Newman Lake Flood Control Zone District
Capital Budget Grant Project

Phase 1a Report – Final

March 1, 2021

Spokane County, WA

Contents

Executive Summary

Spokane County, on behalf of the Newman Lake Flood Control Zone District, applied for and received a State Capital Budget Grant in 2019. The contract was executed in spring of 2020 with Washington State Department of Commerce as the fund managing agency. As part of the Grant, Spokane County seeks to evaluate the condition and efficiency of the existing Speece Cone™ hypolimnetic oxygenation system (HOS) and alum injection equipment (Alum System) installed at Newman Lake for water quality treatment.

GOAL: This report documents the findings and recommendations from the first phase of the above noted Grant and is referred to as the Phase 1a Report. The goal of the Phase 1a study was to determine the inefficiencies and problem areas associated with the existing HOS and Alum System and offer recommendations for improvements within the confines of the State Capital Budget Grant Award. The study included evaluation and analysis of the physical condition and operational efficiency of the HOS.

OUTCOME: A structural inspection showed the Speece Cone to be in "good" condition with an expected remaining life of about 10 years. The in-lake portion of the HOS showed minor to moderate signs of deterioration throughout. Many of the in-lake elements of the HOS are made of coated steel or PVC. The 8-inch diameter steel pipe piles and steel pipe supports are made of uncoated steel and, consequently, showed greater signs of deterioration than the rest of in-lake portion of the HOS. The pump was functioning, and it appeared that the cone, piping and seals were not leaking. See *Recalculation of Hypolimnetic Oxygen Demand* (Appendix A).

The HOS was originally designed to add 3,000 lb O_2/day (1,360 kg O_2/day) of oxygen to the hypolimnion. Modeling analysis of the existing HOS revealed that, due to cone size and pressure, much of the oxygen injected into the cone structure passes through it without dissolving into the water. The existing cone is estimated to be capable of delivering approximately 1,320 lb O_2/day (600 kg O_2/day) at 18 psi (current pressure), which is about half of the oxygen currently being supplied. This is evidenced by visible bubbles under water and at the surface. The study also included a more recent estimate of the hypolimnetic oxygen demand (HOD) of Newman Lake (Appendix A), which is close to 4,400 lb O_2/day (2,000 kg O_2/day). It should be noted that 4,400 lb O_2/day (2,000 kg O_2/day) represents the maximum observed HOD and corresponds more closely to design criteria if the HOS were being designed new or being replaced. Therefore, to predict the efficacy of the proposed options, they are compared to early spring oxygen depletion rates of 2,100 lb O_2/day (950 kg O_2/day). This rate, which parallels that reported in the NewSpecRep2015, is believed to be the most representative oxygen demand in the water column, following initial spring stratification, before any equipment in the lake, e.g. the pump, is operated.

In summary, the existing onshore oxygen generation equipment over-supplies oxygen to the in-lake portion of the HOS (Speece Cone). As the first of its kind, this Speece Cone did not benefit from subsequent 30 years' experience with hypolimnetic oxygenation systems and could never meet the HOD. The study found that maximizing the efficiency of the HOS does not involve major repair. Rather, it is a matter of modifying the HOS to better match today's knowledge of hypolimnetic oxygenation systems.

OPTIONS: There are currently two options for improving the efficiency of the existing HOS. These options would be considered a near-term fix due to the eventual progression of corrosion as the current "fair to good" condition of the in-lake equipment transitions to a "poor to fair" condition in about a decade. Regardless of option choice, modifying current HOS Operational Parameters to increase the duration that oxygen is added to the water column should be evaluated.

> **OPTION NO. 1: MODIFY EXISTING SPEECE CONE WATER FLOW RATE**. Option No. 1 includes replacing the in-lake pump with a lower capacity pump to better match the capacity of the existing cone. Despite the onshore oxygen equipment being able to supply 4,400 lb O_2/day (2000 kg O_2/day) the existing cone is estimated to only be capable of delivering approximately 1,320 lb O_2/day (600 kg O_2/day) at 18 psi (current pressure), which is about half of the oxygen currently being supplied. Replacing the existing pump with a smaller pump (<30 HP) would reduce flow in the cone from 9,450 to 3,150 gallons per minute, which is more appropriate for the cone size and pressure.

Option No. 1 also includes replacing the oldest Air-SEP to provide reliable redundancy and replacing both compressors due to limited remaining useful life and limited availability of spare parts.

Key Findings of Option No. 1:

a. Will lower daily operating cost, as Option No. 1 requires operating one Air-SEP and one compressor only

b. Is the lowest project risk:

   i. The pressure in the cone will not be increased, so there is no additional risk of seal failure due to higher pressure.

   ii. Only involves pump replacement, is more straightforward and biddable than more extensive modifications to the cone

c. Will not prevent hypoxic conditions in the summer; however, can offset hypoxia by at least 30 days, based on 2,100 lb O_2/day (950 kg O_2/day) oxygen depletion model. For 4,400 lb O_2/day (2,000 kg O_2/day) HOD, this offset can be approximately 7 to 10 days.

d. Will increase the reliability and operational efficiency of the existing HOS

e. Additional lake health benefits may be realized by extending duration of HOS operation

OPTION NO. 2: PUMP UPGRADE AND CONE MODIFICATION TO INCREASE SPEECE CONE PRESSURE. Option No. 2 includes replacing the in-lake pump with a lower capacity, higher-pressure pump. Replacing the existing pump with a higher-pressure pump (100 HP) would reduce flow in the cone from 9,450 to 3,150 gallons per minute but would raise the cone pressure to 35 psi (combined hydrostatic and pump pressure). At a higher pressure, the cone could transfer approximately 1,918 lb O_2/day (870 kg O_2/day). This Option also includes replacing the oldest Air-SEP to provide reliable redundancy and replacing both compressors due to limited remaining useful life and limited availability of spare parts.

Key Findings of Option No. 2:

a. Requires operation of one Air-SEP and compressor only; however, it is possible that operating costs may be higher due to the higher pump HP.

b. Has a higher project risk and cost than Option No. 1:

   i. A pressure restriction plate needs to be installed on the discharge of the cone and a new pump type will be needed (screen, brackets, outlet adapter), so construction cost will be higher.

   ii. The cone has no pressure rating; thus, raising cone pressure may cause seals to fail. Additional study (that is outside this scope) would need to be performed to determine a more accurate risk level.

   iii. Underwater construction work and/or raising the cone to a barge is likely to be expensive.

   iv. With more extensive cone modifications, the potential discovery of unknown problems with the retrofit is increased.

   v. A realistic cost estimate requires a design study.

c. Unlikely to meet oxygen demand but may delay onset of hypoxic conditions in the hypolimnion until late September based on 2,100 lb O_2/day (950 kg O_2/day) oxygen depletion model. For 4,400 lb O_2/day (2,000 kg O_2/day) HOD, the offset would be to approximately 60 to 75 days (mid-July).

d. Will increase the reliability and operational efficiency of the existing HOS

e. Additional lake health benefits may be realized by extending duration of HOS operation

CURRENT RECOMMENDATION: Option No. 1 is recommended. With the currently available funds through the State Capital Budget Grant Award, Option No. 1 is the most reliable choice. The HOS modifications proposed via Option No. 1 will add reliability and redundancy (due to the replacement of back-up Air-SEP unit with a newer model and replacing both compressors) and the oxygen generation equipment can be utilized in future long-term upgrades. In addition, if the period for HOS operation is extended, Option No. 1 may further benefit water quality.

The study also recommends replacing clogged alum pipes with larger lines and replacing the alum pump to prevent alum line clogging. The Alum System improvements are within the scope and budget of the Capital Project.

