Orleans Pond Coalition

ORLEANS POND COALITION'S DEMONSTRATION OF NANOBUBBLE OXYGENATION SYSTEM IN SARAH'S POND, A 5.8-ACRE POND IN ORLEANS, MA

REPORT ON SEASON ONE: OCTOBER 2019

Suzanne Moore
President, OPC

ACKNOWLEDGEMENTS

The Orleans Pond Coalition wishes to thank all those who have supported this project from the outset and made this demonstration a reality. It would not have been possible without the financial support of our members and the generous grant from the Fred J. Brotherton Charitable Foundation. We appreciate the cooperation and commitment that the Sarah's Pond community, with a special shout-out to the Losordo family who live with the project every day. We are grateful to Judith Bruce and our other volunteers who are out on the pond, monitoring water quality and documenting the process. This acknowledgement would be incomplete without mention of our scientific advisor, Dr. Kenneth Wagner, who has been most generous with his professional advice and whose guidance and insights have been of inestimable value to the project. We also need to thank Jim McCauley, former President of OPC, and Dr. Mayur Dev, of Gaia, USA, who brought this technology to our attention in 2017.

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EXECUTIVE SUMMARY:

Last November, the Orleans Conservation Commission approved OPC's proposal to pilot an innovative oxygenation solution at Sarah's Pond in South Orleans. OPC recognized that our freshwater ponds are increasingly at risk as excessive levels of nutrients create poor oxygen conditions that cripple ponds and cause more frequent algae blooms, some of which may be toxic. OPC wanted to encourage Orleans and other Cape Cod towns to consider new, non-traditional solutions to address these and other threats to the health of our ponds.

A year later, we're completing the first season of our planned two-year pilot at Sarah's Pond. After selecting a project site, OPC's next move was to engage Dr. Ken Wagner as its project development consultant. Dr. Wagner is often described as the leading authority on freshwater ponds in New England. With Dr. Wagner's support and guidance, OPC developed specifications and then contracted with SOLitude Lake Management to install the LB2000 aeration platform manufactured by Homeport. The LB2000 has a small footprint (37"X37"X31") and processes 9,000 gallons of water per hour to deliver 19 kilograms of oxygen per day. Dr. Wagner determined that up to 12 kilograms per day were needed in the deepest part of the water column. The LB2000 contains proprietary technology from Gaia USA to extract oxygen from the atmosphere, concentrated into nanobubbles too small to be seen with the naked eye. These tiny bubbles remain in suspension far longer than oxygen dispensed from traditional aeration systems that quickly rises to the surface. This improves transfer efficiency for oxygen into the water where needed.

The entire system, including equipment purchase, installation, and a 2-year support contract cost $28,000, entirely funded by OPC, with support from OPC's members and a generous $10,000 grant from the Fred J. Brotherton Charitable Foundation. Additional consulting, unit housing and 5 months operating expenses brought the total cost of the project to an estimated $45,000.

As Orleans has learned from other pilot projects in town, any new technology can experience hiccups and glitches. The Sarah's Pond project was a learning experience for OPC and everyone involved.

At this point, the results are mixed. However, we believe that the problems with the installation and initial operation of the oxygenation system are issues of implementation of an experimental system, not theoretical problems about using oxygenation to improve water quality. We expect to do better in 2020 with an earlier start of a functioning oxygenation system.

- Our original plan called for the pilot to begin by May 1st before rising temperatures in the pond began to increase the overall demand for oxygen. Unfortunately, there were several installation "challenges," and it wasn't until July 31st that the system was stabilized and operating smoothly. As a result, the critical early part of the season was lost. OPC plans to continue the pilot for a second, perhaps a third year.

- Despite its relatively recent development and lack of operational experience in New England, the nanobubble oxygenation system easily obtained from the Orleans Conservation Commission the same basic level of operating permit as any other aeration technology. This low regulatory hurdle is a plus for future projects.

- When in optimal operational mode, the LB2000 unit is relatively quiet; the unit is housed in a small shed to lower the noise level even more. There is some combining of nanobubbles into larger bubbles on route to the pond but the small amount of gas-off bubbling is barely noticeable on the surface.

