Technical Memorandum

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Subject	Alternatives Evaluation Technical Memorandum	**Project Name**	Newman Lake Water Quality Improvements Project
Attention	Derek Vilar, Project Manager	**Project No.**	D3782800
From	Roger Scharf/Jacobs David Austin/Jacobs		
Date	February 2, 2024		

1. Introduction and Purpose

Spokane County (County) and the Newman Lake Flood Control Zone District (NLFCZD) have been awarded funding from the Federal American Rescue Plan Act for implementation of a Newman Lake Water Quality Improvements project. A previous study (Phase 1a of a Capital Budget Grant Project, with the deliverable being the March 2021 Phase 1a Report) focused only on the existing systems. The County and NLFCZD desired to conduct a detailed analysis of the lake and evaluate the most effective approach to improving Newman Lake water quality and eliminate harmful algae blooms. This more detailed analysis included:

- An assessment of Newman Lake water quality during 2023
- Alternatives analysis done in parallel with a water quality assessment

The purpose of this technical memorandum is to document the alternatives that were evaluated and how the best alternative for implementation was selected.

Spokane County and NLFCZD would like to construct the Newman Lake water quality improvements in 2024. To this end, a number of steps required for this detailed analysis were performed simultaneously:

- Water quality assessment
- Oxygen demand calculations
- Alternatives analysis

As a result of the simultaneous evaluation steps, it has been necessary to update the alternatives as more has been learned about water quality needs.

2. Water Quality Goals

In early October 2023, Jacobs led a chartering session workshop (Workshop 1) with County-identified decision makers and stakeholders to define water quality goals and evaluation criteria. Based on the discussion at this workshop, it was agreed that the Newman Lake Water Quality Improvements project should aim for the following water quality goals:

- 12 milligrams per liter (mg/L) total phosphorus (TP) based on Slide 7 data correlating with a 4-meter Secchi depth
- No cyanobacteria cell counts greater than 20,000 cells/mL
- Microcystin less than 4 micrograms per liter (µg/L)[1]
- No human *E. coli* detections violating Department of Ecology primary contact concentrations[2]
- Support a cold-water fishery (lake whitefish or rainbow trout fishery) in the hypolimnion during the summer

3. Non-Monetary Criteria

The following non-monetary criteria were also developed during Workshop 1:

- Water quality impacts
- Reliability
- Equipment Complexity and ability to maintain
- Operational flexibility
- Future nutrient loading
- Efficiency
- Timeline to observed water quality impacts
- Safety and security
- Regulatory requirements

4. Alternatives Evaluation

Based on the goals and criteria developed during Workshop 1, Jacobs provided a short-list of two main alternatives plus sub-alternatives for further consideration (Table 1). The alternatives listed in Table 1 were originally assumed to be necessary to meet project goals from Workshop 1. However, the results of the water quality assessment resulted in a need to revisit the initial short-listed alternatives.

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[1] 4 µg/L is the low-risk threshold recommended by the World Health Organization. It is equivalent to 20,000 cyanobacteria cells/liter. Washington State Department of Health has a recreational standard of 6 µg/L.

[2] The 2012 U.S. Environmental Protection Agency recommendation for safe recreation is a geometric mean of less than 100 cells/mL. Washington State Department of Ecology standard for primary contact use is <50 CFU/100 mL 76.3% of the time. CFU is colony forming units. The geometric mean is based on a minimum of three samples within a 30-day period. Standard practice is to take weekly samples to create a rolling geometric mean.

Table 1. Short-listed Alternatives Prior to Full Analysis of Water Quality Data

1. Linear Diffuser System with Periodic Whole Lake Alum Application
    a. Maintain existing oxygen supply system
    b. Increase oxygen supply
2. Linear Diffuser System with Continuous Alum Feed (upgrade alum system)
    a. Maintain existing oxygen supply system
    b. Increase oxygen supply

4.1 Water Quality Analysis Conclusions and Recommendations

In parallel with the alternatives screening, an assessment of Newman Lake water quality was performed, and this assessment led to the following conclusions:

- A highly aerobic hypolimnion, which is not provided by the current Speece cone oxygenation system, is critical to water quality. Thus, upgrades to the on-shore and in-lake components of the oxygenation system are needed.
- There is no need for alum addition to the hypolimnion because there is more than sufficient sediment iron to bind phosphate-P, provided the hypolimnion is fully aerobic (dissolved oxygen [DO] 4.0-8.0 mg/L).
- A properly sized and functioning oxygenation system alone can probably meet total maximum daily load TP criterion of 20 µg/L.
- The water quality goal of 12 µg/L TP (4.0 Secchi disk depth) is within practical reach but cannot be consistently reached while there is internal phosphorus loading.
- Epilimnetic (surface water) geochemical augmentation with alum to manage the impact of watershed phosphorus loading may be required, but determination of that need first requires water quality data obtained over 1 year after installation of a linear diffuser system.
- It is important to understand the extent to which carp are contributing to the phosphorus loading because it will be difficult, if not impossible, to meet 4.0 Secchi disk if the carp population is excessive. Field observation by Dr. Bajer indicates that the carp population currently may be at low populations densities. A carp study is needed to understand the risk of carp population rebound which would impair future water quality.

4.2 Oxygenation Alternatives

At Workshop 2, which took place in mid-November 2023, Jacobs presented the results of the water quality assessment, which led to an updated list of four alternatives that do not include hypolimnetic alum addition, as it has been determined to be unnecessary per the water quality assessment. Two alternatives proved to be technically infeasible due to obsolete equipment or the risk of destratification, and Jacobs recommended developing hybrids of the two feasible alternatives that include optional items to be provided if budget allows.

Since Workshop 2, hypolimnetic oxygen demand (HOD) has been revisited using data from the 2023 water quality study. An HOD value of 1,541 kilograms of oxygen per day (kg O_2/d) is the recommended design criteria based on 2023 water quality data but recognizing previous HOD calculations that range from 1,000 to 2,350 kg O_2/d (see Attachment 1). Based on the recommended HOD, the feasible alternatives from Workshop 2 were expanded into four hybrid alternatives that all meet design HOD and potentially fit within the budget, depending on bidding climate and project unknowns (Table 2). These hybrid alternatives, which include different sizes of pressure swing adsorption (PSA) equipment among other things, will be refined during the predesign phase as more is learned about project unknowns, and bidders can be asked to provide bids on alternates to be included if budget allows.

An Association for the Advancement of Cost Engineering International (AACE) Class 5 opinion of probable construction cost (OPCC) for each alternative is presented in Table 2. The costs in Table 2 include demolishing the existing Speece cone and replacing it with a modern linear diffuser system. An estimate of this type would be accurate within plus 100% or minus 50%. A 30% contingency has been included in this cost estimate as a provision for unforeseeable additional costs within the general bounds of the project scope. Annual operating costs, which include power only since other annual costs are considered to be the same for all alternatives, are also shown in Table 2.

Table 2. Hybrid Alternatives Data

Alternative	Design Oxygen Delivered to Hypolimnion, kg/d[a]	Scope	OPCC, $M[b]	Annual Operational Cost $K[c]
1	1,678	▪ Rehab existing AS-L[d] ▪ New compressor for existing AS-L ▪ New AS-L PSA and compressor	1.64	32
2	1,911	▪ Rehab existing AS-L ▪ New compressor for existing AS-L ▪ New AS-N PSA and compressor	1.69	40
3	2,219	▪ Rehab existing AS-L ▪ New compressor for existing AS-L ▪ New AS-P PSA and compressor	1.87	48
4	2,836	▪ Two new AS-P PSA system and compressors (completely redundant)	2.16	64

[a] Assumes 95% oxygen purity and 72% oxygen transfer

[b] Plus 100% or minus 50% accuracy range with a 30% contingency; does not include engineering, administration, permitting, or sales tax.

[c] Assumes 250 days of continuous operation per year, $0.07/kWh, $37.20/month service charge, $7.82/kW demand charge.