FUTURE RECOMMENDATION: A pure-oxygen line diffuser should be considered for future replacement of the Speece Cone HOS. This technology has emerged in the last 20 years with some 36 projects in operation in the United States. It would also lower operational costs compared to the current HOS Operational Parameters, while still utilizing the existing, and proposed upgraded/replaced, onshore equipment. However, this alternate does not fit within the Capital Project scope and budget and is therefore not considered a feasible option at this time.

1. Introduction

1.1 Background

In the 1980's, algae blooms were having an impact on the beauty, habitat, and recreational uses of Newman Lake. The Newman Lake Flood Control Zone District (District) undertook a study that concluded that the algae problem was caused by nutrient overloading, which fed excessive algae growth creating a high biological oxygen demand that caused extremely low oxygen levels in the lower level of the lake. To reduce nutrient levels and maintain them at a low level into the future, the District implemented surface alum treatment, a hypolimnetic oxygenation system (HOS), and a Micro Floc alum injection system (Alum System) in 1992. Injecting alum into Newman Lake is done under an Administrative Order from Ecology, which requires the District to monitor Newman lake, submit a sampling and analysis plan, submit an annual "State of the Lake Report," and maintain coverage under the Aquatic Plant and Algae Management General Permit.

The Newman Lake Alum System is operated when the lake is mixing and the HOS is operated after stratification and loss of hypolimnetic dissolved oxygen. Recently, both the HOS and Alum System have shown signs of age, and the District desires a detailed study on the physical condition and operational efficiency of the existing HOS and Alum System as Phase 1a of a Capital Budget Grant Project.

1.2 Existing Hypolimnetic Oxygenation System (HOS)

1.2.1 Speece Cone™

The existing HOS installed in Newman Lake is a downflow bubble contactor, aka Speece Cone™, that was one of the original designs by Dr. Richard Speece during his tenure at Vanderbilt University. The Speece Cone's operational functionality is based on the injection of pure oxygen gas into a water stream through a structure with increasing diameter as the water flows downward through it (Figure 1). Initially, bubbles are entrained in the higher velocity flow at the top of the structure where they dissolve into the water as they are essentially held in suspension. As the water velocity decreases towards the bottom of the structure, the bubble rise velocity is greater than the downward water flow velocity. The bubble swarm stays in mid-cone, dissolving into the water. Water supersaturated with oxygen flows out the bottom. In a pure-oxygen environment the saturation of dissolved oxygen is approximately five times greater than with air (law of partial pressures).

Figure 1. Speece Cone with bubble swarm in top of cone dissolving into water by the bottom of the cone. The oxygen feed is at the top of the cone. Note the bubble swarm trapped in mid-cone. Screenshot from https://www.youtube.com/watch?v=6thCFEWWSrw.

The central idea of the Speece Cone is that oxygen leaves the cone only dissolved in water, not as bubbles. The bubble swarm is chaotic. Consequently, an occasional bubble or "burp" will escape the cone at an optimal oxygen gas feed rate. A bubble carryover rate representing about 5 percent of the oxygen injected into the cone is acceptable. However, regular streams of bubbles escaping from the cone indicate that the oxygen feed rate exceeds the capacity of the cone to dissolve oxygen into the water.

The original Newman Lake design per notes from Jerry Nichols and Richard Speece identified a cone structure 18 feet tall and 20 inches diameter at the top and 9 ft diameter at the base. The cone portion is 15 ft tall with a 3 ft section at the bottom of consistent 9 ft diameter. Water is pumped into the structure from a submerged Flygt Pump and exits the structure at the bottom into a distribution header. The recommended operating point for the pump is 9,450 gpm (21 cfs) and 14 ft head (6 psi). The distribution header is a 24-inch diameter PCV pipe that is 120 ft long and has 2.5-inch holes evenly spaced along the entire length. The entire structure is submerged to take advantage of the hydrostatic pressure naturally occurring at depth.

The Newman Lake cone was originally designed to add 3,000 lb O_2/day (1,360 kg O_2/day) of oxygen to the hypolimnion. HOS operation at the prescribed water and oxygen gas flow rates resulted in a calculated discharge concentration to be 26.5 mg/L. The cone structure has an estimated volume of 315 ft^3 and at the design water flow rate, it has a hydraulic residence time (HRT) of approximately 15 seconds.

This residence time is too low to ensure that gaseous oxygen is dissolved in the cone as the design intended. It was the first such application of the Speece Cone. Current Speece Cone designs have residence times in the range of 45 to 100 seconds. There was no mistake in design of the Newman Lake Speece Cone; rather the design standard is outdated. As a pioneering design it could not benefit from operational experience.

A more recent Speece Cone design, the same size as the Newman lake Speece Cone, is in the Marston Reservoir near Denver, CO. The Marston Reservoir cone structure has the same dimensions as the Newman Lake cone; however, the water flow rate and design oxygen addition differ. The Marston Reservoir Speece Cone has an oxygen addition capacity of 2,000 lb O_2/day (910 kg O_2/d) and a design water flow rate of 3,200 gpm at 23 ft head (10 psi) provided by the pump. At the design water flow rate, the hydraulic residence time in the Marston Reservoir cone is approximately 45 seconds.

Like the Newman Lake installation, the Marston Reservoir Speece Cone and diffuser are deployed at the bottom of the reservoir. The main differences between these two systems are the reduced design oxygen input capacity, reduced water flow rate, and increased HRT for the Marston Reservoir cone. The Marston Reservoir has a maximum depth of 66 ft compared to 30 ft at Newman Lake, which results in the Marston Reservoir cone being under an additional 16 psi of hydrostatic pressure. Additionally, the discharge dissolved oxygen concentration at Marston Reservoir was calculated to be 52 mg/L.

Applying current design standards to the existing cone will enable the HOS to operate without the excessive bubble carry over but will decrease rated capacity as discussed in Section 2.

1.2.2 Oxygen Generation Equipment

The original oxygen supply for the System was two Air-SEP AS 1000, which were rated at 1,000 SCFH each and capable of delivering 2,000 lb O_2/day (902 kg O_2/day). Over time, the units wore out and one of them was replaced with an Air-SEP AS-L rated at 1,000 – 1,300 SCFH and is capable of producing 2,000 – 2,580 lb O_2/day (902 – 1,172 kg O_2/day). Continued maintenance has been performed on the second original unit to keep it operational.

As indicated in the *Memorandum: System Inefficiencies and Problem Areas Noted During the Site Visit* (Appendix B), the onshore oxygenation equipment is in good operating condition. The original Air-SEP unit is at the end of its operational life because of lack of spare parts. The compressors (50 HP Quincy Northwest model QNW-240-D1) are at 70% of their lifespan. Lack of spare parts for the compressors will necessitate the need for replacement within a few years.

1.2.3 Design Oxygen Transfer Requirements

An accurate determination of hypolimnetic oxygen demand (HOD) can be reached by taking several approaches. The basic approaches are calculation and direct measurement. Each has its strengths and weaknesses. Considered together, a design HOD can be developed with confidence.

Moore et al. (1996) identified the original HOS was designed to deliver about 3,000 lb O_2/day (1,360 kg O_2/day) when installed in 1992. In 2015, a special assessment (NewSpecRep2015) was conducted to evaluate HOD and estimated that HOD had decreased to approximately 2,100 lb O_2/day (950 kg O_2/day). The reduction in oxygen demand was attributed to oxidization of legacy sediment organic matter and reduced delivery of new organic matter from improved water quality over the past decade or more. Reduction in oxygen demand following several years of hypolimnetic oxygenation is common (Gantzer et al., 2019). Review of data collected during the 2014-15 sampling campaigns indicated that pump mixing of the water column biased the observed oxygen demand to a low value.