- The pond's birds and other wildlife quickly adjusted to the presence and sounds of the system; there has been no indication of any harm to flora or fauna from its operation.

- In designing next year's monitoring protocols, it is recommended that at least two ponds with comparable bathymetry and environment be selected for monitoring and comparison to water quality data from Sarah's Pond, rather than using the western basin as a control.

- An additional consideration for the monitoring program might be to increase the number of monitoring stations around the 10-12 foot water depth contour to check for DO in other parts of the pond.

- The limits of the LB2000 unit's 3 HP pump require careful consideration of demands placed on it by the unit's location, in terms of proximity to and elevation above the water. Length and weight of hose required to reach pond's oxygenation target area are also important load factors. The unit had to be relocated to a lower site, closer to the water's edge, to reduce strain on the pump.

- Operational costs are higher than expected from the LB2000 specification literature that erroneously computed the monthly electrical costs at $31.

- The project team has monitored Sarah's Pond throughout the project season, carefully recording the dissolved oxygen and temperature levels at half meter increments every week from April until mid-October. The team has also recorded concentrations of algae and, with Dr. Wagner's assistance, analyzed what forms and amounts of algae were present in Sarah's Pond. While the three-month installation delay renders this season's operational results inconclusive, these data will provide an important baseline for comparison with next and subsequent years' results.

- Sarah's Pond did contain elevated concentrations of cyanobacteria and other algae that suggest ongoing water quality issues. OPC has closely followed the reports of algae blooms and pond closings from other towns on Cape Cod, and many ponds had similar or greater algae presence than Sarah's Pond, but the oxygenation system did not provide the intended relief in 2019.

The Orleans Pond Coalition continues to believe this technology is "too promising to ignore." We're optimistic the system will operate smoothly next year and Sarah's Pond will benefit from higher oxygen levels throughout the summer. We expect the LB2000 will effectively deliver oxygen to the deepest level of the pond, and that the supplemental oxygen will prevent the release of phosphorus and other nutrients from the pond sediment, countering and reducing the pond's overall demand for oxygen.

INTRODUCTION:

WHY IS OPC DOING A DEMONSTRATION PROJECT? The problem, as we see it, is that most lakes and ponds on the Cape are impaired and there are limited options for remediation. Choices are often constrained by costs, limited efficacy, and high regulatory approval thresholds. The vast majority of fresh and marine water bodies will never qualify for any kind of public funding. ***OPC wants to learn if it is possible to introduce a new technology that could be effective and affordable, a potential option for a wide variety of private and public lakes and ponds, both freshwater and marine.***

IMPORTANCE OF DISSOLVED OXYGEN IN LAKES & PONDS: Dissolved oxygen is one of the most important elements dictating the water quality of lakes and ponds. A pond or lake is considered impaired when its dissolved oxygen levels fall below 5 parts per million. Below that level, many forms of aquatic life suffer. If the oxygen level drops below 2 parts per million, most fish cannot survive; reactions in the sediment can release contaminants back into the water column. Released phosphorus can support blooms of toxic algal forms such as cyanobacteria, presenting significant health issues to humans and wildlife.

Oxygen depletion can occur when a pond becomes overly enriched with nutrients that stimulate excessive plant and algae growth. The breakdown of this biomass can push the oxygen demand beyond what the pond can provide, resulting in anoxic conditions that cannot support life. Nutrients can come from external sources such as the nitrate and phosphate contaminants from road runoff and septic systems. However, the major

source of excessive nutrients is often internal, built up over years in the pond sediment. If enough dissolved oxygen is present, it can keep phosphorus combined with iron, a common element in Cape Cod sediment, to form ferric compounds that can lock this phosphorus in the sediment. But when dissolved oxygen is depleted, the ferric bonds break down and phosphorus is released into the water column.

