected to overall lake level as influenced by precipitation trends.

The LSCCF data shows significant depth increases in close proximity to the aeration diffusers. However, these depth changes were not observed from the bathymetric surveys conducted by theVT DEC. The fluid dynamics of organic sediments are poorly understood and small localized changes in depth are difficult to interpret. It is possible that the diffusers transport organic sediment away from their area of influence. Measuring depth using the sludge sampler will increase consistency and accuracy of data collection. The VT DEC recommends that the LSCCF use a standardized monitoring protocol for water quality data and for depth measuring so that the data may be better used for data assessment. Additionally, continuing to measure depths along a transect away from the diffuser will better characterize the effects of aeration.

Lake and Watershed Management

None of the data show anoxic conditions within Little Lake prior to nor after the installation of the DAC system, meaning that the addition of oxygen may not be altering the natural condition of the waterbody. If the natural water chemistry and depth conditions of the waterbody have remained relatively stable while the DAC system has been in operation, any potential benefits from the operation of the system are not well expressed, predictable, or repeatable. However, continuing to work with local partners to implement watershed practices that address sedimentation may provide the clearest and most predictable path forward for addressing sedimentation concerns in Little Lake. Shoreline development, runoff from roads, and increased development pressure elsewhere in the watershed all contribute to sedimentation in Little Lake.

Aquatic invasive species and dense aquatic plant growth is an important issue affecting Little Lake and methods other than aeration may be more effective at addressing this issue. The aquatic plant harvesting program on Little Lake to maintain travel lanes is a feasible alternative to aeration that provides tangible benefits through recreational access.

Prior to the construction of the dam, Little Lake was likely a wetland and many parts of the lake are currently mapped as protected Class II wetlands. Lakes and wetlands are dynamic systems and clear boundaries do not always exist between them. Wetlands provide many ecosystem services for water quality, flood prevention, and habitat. Understanding the natural characteristics of Little Lake can help provide realistic expectations of what kind of features the lake can support.

Exploring the Use of Aeration in Lake Carmi, Franklin

Lake Carmi has long suffered the effects of eutrophication due to nutrient inputs from the surrounding watershed. In response, a total maximum daily load (TMDL) “pollution diet” was created for Lake Carmi to direct lake restoration activities. Cyanobacteria blooms are not unusual for Lake Carmi, however, the intensity and longevity of blooms in 2017 brought all lake recreation to a halt.

Currently, watershed work is underway to address nutrient inputs from multiple sources into Lake Carmi, however internal loading of nutrients is contributing to and amplifying the impacts from eutrophication. In 2017, heavy rains brought nutrients into the waterbody while typical summer stratification led to a lack of mixing in the hypolimnion and depletion of oxygen from biological activity. Under these anoxic conditions, legacy phosphorus was released from sediments along the lake bottom and built up in the hypolimnion. Weather conditions created early destratification of Lake Carmi causing prolonged cyanobacteria blooms throughout the lake.

The VT DEC typically prioritizes watershed management to address nutrient inputs. In-lake management options to reduce internal loading are costly and considered only when watershed-based efforts to reduce external loading have made sufficient progress. Otherwise, in-lake controls may be overwhelmed by continued watershed loading. The potential human health risks associated with cyanobacteria blooms have made reducing their occurrence a priority. In collaboration with members of the Lake Carmi TMDL Implementation Team, the VT DEC plans installation of an aeration system to address internal loading on a short-term basis with the goal of providing more immediate relief for the lake community by reducing the frequency and severity of cyanobacteria blooms, while the greater community accelerates work within the watershed and shoreline to meet long term water quality goals. When an aeration system is selected, it will require authorization under a Lake Encroachment permit to determine impacts to the public good and the public trust.

Summary and Recommendations for Future Aeration Use in Vermont

Aeration as an in-lake management tool has the potential to improve water quality, but it is important that it be applied correctly to meet clearly articulated water quality management goals and that the systems are designed appropriately in the context of the physical characteristics of a specific waterbody and its watershed. Aeration installations that cannot meet these criteria are likely to be unsuccessful and may potentially cause additional harm to water quality or the lake environment.

The two authorized SolarBee circulation installations in Vermont were unsuccessful at demonstrating an improvement to water quality. As such, a recent request to continue SolarBee usage in Tinmouth Pond was denied, and the VT DEC has encouraged the applicants to focus on watershed management and shoreline best management practices to address water quality.

Looking Forward: Permitting Future Aeration Projects

The DEC is charged with ensuring that projects authorized through permitting are not causing adverse impacts to surface waters and support the natural biological communities of lakes. Appropriate lake management tools should:

1. Have a known and understood mechanism of control
2. Be documented as low risk to natural ecosystem functions
3. Be of widespread value to meet management goals
4. Be predictable and repeatable in efficacy and outcome
5. Compatible with other water uses
6. Incorporate additional watershed management projects
7. Will not adversely affect the public good

The VT DEC approaches the application of in-lake treatments with caution and on a case-by-case basis. The use of in-lake treatments is typically not consistent with the Surface Water Management Strategy and with the watershed management strategies promoted by the VT DEC and supported through the Tactical Basin Planning process. However, there may be extenuating circumstances in which aeration may be used to support active watershed restoration.

The permit history of allowing limited aeration in waterbodies in Vermont does not guarantee that future projects will be permitted, as each request for an in-lake treatment must be reviewed in the context of the specific characteristics of a waterbody and its watershed. To assist with determining whether an in-lake treatment can be permitted, an applicant for any future in-lake treatments should include the following information:

- A minimum of three years of pre-aeration water quality data (Lay Monitoring data is acceptable)

- Clear identification of a problem
- Clear, concise short and long-term goals, water quality targets, and expectations achieved by an in-lake treatment
- A demonstration, supported by scientific literature, that the proposed in-lake treatment is appropriate to address the identified problem
- A demonstration that the in-lake treatment will not adversely affect the public good
- A reasonable expectation that the treatment will not adversely affect natural lake functions
- Demonstration that the applicant is actively working toward implementation of watershed management actions to address the water quality concerns

Any potential future in-lake treatments will be reviewed in the context of the above list to ensure that the future project aligns with the Surface Water Management Strategy. Reauthorizing the use of aeration within a waterbody will also be reviewed under the same guidelines. In-lake aeration projects that have been authorized will require the applicant to develop a water quality monitoring plan to be approved by the VT DEC. The water quality monitoring plan shall include monitoring protocols, and clear water quality benchmarks to track success and any potential adverse impacts. If an in-lake treatment is authorized under an experimental or scientifically supported use, water quality trends must improve or be stable over an identified period, or the project may be terminated.

Climate change is widely accepted to have significant impacts on aquatic ecosystems. Temperature increases and an increase in frequency of intense storms will likely impact internal nutrient loading and external nutrient loads. It is expected that climate change will increase internal loading in lakes and ponds and it is likely that cyanobacteria benefit, as they are adapted to warm, turbid conditions (Bormans et al. 2015). If Vermont sees an increase in the effects of eutrophication in its waterbodies, it is likely that there will be an increased interest in pursuing in-lake management techniques, like aeration, to address these undesirable effects.

The use of aeration as an in-lake management tool has a potential role in lake management, provided a clear definition of the problem has been made and the use of aeration is a scientifically proven method for addressing the problem. Elements of watershed management must be incorporated as a part of the project, in accordance with the VT DEC's Surface Water Management Strategy and to address long-term restoration goals.

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