During 2014, Paul Gantzer, Ph.D., a coauthor of this report, was involved with data collection to improve understanding of oxygen demand and water column response to HOS operation in Newman Lake. Data collected by Gantzer consisted of three methods, (1) collecting water column profiles at 37 locations using a SeaBird Electronics SBE 19PlusV2 high resolution water column profiler for conductivity, temperature, depth, and dissolved oxygen (DO), (2) deploying *in-situ* sediment oxygen demand (SOD) chambers to measure SOD directly, and (3) deploying remote sensors throughout the hypolimnion during winter and spring to track water column changes during winter ice cover periods and initial spring stratification. From results of the 2014 analysis (See Appendix A) HOD was estimated to be 4,400 lb O_2/day (2,000 kg O_2/day).

It should be noted that 4,400 lb O_2/day (2,000 kg O_2/day) represents the maximum observed HOD and corresponds more closely to design criteria if the HOS were being designed new or being replaced. Therefore, to predict the efficacy of the proposed options, they are compared to early spring oxygen depletion rates of 2,100 lb O_2/day (950 kg O_2/day). This rate, which parallels that reported in the NewSpecRep2015, is believed to be the most representative oxygen demand in the water column, following initial spring stratification, before any equipment in the lake, e.g. the pump, is operated.

1.3 Alum

Alum addition is often used to enhance phosphate inactivation in the lake. However, the Alum System needs upgrades. Alum pipes are currently clogged and need to be removed and replaced with new larger diameter lines of a material compatible with alum. In addition to replacing clogged alum pipes with larger lines, replacing the alum pump to prevent alum line clogging is recommended.

An ideal alum dosing system would use a progressive cavity dosing pump operating at medium pressures (100 to 200 psi) to blow out alum clots. Alternatively, the alum line supply could be constructed with valving to allow a compressor pressurization to blow out clots. The dosing pipe would need to be rated to these pressures (HDPE sidewall thickness sdr-9). Also, a higher diameter pipe of 1 to 1.25 inches would have less tendency to become clogged.

Beyond the mechanics of the alum dosing system, there is the question of how much alum to add. The US EPA ambient aluminum criteria were revised in December 2018 (USEPA 2018). These criteria calculate the effect of pH, harness, and dissolved organic carbon (DOC) on aluminum toxicity. Assuming hardness of 20 mg/L as $CaCO_3$, pH 7.0 and DOC of 3.0 mg/L the chronic toxicity threshold is 390 µg/L[1]. Continuous dosing near this concentration will remove more phosphorus from the water column than the current Alum System. Although recalculation of dosing is beyond the scope of this project, it is important to consider that future dosing can be safely done at higher rates than in the past. In addition to helping with clogging, larger-diameter alum pipe would allow higher dosing rates in the future.

[1] The EPA model for ambient aluminum criteria can be downloaded: https://www.epa.gov/sites/production/files/2018-12/aluminum-criteria-calculator-v20.xlsm

2. Physical Condition and Operational Efficiency of Existing System

2.1 Design Criteria

As previously discussed , a new HOS should be designed to add an average of 4,400 lb O_2/day (2,000 kg O_2/day), which can be provided by the existing onshore oxygen generation equipment with both Air-SEP and compressor units in operation. In simple terms, the oxygen demand is close to the current oxygen generation capacity. However, the in-lake Speece Cone HOS is only able to deliver about a quarter of the oxygen demand.

The problem lies in the original design, as stated previously. A modern Speece Cone design would use a higher cone pressure provided by a different pump type (see below). Hydraulic residence time in the cone would be three to six times longer, which would require a larger cone. As discussed below, there are limited choices with the existing System.

2.2 Dive Inspection and Field Visit Findings

As discussed in the *Routine Level Dive Inspection Letter Report* (Appendix C), the in-lake portion of the HOS showed minor to moderate signs of deterioration throughout. The majority of the in-lake elements of the System are made of coated steel or PVC. The 8-inch diameter steel pipe piles and steel pipe supports are made of uncoated steel and, consequently, show greater signs of deterioration than the rest of the HOS. The pump is functioning, and it appeared that seals are not leaking. Additional details of the physical condition are found in the Dive Inspection Report. The expected remaining life of the in-lake HOS is about 10 years.

The field visit observed strong bubble plumes coming from various locations along the distribution header, but closer to the cone. These bubbles plumes were observed on the surface with both Air-SEP units operating.

The oxygenation generation machinery is in good shape, but the compressors and the old Air-SEP unit are within a few years of their operating life span. Please refer to Appendix B for details.

2.3 Existing Speece Cone Capacity to Provide Required Oxygen Transfer

Large quantities of bubbles are not an indication of seal failure or other leaks in the HOS. Massive bubble carry-over from the cone shows that the existing Speece Cone cannot dissolve the design input of 3,000 lb O_2/day (1,360 kg O_2/day), of oxygen into the water. The problem lies in the existing Speece Cone design, as will be discussed in this section.

2.3.1 Speece Cone Model

The Marston Reservoir (Colorado) Speece Cone was used to compare a modern Speece Cone design to the Newman Lake Speece Cone. The comparison highlights oxygen addition limitations of the existing Newman Lake cone. A Speece Cone model analysis takes into consideration water flow rate, system operating pressure, oxygen flow rate, residence time, and DO saturation conditions. Water flow rate and corresponding residence time determine the likelihood of bubble carry over and ultimately oxygen transfer efficiency. As residence time decreases, the water moving through the cone has less time to dissolve oxygen and thus reduced oxygen transfer efficiency. As the oxygen flow rate increases relative to water flow rate, conditions in the cone are closer to saturation (DO) conditions, which in turn results in lower oxygen transfer rates and ultimately bubble carry over. As system pressure increases DO saturation limits are increased, thus providing increased oxygen transfer efficiency for the same oxygen input level. Two operating conditions were evaluated based on oxygen addition limits of the existing Speece Cone.

2.3.2 Oxygen Addition Limitations Using Existing Speece Cone

The water flow rate in the existing Newman Lake Speece Cone (315 ft^3) would need to be reduced to 3,150 gpm to achieve a hydraulic residence time of 45 seconds, like the Marston Reservoir. Per model results, at this reduced flow rate, the oxygen addition capacity would be limited to 1,320 lb O_2/day (600 kg O_2/day) at the current Speece Cone operating pressure of 18 psi (12 psi hydrostatic and 6 psi provided by the existing pump).

Raising the Speece Cone operating pressure to 35 psi (12 psi hydrostatic and 23 psi provided by the pump) could increase oxygen addition capacity to 1,923 lb O_2/day (870 kg O_2/day).

The existing cone, however, cannot be operated at higher pressures without two fundamental changes:

1. Installing an orifice plate at the cone discharge to raise pressure in the cone
2. Install a new type of pump that can provide the required pressure

2.3.3 Speece Cone Modifications Required to Add up to 1,923 lb O_2/day (870 kg O_2/day)

Raising the cone pressure would require a different type of pump and modification of the cone outlet to create backpressure. The existing axial-flow, propeller pump operates at high flows at low pressures. There are other submersible pumps made by the same manufacturer (Flygt) that are designed for higher pressures at lower flows. These N-series pumps have pump curves that could meet any theoretic pressure and flow demand for this cone. A Flygt 3306 model is a possible candidate replacement pump to operate the cone in Newman Lake at 35 psi to get 1,923 lb O_2/day (870 kg O_2/day) (Figure 2, Figure 3). The required pump horsepower would be 90 – 100 HP. Additionally, a plate with an engineered orifice, located at the cone discharge will be required to obtain a higher pressure in the cone if the pump has the capacity to generate the pressure. However, there are practical limitations and a physical limit to this approach:

1. Changing the pump type and installing an orifice plate would require construction underwater or raising the Speece Cone out of the water to make the modifications on a barge and then reinstalling. The unknowns associated with this operation result in risk of cost overruns due to inclement weather or discovery of mechanical problems that force more underwater construction time or limit barge deployment.
2. The existing Speece Cone has no pressure rating, so increasing the pressure in the cone involves the risk that the cone structure or seals would fail.
3. Finally, the pressure cannot be raised high enough to meet the oxygen demand without recreating oxygen loss by a different method, degassing in the water column. At higher pressures more oxygen can be dissolved into the water; however, dissolved oxygen concentrations leaving the cone are supersaturated with respect to ambient water pressure. There is a stable degree of supersaturation in which supersaturated water can be instantaneously mixed with ambient water and not have dissolved gas flash out of solution[2]. This limit of supersaturation with regards to the design and operation of the distribution header is ~50 mg/L dissolved oxygen, which corresponds to the discharge concentration at 35 psi and water a flow rate of 3,150 gpm, with the oxygen flux rate would of 1,923 lb O_2/day (870 kg O_2/day).