A COMMON SOLUTION: AERATION: S*aturating water with oxygen to replenish what has been lost*. There are various aeration methods and products on the market. Some common types are fountains, bottom diffusers, floating surface aerators, and paddlewheel aerators that put air into the water. Many are low-efficiency oxygen transfer systems whose benefits are quickly lost when much of the oxygen rises and gases off before being absorbed into the water. Some systems stir up bottom sediments, releasing excessive nutrients into the water column and actually increasing the dissolved oxygen needs of the water body and increasing algae blooms.

NANOBUBBLE OXYGENATION: A TECHNOLOGY TOO PROMISING TO BE IGNORED! New gas delivery technologies have been developed that inject water with 90-95% pure oxygen, using oxygen concentrators that create bubbles so extremely small (measuring less than 0.1 micron in diameter) that they are invisible under a typical microscope. These oxygen "nanobubbles" can be directed where oxygen is most needed. Unlike larger bubbles, nanobubbles do not rise and escape, but remain in the water for extended periods of time, allowing the maintenance of higher oxygen levels in the lower depths of the pond. The technology is available in various products, including some designed for smaller scale sites such as ponds and lakes, but has not been previously used in New England lake and pond management. Despite relatively thin formal documentation of operational experience and results in this emerging field of technology, OPC believes that nanobubble oxygenation is too promising to be ignored.

DEMONSTRATION SITE: SARAH'S POND: This 5.8-acre freshwater pond in South Orleans is in many ways a typical Cape Cod kettle pond, a product of the retreating Ice Age. Its watershed is largely undeveloped, but there is evidence of past agricultural activity in its drainage area that has contributed a substantial legacy of sediment with potential to release nutrients into the water column. Water quality data collected between 2001 and 2016 provide evidence of impaired conditions, with average deep summer oxygen concentrations below the State regulatory minimum. Although rooted plants have not been excessive in the past, the growths were extreme in 2018. Primary abundant species observed include coontail, yellow floating heart, and unidentified thin-leafed pondweed. There have been past reports of cyanobacteria blooms although none recently. We do know there are several types of cyanobacteria in the pond.

Sarah's Pond is elongated with two basins (Attachment A). Its eastern basin is 17.5 feet deep (5.3 m), the deepest part of the pond. By using the nanobubble oxygenation system in the eastern basin and keeping the other basin as a rough control, we intended to measure differences in water quality, such as improved oxygen levels, water clarity,

suppression of algal blooms and improvement of the pond's natural biome. There is a particular interest in whether nanobubble oxygenation will inhibit phosphorus release from sediments, suppressing this internal nutrient source.

DEMONSTRATION STRUCTURE AND TIMELINE:

Who is our Technical advisor? OPC has contracted with Dr. Kenneth Wagner, the noted limnologist with over 40-years' experience, as project advisor. Dr. Wagner developed the project's water quality monitoring program and the oxygen demand targets for the project estimated from past oxygen data collected on the pond.

Oxygenation System and Contractor Selection: After reviewing responses to a request for proposals based on Dr. Wagner's oxygen demand estimates for Sarah's Pond, OPC chose the land-based system manufactured by Homeport and distributed by SOLitude Lake Management, to test the technology. This product, the LB2000, has a minimal footprint of 37"X37"X31" and is designed to process 9,000 gallons of water per hour and to produce 19 kg of oxygen per day from ambient air. Independent testing found gas transfer efficiency of the unit to be over 90%, increasing critical dissolved oxygen levels in water bodies much more rapidly and to higher concentrations than other aeration products.

Dr. Wagner calculated that the low oxygen target area in the eastern bowl measures just under 2 acres. To be successful, he estimated that the nanobubble oxygenation system must produce and deliver 8-12 kg/day oxygen to the target area's deepest level to meet demand. Further, the oxygen must be distributed without stirring up the bottom sediment.

Approval & Permitting from MA Dept. of Environmental Protection: Although this oxygenation technology is new in MA, on November 6, 2018, the Orleans Pond Coalition received approval from the Orleans Conservation Commission for the same permit required for any aeration technology on the MDEP books. With OPC setting this important precedent, other communities can be encouraged by the low regulatory threshold to consider nanobubble strategies for their own ponds and lakes.