The power cost associated with operating the higher-pressure pump will be higher than the existing pump. The diver servicing cost would be the same.

[2] There is an important footnote here to the original design. A clearer understanding of dynamics of supersaturation in reservoirs has only recently emerged. Degassing or gas flashing out of solution is an effervescent bubble cloud that slowly coalesces into large bubbles. In deeper applications, such as Marston Reservoir, most of the bubble cloud has time to re-dissolve into the water. In a shallow application, such as Newman Lake, most of the cloud mixes upward, out of the hypolimnion, and does not dissolve. The high flow rate in the Newman Lake cone enhances this upward mixing. These dynamics were not clearly understood at the time of the original design almost 30 years ago.

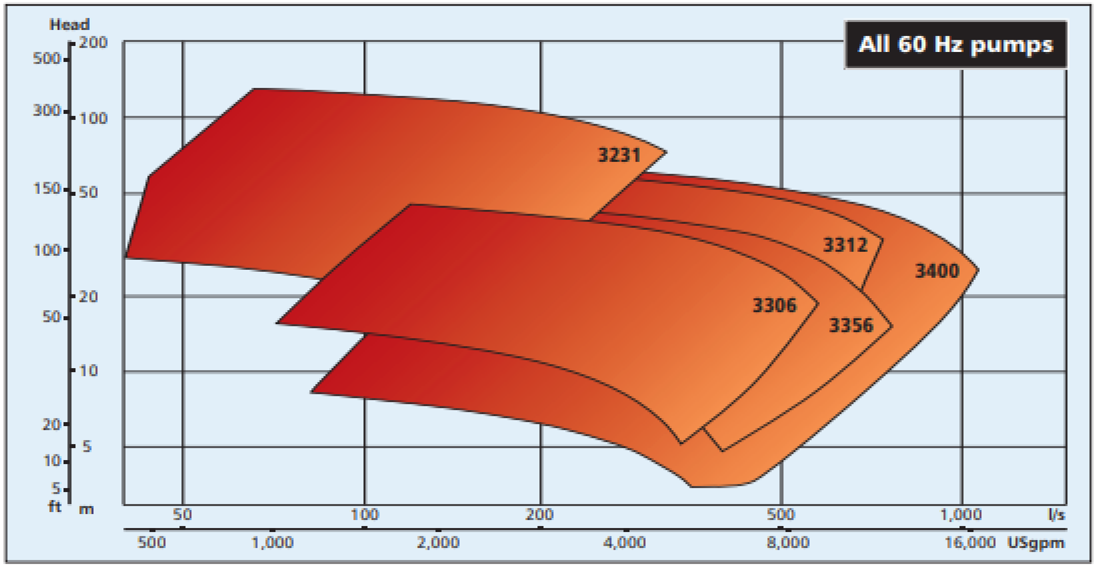

Figure 2. Flygt 3306 pump composite curve.

Figure 3. Flygt 3306 pump

2.3.4 Modified Operation

With either Option No. 1 or No. 2, changing the HOS operation period should be explored. As previously stated, the HOS is operated after stratification and loss of dissolved oxygen in the hypolimnion is observed. HOS operation should begin in later winter / early spring and continue through fall turnover. This would increase the current time of HOS operation from five months to nine months. By lengthening the period of HOS operation, the total annual oxygen deficit cannot be eliminated, but could be reduced. For example, historically, approximately 335,100 lb (152,000 kg) of oxygen have been added to the water column annually. This is based on 2,200 lb O_2/day (1,000 kg O_2/day) applied for five months between May and September. A reduced capacity of 1,320 lb O_2/day (600 kg O_2/day) with higher oxygen transfer efficiency, applied for nine months (March – December) would result in an annual oxygen applied to the water column of 363,760 lb (165,000 kg), a net increase over traditional operation.

The goal of the operational change is to maintain as high an oxygen concentration over the sediments for as long as possible. This strategy provides the best opportunity to aid a downsized HOS through stratification and ice cover periods in winter.

Regarding the Alum System, this would need to be explored in greater detail. Currently the Alum System is operated before the HOS. The amount of alum being added would need to be evaluated and the Alum System operation, if it is prudent to be modified, would parallel the proposed HOS operational strategy.

3. Evaluation of Alternatives for Improving the Efficiency of the Existing HOS

The Capital Budget Grant Project includes approximately $130,000 for a new pump and Speece Cone repair/reconfiguration, which would likely allow the existing HOS to continue functioning as it does currently for 10 more years, perhaps longer. As discovered in underwater inspection, the cone is in fair to good shape. It does not need repair to operate to the limit of its current calculated capacity of 1,320 lb O_2/day (600 kg O_2/day). If operated beyond the current capacity, bubbles will escape from the cone.

There are two options for Improving the efficiency of the existing HOS:

1) Operate the cone at 1,320 lb O_2/day (600 kg O_2/day)
2) Upgrade the cone to 1,923 lb O_2/day (870 kg O_2/day)

Both options include replacing the oldest Air-SEP to provide reliable redundancy and replacing both compressors due to limited remaining useful life and limited availability of spare parts (see Appendix B).

Per the current grant scope and budget, implementation of in-situ continuous monitoring, in the vicinity of the Speece Cone location, should be conducted to provide robust data sets taken more frequently. These data sets are useful for providing real-time feedback to optimize oxygen supply and alum dosage. Data can be uploaded several times per day and made available on a web tool to both the County and citizens.

As noted before both options result in a potential oxygen deficiency throughout the year. It was noted that possibly extending operation of the HOS could offset the deficiencies for either option.

3.1 Oxygen transfer modeling of the two options

The context for the evaluation of alternatives is how much oxygen each option can transfer to the hypolimnion. Oxygen transfer for each option is reviewed before the details of each option is discussed in sections below. The existing Speece Cone oxygen delivery system does not meet the HOD. Data provided by the County (Figure 4) agree with this conclusion. An important observation from these data is that dissolved oxygen depletion is strong even when stratification is weak (Figure 4).

Newman Lake is polymictic, meaning it turns over in the summer occasionally with prevailing winds. Vertical water mixing from the Speece Cone weakens the thermocline, increasing the tendency for summer turnover. Yet, despite weak thermal stratification and summer turnover, the oxygen deficit intensifies until the end of August. Modeling oxygen predictions in the hypolimnion looks at two oxygen transfer rates relative to the HOD rate of 2,100 lb O_2/day (950 kg O_2/day), which corresponds to observed spring HOD before the water column is influenced by historical pump operation as previously stated:

The oxygen transfer calculations are as follows:

1) Current cone capacity 1,320 lb O_2/day (600 kg O_2/day)
2) Upgraded cone capacity 1,923 lb O_2/day (870 kg O_2/day)

If future HOS operation follows historical HOS operation, starting after the onset of stratification and loss of oxygen in the hypolimnion is observed, then for an oxygen demand of 2,100 lb O_2/day (950 kg O_2/day) and a cone capacity of 1,320 lb O_2/day (600 kg O_2/day), the onset of anoxia is postponed by approximately 30 days (Figure 5). Likewise, with a cone capacity to 1,923 lb O_2/day (870 kg O_2/day) the hypolimnion maintains oxic conditions through destratification in late September (Figure 5).