DEMONSTRATION PROJECT BUDGET:

The entire system, including equipment purchase, installation, and a 2-year support contract cost $28,000, entirely funded by OPC, with support from OPC's members and a generous $10,000 grant from the Fred J. Brotherton Charitable Foundation. Additional consulting, unit housing and 5 months operating expenses brought the total cost of the project to an estimated $45,000.

Project Design Consultation:	$10,000

Upfront consulting costs to assist with the project design and permitting process for a technology new to MA, which should be lower for subsequent applications,

Equipment purchase, installation & Maintenance: $27,610

Under a contract with SOLitude Lake Management, equipment purchase & delivery: $18,090; installation and 2-year support: $9,520.

Oxygenation Housing: $3,835

The LB2000 unit doesn't require housing, but this was done to accommodate the property residents' concerns about noise.

Monthly operating costs: $600

Adding up to $3,000 for a 5-month season, assuming monthly electrical usage at 2,750 kWh, charged at current MA rates, which we are told is at the lower end for many types of aeration/oxygenation systems.

Miscellaneous expenses:

Electrical use meter:	$689
Costs associated with site relocation:	$2,000

These items are mentioned only as an indication of a need for a contingency line item for unforeseen expenses in any future project budget.

CURRENT PROJECT TIMELINE AND UPDATE:

Permitting & Contracting: On November 6, 2018, OPC received a permit from the Orleans Conservation Commission to proceed with the demonstration project. OPC contracted with SOLitude Lake Management on December 12, 2018.

Site Preparation: The operational location selected for the oxygenation unit was approximately nine feet above the water's edge. Although the LB2000 does not require additional housing, a containment structure was built and sound-proofed to prevent any potential disturbance to the residents and wildlife.

Installation: The equipment was delivered on May 1, as planned, before pond waters warm and plant life cycles begin to increase oxygen demand in the pond's lower depth. Our goal was to begin supplementing oxygen on the pond bottom with nanobubbles before the oxygen levels drop, to prevent release of these excessive nutrients from the sediment and to improve the health of the pond. However, installation problems abounded, preventing any continuous operation of the system until July 31, 2019.

Problems included:

- The May delivery did not include enough intake and distribution hose to deliver oxygen to the target area: the deepest level of the pond. The installation was called off until later in May when sufficient hose was procured.

- Per instructions from Homeport (the unit manufacturer), additional 40 PVC pipe was requisitioned that proved too heavy and inflexible for successful connection to the elevated site and extension to the target oxygenation area 200 feet away.

- A subsequent attempt in early June to assemble the hard pipe using flexible unions likewise failed, causing the hard pipe sections to come apart and sink into the Pond. Another workaround was clearly required, and it was decided to replace all the hard pipe with 4-inch flexible hose for intake, which was completed on June 10. However, attempts to prime the unit were unsuccessful.

- On June 13, after some check valve corrections on the intake line that were interfering with the priming of the unit and the installation of the two 2.5-inch flexible output lines to the target area, the unit was primed and operational.

- Over the next two weeks, the unit was discharging considerable gas above both output lines, with visible bubbles of various sizes, an indication that the unit was not functioning optimally. Although some visible bubbles might be expected, the amount observed was excessive, raising concerns about thermal mixing.

- On July 2nd, the unit pump broke down completely, unable to accommodate the site's nine-foot elevation from the water's edge. It was decided to lower the unit location to three feet above the water's edge, reducing the load on the pump.

- That change seems to be working. The unit was restarted on July 31st and has been operating continuously without problems ever since.

What does this do to the timeline and anticipated results of the project? By the time a successful installation was achieved, most of the test season had been lost; the pond's waters had warmed and stratified; dissolved oxygen levels on the bottom had been depleted. The net result – the system now had to overcome a substantial oxygen deficit. While some of the most recent water quality monitoring data suggests that the oxygenation might have impacted the hypolimnion, it is not possible to determine how much of the change in dissolved oxygen was due to the system or to late season thermal mixing of the water column. We'll need to wait until next year to determine if nanobubbles can realize the promise in water remediation that OPC has hoped for.

WHAT HAS BEEN LEARNED SO FAR: *Findings and Recommendations:*

Although the delayed installation of the oxygenation system precludes any meaningful interpretation of the water quality monitoring data with respect to the system's performance, operational information gathered since August will inform next season's startup in early May 2020, as well as any subsequent projects.

- The project team has tirelessly monitored Sarah's Pond, recording the dissolved oxygen and temperature levels at half meter increments every week. The team has also collected algae samples and, with Dr. Wagner's assistance, analyzed what forms and amounts of algae were present in Sarah's Pond. These data will provide an important baseline for comparison with next and subsequent years' results. (See Appendices A & B for data analyses)

- The nanobubble oxygenation system easily obtained the same level of operating permit as any other aeration/oxygenation technology from Orleans Conservation Commission, despite its relatively recent development and lack of operational experience in New England. This low regulatory hurdle is a plus for future projects.

- When in optimal operational mode, the LB2000 unit is relatively quiet; the unit is housed in a small shed to lower the noise level even more. There is some combining of nanobubbles into larger bubbles on route to the pond but the small amount of gas-off bubbling is barely noticeable on the surface of the pond.

- Sarah's Pond did contain elevated concentrations of cyanobacteria and other algae that suggest ongoing water quality issues. OPC has closely followed the reports of algae blooms and pond closings from other towns on Cape Cod, and many ponds had similar or greater algae presence than Sarah's Pond, but the oxygenation system did not provide the intended relief in 2019

- The pond's birds and other wildlife quickly adjusted to its presence and there has been no indication of any harm to flora or fauna from its operation.

- In designing next year's monitoring protocols, it is recommended that at least two ponds with comparable bathymetry and environment be selected for monitoring and comparison to water quality data from Sarah's Pond, rather than relying on the western basin as a control.

- An additional consideration for the monitoring program might be to increase the number of monitoring stations to check for DO in other parts of the pond.

- The limits of the LB2000 unit's 3 HP pump require careful consideration of demands placed on it by the unit's location, in terms of proximity to and elevation above the water. Length and weight of hose required to reach pond's oxygenation target area

are also important load factors. The unit had to be relocated to a lower site, closer to the water's edge, to reduce strain on the pump.

- Operational costs are higher than expected from the LB2000 specification literature that erroneously computed the monthly electrical consumption and costs at $31. The electrical consumption of the unit was metered at about 2,750 kWh per month, or about $600 per month of continuous operation at current MA rates. We are told this monthly cost is at the lower end of operational costs for many types of aeration/oxygenation systems, because the unit generates its own oxygen, rather than requiring transportation and storage of oxygen at the site.

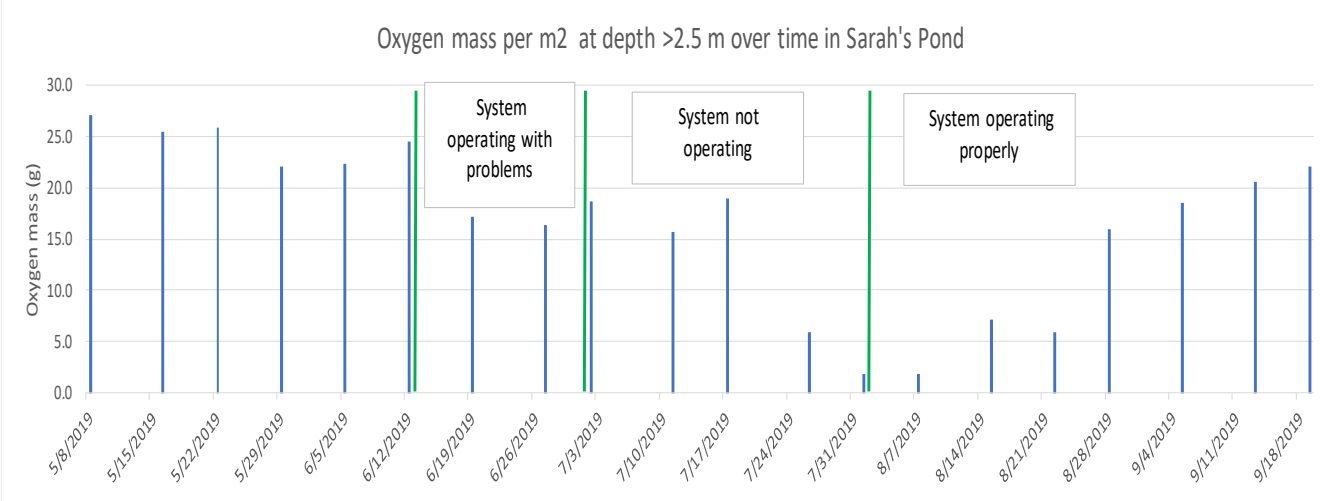
At this point, the demonstration results are mixed. However, we believe that the problems with the installation and initial operation of the oxygenation system are issues associated with the implementation of an experimental system, not theoretical problems about using oxygenation to improve water quality. We expect to do better in 2020 with an earlier start of a functioning oxygenation system.