These results consider HOD alone without potential for wind mixing transfer of oxygen within a partially destratified system. Note that these results overpredict onset of hypoxia by two months for 1,320 lb O_2/day (600 kg O_2/day) cone capacity compared to 2020 data. However, there can be strong interannual variability in the onset of hypolimnetic hypoxia. Higher winds in the spring will delay onset of hypolimnetic anoxia because there is little or no thermal stratification. The oxygen depletion model cannot account for wind mixing. Note that in

2020 thermal stratification began at the end of May. The cone began operation on May 29 and was followed by onset of hypoxic conditions within one month. Therefore, the model reproduces similar results of the time required for onset of hypolimnetic anoxia.

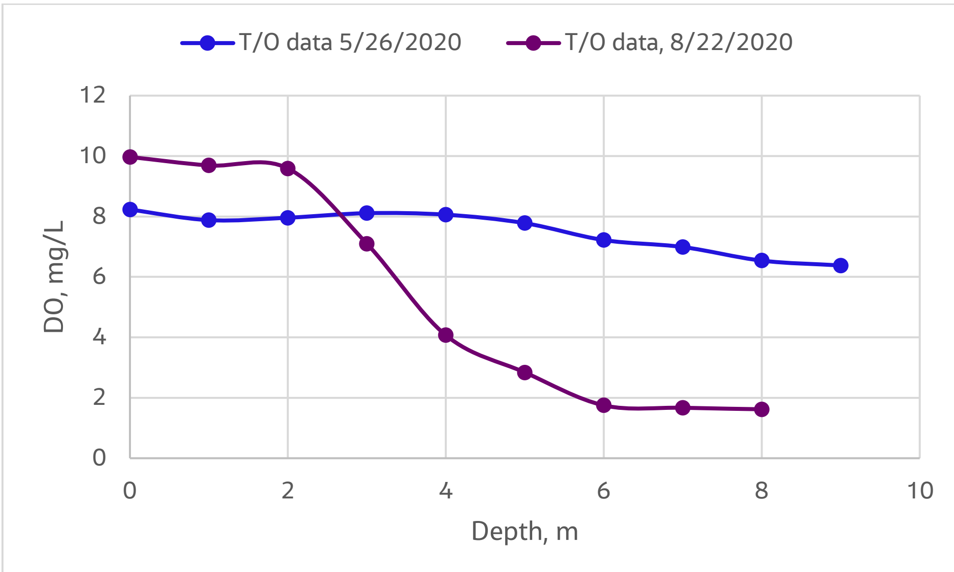

Figure 4. 2020 DO data

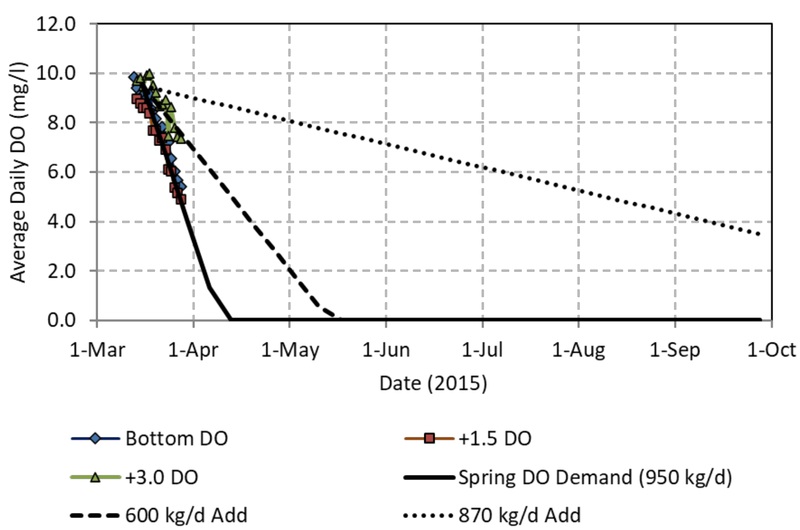

Figure 5. Remote data collected in March 2015 showing dissolved oxygen (DO) data, average depletion rate per the data (solid line) of 2,100 lb O_2/day (950 kg O_2/day) and predictions for 1,320 (dashed line) and 1,923 (dotted line) lb O_2/day (600 and 870 kg O_2/day) oxygen addition rates. Data points are from Figure B4 (Appendix A) and represent data collected 0.1 (red squares) 1.5, (blue diamonds), and 3.0 (green triangles) meters above the bottom.

3.2 Option No. 1 – Modify Existing Speece Cone Water Flow Rate to add 1,320 lb O_2/day (600 kg O_2/day)

As discussed above, running the existing Speece Cone at its capacity would require water flow rate to be reduced to 3,150 gpm to achieve a hydraulic residence time of 45 seconds. At this reduced flow rate, the oxygen addition capacity would be limited to 1,320 lb O_2/day (600 kg O_2/day) for 18 psi.

This option requires specifying a new pump that is similar to the existing pump but with lower capacity, mechanical design for a new pump, and replacement of the pump with additional construction underwater to adapt the new pump to the cone. A candidate replacement pump would be a Flygt 7020 (27 HP).

This option will not increase oxygen transfer to the hypolimnion but can reduce daily operating costs because of lower pump energy demand and lower oxygen production (compressor run time).

3.3 Option No. 2 - Pump Upgrade and Cone Modification to Increase Speece Cone Pressure to 35 psi to add 1,923 lb O_2/day (870 kg O_2/day)

To achieve a capacity of 1,923 lb O_2/day (870 kg O_2/day) a new pump with a capacity of 3,150 gpm at 35 psi is needed, along with an orifice plate to generate 22 psi of back pressure in the cone.

This option increases oxygen input to the hypolimnion and could noticeably delay the onset of hypoxia in the hypolimnion.

There is significant construction and budget risk to the option. There is a need to specify a new pump, adapt the new pump to existing infrastructure (power, transformer/panel (if needed), brackets, fish screen, adaptor to the cone inflow pipe), which entails some design work, and then install the new pump. Installation entails days of underwater work. The alternative to doing the work underwater would be to raise the cone to a barge, adapt the new pump on the barge, and then reset the pump in place. Labor costs alone would be $5,000 to $10,000 per day. There is substantial opportunity for budget overrun and unknown mechanical problems with the retrofit. An additional problem with budget risk is that there are few contractors in the region that are qualified to bid on this design.

Justification of this option is marginal. It would require a design study and getting bids for the retrofit from contractors to establish a budgetary evaluation.

3.4 Cost Evaluation

The costs provided in this section are high level for purposes of screening options and evaluating budget.

3.4.1 Capital Cost Comparison

- **Option No. 1 - Modify Existing Speece Cone Water Flow Rate to add 1,320 lb O_2/day (600 kg O_2/day):** Continue with the existing Speece Cone configuration but reduce water flow rate to 3,150 gpm and reduce the oxygen flow rate to 1,320 lb O_2/day (600 kg O_2/day). Deferring upgrade of Air-SEP units is an option because of reduced oxygen flux to cone. The $130,000 in the Capital Budget Grant Project for a new, smaller pump and a mass flow controller for oxygen supply is likely adequate for this option.
- **Option No. 2 - Pump Upgrade and Cone Modification to Increase Speece Cone Pressure to 35 psi to add 1,923 lb O_2/day (870 kg O_2/day):** Change the cone pump to meet a flow rate of 3,150 gpm and to meet a combined (pump head and static head) cone pressure of 35 psi to deliver 1,923 lb O_2/day (870 kg O_2/day). Install an orifice plate in the cone outlet to build up approximately 22 psi of back pressure (gauge pressure) in the cone. Costs for this upgrade unknown but are anticipated to be greater than the $130,000 in the Capital Budget Grant Project. A week of diver time alone, which may be necessary for reconstruction of the pump side of the cone could exceed this budget.

3.4.2 Relative Operation and Maintenance Costs

- **Option No. 1 - Modify Existing Speece Cone Water Flow Rate to add 1,320 lb O_2/day (600 kg O_2/day):** Power cost is predicted to be less than the existing operation due to only operating a single oxygen generator and lower energy from operation of a smaller pump, if operational strategies remained as they are. It should be noted that extending HOS operation could offset these operation cost gains.
- **Option No. 2 - Pump Upgrade and Cone Modification to Increase Speece Cone Pressure to 35 psi to add 1,923 lb O_2/day (870 kg O_2/day):** Power cost is predicted to be higher due to higher pump horsepower if operational strategies remained as they are. It should be noted that extending HOS operation would further increase power costs.

4. Future Consideration - Replace Existing Speece Cone with a Line Diffuser System to Add 4,400 lb O_2/day (2,000 kg O_2/day)

Another method to oxygenate the hypolimnion is to directly sparge oxygen gas to the hypolimnion through a mechanism such as a line diffuser (Figure 6). This is performed by adding small (oxygen) bubbles over a long length of the deepest part of the water column. Direct oxygen injection offers the same mechanism of geochemical control of internally loaded phosphorus by maintaining an oxygenated hypolimnion, more specifically elevated DO levels at the sediment-water interface through oxygen maintenance of the bulk water above.

The line diffuser system is different from destratification aeration (adding air for lake mixing). A pure oxygen line diffuser system would be designed at a low oxygen flux rate, which allows approximately 90% of oxygen gas to dissolve in water. Air bubbles, in contrast, are 78% nitrogen, none of which dissolves into the water because the water is already saturated with dissolved nitrogen.

Figure 6. Residual dissolved oxygen bubbles from a pure oxygen line diffuser in Vadnais Lake, Minnesota. Depth of diffuser is 14 meters.

The line diffuser system requires no diver inspection and would run from the oxygen pressure delivered by the Air-SEP units (> 60 psi). Thus, the line diffuser system does not require a pump.

Direct sparging, unlike Speece Cones, inject oxygen directly to the water column and utilize the hydrostatic pressure and the rate of bubble rise to facilitate oxygen transfer. As the bubbles are added by the line diffuser, they entrain the surrounding cold water as they rise towards the surface. The bubble-water mixture, termed a plume, rises through the water column in which the oxygen dissolves in the plume water.

As the plume rises through the water column, it eventually encounters warmer water at which point the plume loses momentum. This is identified as the depth of maximum plume rise (DMPR). Any remaining bubbles continue to rise to the surface, while the oxygenated water falls away from the plume. Since the oxygenated water is cooler than the surrounding water, but slightly warmer than the water where it was entrained at the bottom, it falls to a depth of equal density (ED). As the oxygenated water plunges to a depth of equal density, it mixes with the surrounding hypolimnion waters thus circulating the hypolimnion. This is displayed graphically in Figure 7 showing the different regions of the water column and the corresponding plume circulation. Additionally, line diffusers are very efficient at circulating a large volume of water because bubbles are added over a long diffuser run. It is a widely dispersed bubble plume that facilitates a broader distribution of geochemical augmentation by alum injection.

Line diffusers can be run at low flux rates that preserve thermal stratification or higher flux rates that partially disrupt it. The DMPR can be adjusted by altering the gas flux rate. A higher DMPR will tend to disrupt thermal stratification and a lower one will preserve it.

Line diffusers are designed using a plume model (Singleton et al, 2007) to model oxygen addition, water circulation, depth of maximum plume rise, and depth of equal density. The line diffuser consists of a supply pipe to carry the oxygen gas, a buoyancy pipe to position sans divers, anchors to hold it on the bottom, and porous hose to create the small bubble pattern (Figure 8).

Three data sets were used to evaluate plume dynamics, oxygen input capacity, and water column circulation for Newman Lake, April 22, May 28, and August 12, 2014.

The plume model was used to evaluate original oxygen delivery capacity of 3,000 lb O_2/day (1,370 kg O_2/day) and estimated maximum oxygen delivery capacity 4,400 lb O_2/day (2,000 kg O_2/day), which were 27 and 40 SCFM, respectively. Additionally, increasing oxygen delivery rates were evaluated which are typical for eutrophic systems that experience increased organic loading throughout the stratified period, applying 10, 20, and 30 SCFM in April, May, and August, respectively.

It was determined that a 2,000 ft line diffuser provided the best results for oxygen delivery to the hypolimnion within the deepest region of the lake after reviewing morphology and plume model results. Positioning of a 2,000 ft line diffuser is shown in Figure 9. Examples of plume model results for 27 and 40 SCFM applied gas flow rates are shown in Figure 10 for the May data set. Plume model results showed nearly 90% of the oxygen addition occurred in the hypolimnion for both flow rates. Review of the increased applied gas flow rate throughout the stratified period predicted 80 – 90% of the oxygen applied was added to the hypolimnion, in the initial plume created by the line diffuser (Figure 11). On occasion, a second plume was predicted, which demonstrates how oxygen is continued to be delivered to the middle water column, above the initial plume, which in turn results in a higher overall oxygen transfer efficiency to the water column.

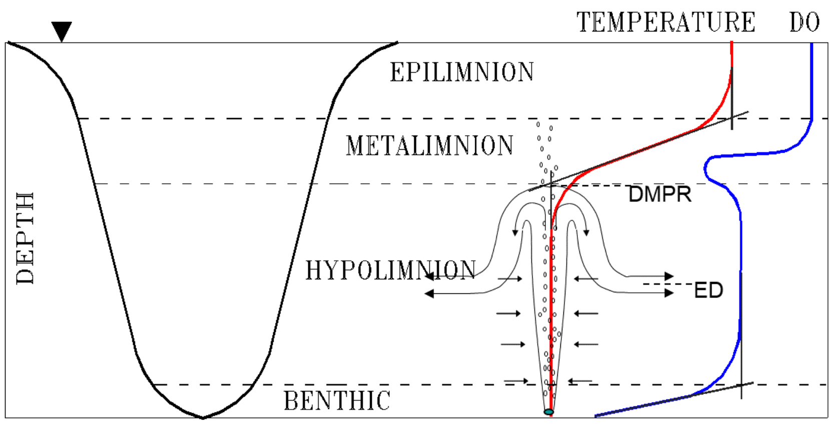

Figure 7. Schematic showing water column regions based on thermal structure with plume overlay showing example of circulation. Blue line represents a typical oxygen profile and red line represents a typical temperature profile. DMPR is the depth of maximum plume rise and ED corresponds the equal density layer plume water falls back to.

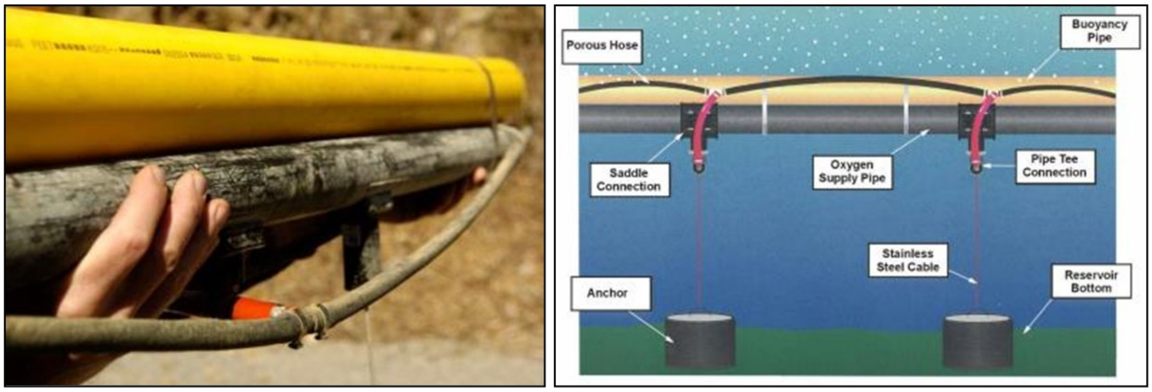

Figure 8. Line diffuser section (left) and deployment schematic (right).