APPENDIX A: ANALYSIS OF SARAH'S POND WATER QUALITY MONITORING DATA, APRIL 8 – SEPTEMBER 18, 2019: Contributed by Dr. Kenneth Wagner, Water Resource Services, LLC.

The key water quality feature being assessed is dissolved oxygen in deeper water within Sarah's Pond. Several other features are measured as well in support of the overall analysis, including temperature, water clarity, and phosphorus concentration. What we are seeking is great oxygen in deeper water, which can be measured at each depth increment as a concentration but can also be viewed as a total mass below some target depth, here taken to be 2.5 m or about 8.3 feet. Below that depth oxygen has been low in past years and was indeed depressed in 2019 before the oxygenation system was operating properly.

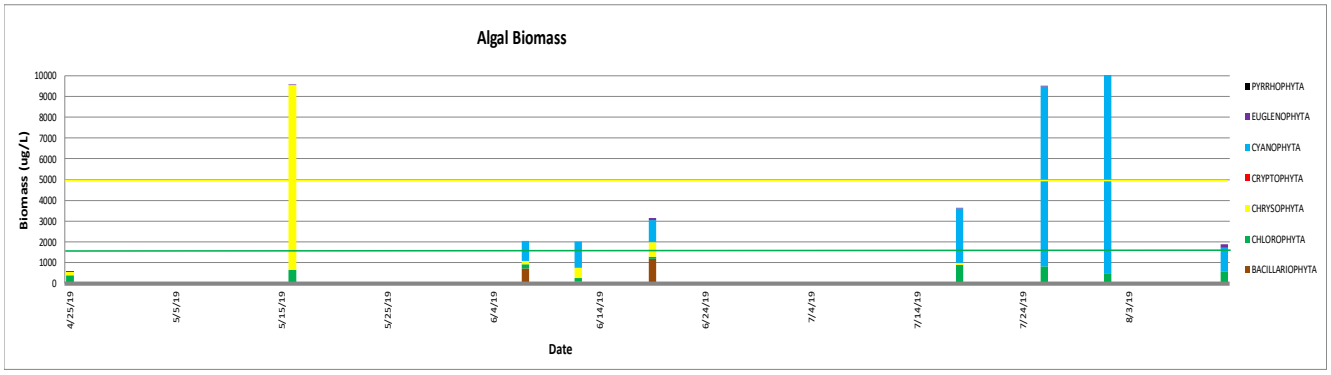
The following graph depicts oxygen mass in water deeper than 2.5 m, which is the primary target zone for this project, over the period of April-September 2019. The system may have added enough oxygen to slow depletion during June, but non-operation in July resulted in very low oxygen mass in deep water. Resumption of system operation with continuous operation in August and September suggests a major increase in deep water oxygen, but this period also coincided with cooling temperature.