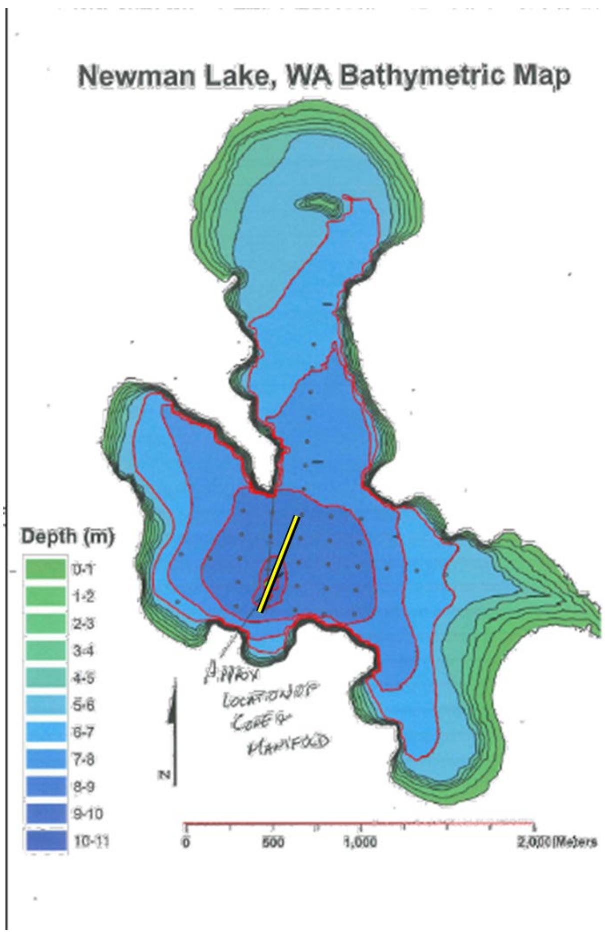

Figure 9. Example layout of a 2,000 ft line diffuser in Newman Lake

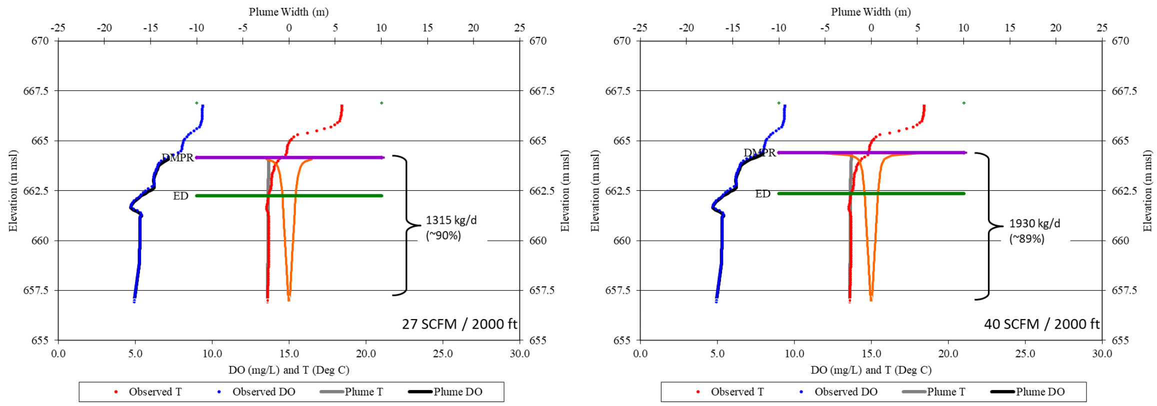

Figure 10. Example of plume model predictions for 27 and 40 SCFM applied gas flow rates for May 28, 2014 data set. Blue and red data points represent observed dissolved oxygen and temperature data respectively. Black and gray lines represent model predictions for dissolved oxygen and temperature respectively. Orange lines represent plume width and the purple and green lines correspond to DMPR and ED respectively.

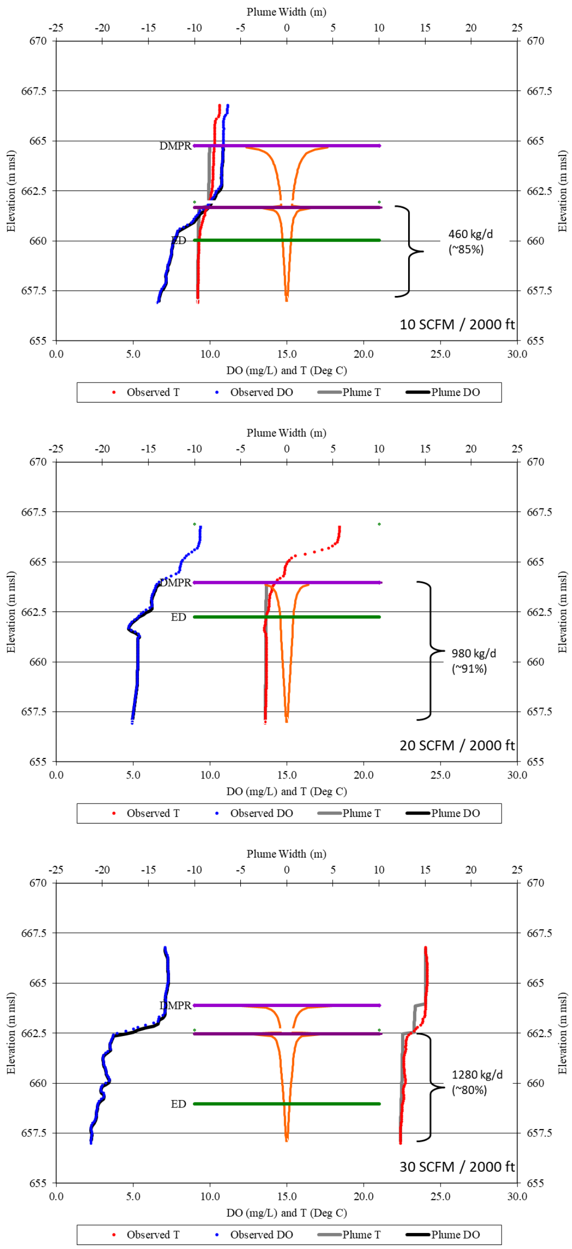

Figure 11. Example of plume model prediction for 10, 20, and 30 SCFM applied gas flow rates on April 22 (top), May 28 (middle), and August 12, 2014 (bottom) respectively.

Using an average oxygen transfer efficiency (OTE) of 90% per the plume model predictions, a line diffuser is predicted to add approximately 1,900 kg O_2/day. This oxygen addition rate would enable the hypolimnion to maintain oxic conditions through predicted destratification in late September as shown in Figure 12.

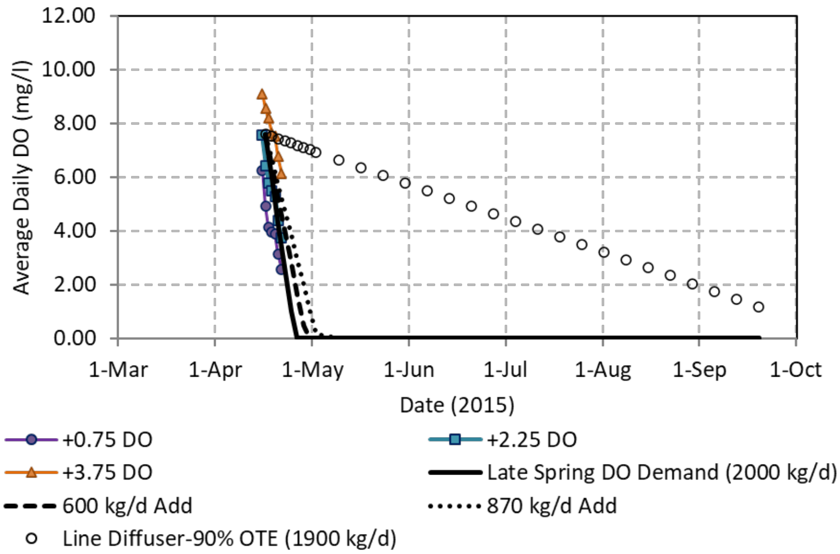

Figure 12. Remote data collected in May 2015 showing dissolved oxygen (DO) data, average depletion rate per the data (solid line) of 4,400 lb O_2/day (2,000 kg O_2/day) and predictions for 1,320 (dashed line), 1,923 (dotted line), and 4,200 (open circles) lb O_2/day (600, 870, and 1,900 kg O_2/day) oxygen addition rates. Data points are from Figure B4 (Appendix A) and represent data collected 0.1 (red squares) 1.5, (blue diamonds), and 3.0 (green triangles) meters above the bottom.

Installing a line diffuser system would require removing the cone and distribution pipe. The likely method of removal would be to raise the cone using salvage floats, crane the cone to a barge, and then transfer the cone to the public boat landing where it would be hauled off to be cut up for scrap metal. It is assumed that the cone has no other salvage value.

The line diffuser system would be constructed shoreside at the Sutton Bay resort or the public boat landing. It would be connected to the oxygen supply at the water edge, moved into position and then sunk in place. An alum dosing pipe would be strapped to the line diffuser where alum pumped into the lake would be mixed by the plume.

Installing a line diffuser hypolimnetic oxygenation system that can meet the maximum observed HOD has a Class 4 preliminary estimated cost of $387,000 in 2020 dollars, including removal of the current Speece Cone and distribution header (Table 1). A Class 4 preliminary estimate is a study level estimate based on 1% to 15% Project Definition. A Class 4 estimate is assumed to be accurate within a - 30% to +50% range, with unknowns for this project that include:

- Bidding climate
- Availability of materials and labor. For example, had the improvements been constructed in 2020, material costs would likely have been higher than anticipated due to Covid 19 disruptions.
- Construction access

Table 1. Line diffuser cost summary (Class 4* estimate in 2020 dollars)

DESCRIPTION	QUANT	UNIT	$/UNIT	TOTAL COST
Structural/Mechanical				
Mobley - Diffusers	1	1	$150,000	$165,000
Electrical Work (Mass flow controller)	1	1	$5,000	$5,000
Civil Work (simple connection to supply line)	1	EA	$2,000	$2,000
SUBTOTAL				$172,000
CONTRACTOR MARKUPS (OH, Profit, Mobilization, Bonds, Ins)	29%		$172,000	$49,880
ENGINEERING (Design, Construction Observation)	20%		$172,000	$34,400
SUBTOTAL				$256,280
CONTINGENCY	25%		$221,880	$55,470
SUBTOTAL				$311,750
Demo of existing in-lake equipment	1	EA	$75,000	$75,000
TOTAL COST				$386,750
Note: A Class 4 preliminary estimate is a study-level estimate based upon 1% to 15% Project Definition. A Class 4 estimate is assumed to be accurate within a -30% to +50% range.				

Replacing the Existing Speece Cone with a Line Diffuser System to add 4,400 lb O_2/day (2,000 kg O_2/day) would result in a system with lower power cost due to no need to power a pump. Operational costs would also be lower due to no need for underwater pump maintenance.

5. Recommendations

5.1 Recommendations for Improving the Efficiency of the Existing HOS

To improve the efficiency and operation of the existing HOS, Option No. 1, Modify Existing Speece Cone Water Flow Rate to add 1,320 lb O_2/day (600 kg O_2/day), is recommended. Option No. 1 includes replacing the current pump with a lower capacity pump and reducing the oxygen flow rate. With the State Capital Budget Grant Award funds currently available, Option No. 1 is the most reliable choice.

Additional recommendations to increase the reliability and redundancy of oxygen generation in the near term, as well as after future long-term upgrades have been implemented, include:

- Replacing the back-up Air-SEP unit with a newer model
- Replacing both compressors

Option No. 1 and related recommendations will provide the following benefits:

- Will lower daily operating cost, as Option No. 1 requires operating one Air-SEP and compressor only
- Is lower project risk than Option No. 2:
    - The pressure in the cone will not be increased, so there is no additional risk of seal failure due to higher pressure.
    - Would only involve pump replacement, which is more straightforward and biddable than more extensive modifications to the cone
- Will not prevent hypoxic conditions in the summer; however, can offset hypoxia by at least 30 days, based on 2,100 lb O_2/day (950 kg O_2/day) oxygen depletion model. For 4,400 lb O_2/day (2,000 kg O_2/day) HOD, this offset would be approximately 7 to 10 days.
- Will increase the operational efficiency of the existing HOS, resulting in more oxygen being dissolved in the water as it passes through the cone and fewer bubbles being released to the water column
- Additional lake health benefits may be realized by extending duration of HOS operation
- Will add reliability and stability (due to the replacement of back-up Air-SEP unit with a newer model, and replacement of the compressors)
- Will provide equipment that can be utilized for future long-term upgrades
- May benefit water quality if the period for HOS operation is extended

5.2 Alum System Recommendations

As described in Section 1.3 Replacing clogged alum pipes with larger pipes and replacing the alum pump to prevent alum pipe clogging are also recommended and within the scope and budget of the Capital Project.

5.3 Additional Considerations

Along with implementation of Option No. 1 to modify the pump supplying the Speece Cone, the following should also be considered:

- Explore operational changes, such as initiating HOS and Alum System operation earlier in the spring, that could add to lake health. Operating the HOS and Alum System longer will result in additional operating costs for electricity, alum, staffing, etc.
- Evaluate the effect of onset of ice cover in a field trial from extending HOS operation up to observations of ice formation.

- Reevaluate the rate of alum addition per new EPA ambient aluminum criteria. Longer-term alum addition to sequester phosphorus may be required.
- The structural condition of the existing Speece Cone and distribution pipe are “fair to good” and will degrade with progression of corrosion to “poor to fair”. It is predicted that within a 10 years, the expected remaining life, that the Speece Cone and distribution pipe will need to be replaced.

5.4 FUTURE RECOMMENDATION

A pure-oxygen line diffuser HOS should be considered for future replacement of the Speece Cone HOS. This technology has emerged in the last 20 years with some 36 projects in operation in the United States. It would lower operational costs compared to the current HOS Operational Parameters, while still utilizing the existing, and proposed upgraded/replaced, onshore equipment. However, this alternate does not fit within the Capital Project scope and budget and is therefore not considered a feasible option at this time.

The line diffuser system is the only option that will meet the maximum observed HOD, it does not fit within the Capital Budget Grant Project scope and is therefore not considered a feasible option at this time.

Finally, the authors of this report emphasize that the oxygen delivery shortcomings of the current Speece Cone HOS do not indicate fault of the original design. Rather, the original design was first of its kind worldwide, a milestone of lake restoration technology. Much has been learned since then. Findings of this study reflect those advances in knowledge and provide a technical path forward to manage Newman Lake.

6. References

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Appendix A. Recalculation of Hypolimnetic Oxygen Demand

Appendix B. Memorandum: System Inefficiencies and Problem Areas Noted During the Site Visit

Appendix C. Routine Level Dive Inspection Letter Report