The difference between the surface and bottom temperature in Sarah's Pond in July was substantial (>10 C) through August 1st, but this difference was much less in August and September (<2-6 C). This means that the water can mix vertically more easily and allow oxygen from shallower water or even the atmosphere to reach the deeper water. The weather did cool off some in August this year, but the temperature change may also be a consequence of system operation. The nanobubbles are not supposed to cause vertical mixing, but some larger bubbles did form and may have mixed the pond. If the vertical mixing and increased oxygen in deeper water is a function of weather, this precludes evaluation of system performance. If the mixing is a function of bubbles from the system, this is not how the system is designed to provide the extra oxygen. We need data from a time period when the temperature differential between top and bottom of the pond is high enough to limit mixing and demonstrate oxygen addition to the bottom waters. The increase in oxygen from early August to mid-September is encouraging, but can't be confidently attributed to the proper operation of the system.



APPENDIX B: PHYTOPLANKTON ANALYSIS, APRIL 25 – AUGUST 23, 2019; Contributed by Dr. Kenneth Wagner, Water Resource Services, LLC

Phytoplankton analyses demonstrate that there was a pulse of golden algae in May, followed by a fairly clear water period in June, typical of Cape Cod ponds. Cyanobacteria become more abundant in July and early August, although the “pea soup” appearance of some other years was not observed. The dominant cyanobacterium was Aphanizomenon, a possibly toxic form, that was present in June but reached bloom proportions in July and early August. It subsided in mid-August about 2 weeks after the oxygenation system came online and operated properly on a continuous basis. This is an encouraging sign, but samples from later in August and into October have not yet been examined to complete the analysis.



ATTACHMENT A:

Diagram of Sarah's Pond with eastern bowl demonstration area outlined in white, red star indicates shoreline equipment location

ATTACHMENT B: LB2000 Aeration Platform

MaxDo Aeration Platform Features & Benefits:

- Low profile, land and water-based units to suit customer application
- Attractive, modern, heavy duty, environment resistant, Roto Moulded Alkatuff® Polyethylene LL711UV housing for superior toughness and UV protection
- Heavy duty IP 68 components ensure long operational life and reduced maintenance
- Simple configuration designed to allow for plug & play maintenance, reduced operating costs
- Leverages hydrodynamic Ultrafine bubble generation, most energy efficient method
- Platforms easily modified or enhanced extending applications and lifecycle
- Platforms allow for multiple beneficial gases to be injected, solving specific water problems
- Multiple monitoring levels radically reduce service expense and allow predictive planning
- Vacuum diffusion technology eliminates harm to aquatic animals, our machines don't suck
- Screening technology ensures non-proliferation of nuisance species
- Simple, robust construction ensures durability in extreme environments and long service life
- First aeration solution combining "Industry 4.0" technologies
- Leverages pure oxygen, instead of atmosphere, delivers 90% pure oxygen vs. 20%

The specific MaxDO unit SOLitude and Homeport are recommending for Sarah's Pond is the LB2000 land-based unit. We have taken in to account that the system location chosen by the Orleans Pond Coalition is roughly 10' vertical above the pond. The LB2000 Unit's pump is extremely powerful and capable of overcoming this incline; this has been confirmed with both Homeport and the pump manufacturer. SOLitude will ensure that the hoses are free from obstruction, kinks, and elbows. Specifications for this specific unit are below:

LB2000 – Processes 9000 Gallons Water/Hour or 150 Gallons Water/Minute
Processes 34,068 Liters Water/Hour or 568 Liters Water/Minute

- Land Based 37"x37"x31" IP 44/54 Roto Molded, Heavy Duty Polyethylene Cabinet
- Power Consumption = Single Phase 208/230V 3HP
- Generates NanoSight™ Tested 160bn/ml Ultrafine Bubbles
- Included Level of on-board monitoring
  - Smart Premium (Level 3)
- The WB2000 Unit produces 19.15kg of oxygen per day, which far exceeds the requested 8-12kd/day.
- The expected cost to operate the WB2000 unit on a monthly basis is $31. We've based this figure on the Massachusetts average cost per kilowatt hour (22 cents) and multiplying this by the daily energy consumption of the unit (4,700 watts). We then anticipated that the machine will be running 24 hours per day, 30 days per month.