[d] AirSep Standard Generator models are numbered AS-D+ through AS-P

kWh = kilowatt-hours

4.3 Design Contingency and Redundancy

Because the alternatives in Table 2 involve similar technology, they are equal with respect to meeting most of the non-monetary criteria. However, the alternatives that provide more oxygen could be considered slightly better at meeting the non-monetary criteria of reliability, flexibility, and perhaps future nutrient loading.

As discussed in Attachment 1, Newman Lake HOD calculations have varied. The alternatives in Table 2 provide increasing oxygen delivery with increasing cost. HOD is not anticipated to increase in the future based on past experience with pure oxygen projects where long-term HOD tends to decrease when hypolimnion DO is maintained near saturation. However, redundancy for mechanical failure or maintenance is desirable should the project budget allow it. Jacobs is confident that Alternate 1, which minimizes compressor building modifications and thus minimizes cost, will provide sufficient oxygen. However, the other alternatives provide a larger contingency and may provide redundancy.

4.4 Discussion of Alternatives

Final alternatives selection will take place during predesign as project costs are refined. All can be constructed in 2024. Things to consider when making a final selection include the following:

- Alternative 1 meets design criteria and is the lowest cost.
- Alternative 1 does not provide redundant capacity.
- Alternatives 2 and 3 may provide redundancy if the future HOD is at the lowest observed HOD of just under 1,000 kg/d.
- Alternative 4 is fully redundant for even the most conservative HOD calculations.
- Alternative 2, with the new AS-N PSA, may allow for future upgrade to Alternative 4 when the second PSA is replaced.

5. Project Unknowns

There are unknowns associated with this project to be investigated during predesign. These unknowns, which will impact total project cost, include the following:

- Compressor Building layout to fit larger equipment may result in the need to move receiver tanks outside the building or other modifications that add cost to the project.
- Compressor Building upgrades required to meet update building codes
- Power supply upgrade requirements
- The extent of re-trenching required for oxygen supply lines from the Compressor Building to the lake

6. Other Water Quality Improvement Recommendations

Upgrading the oxygenation system as described in Section 4 is a crucial step toward improving Newman Lake water quality. Other recommendations for improving Newman Lake water quality include the following.

- Install multi-parameter water quality sensors for Newman Lake to monitor DO, temperature, conductivity, and pH at one location at two depths (9 meters and 2 meters) on cellular telemetry.
  - If budget allows, also include a phycocyanin and Chlorophyll-*a* sensor.
  - Make data available to citizens via a web tool.
- Carp study:
  - Determine age class structure and density of carp population. This study will determine how close the carp population is to the critical water quality threshold of 100 kilograms per hectare (kg/ha) (89 pounds per acre).
  - Determine years of greatest carp recruitment to understand conditions that favor carp recruitment.
  - Estimate at least qualitatively the potential for a successful recruiting year to raise carp populations above 100 kg/ha.
  - Create a conceptual carp management plan suggested by study results.
- Epilimnetic alum dosing
  - Involves injecting low doses of alum into a bubble plume at an alum dosing station at key locations in the epilimnion, with operational control over dosing rates
- Citizen science:
  - With citizen consultation, determine how a citizen science group can be integrated into water quality monitoring program
  - Organize and equip the citizen science group per the program

Attachment 1

Calculation of Newman Lake Hypolimnetic Oxygen Demand from Dissolved Iron, Manganese, Ammonia-Nitrogen, and Chlorophyll-*a*

Calculation of Newman Lake Hypolimnetic Oxygen Demand from Dissolved Iron, Manganese, Ammonia-Nitrogen, and Chlorophyll-*a*

Abstract

Based on an analysis of 2023 data, the hypolimnetic oxygen demand (HOD) is 1,541 kilograms of oxygen per day (kg O_2/d). This HOD calculation breaks up oxygen demand into constituent parts: iron, manganese, ammonia-N, settled algae (Chl-*a*), and oxygen required to raise hypolimnion dissolved oxygen to saturation. The sum of oxygen demand from iron, manganese, ammonia-N, and settled algae is 678 kg O_2/d. The Speece cone can only provide 556 kg O_2/d when operating at 95% O_2 purity, which provides an explanation for the summer oxygen sag consistently observed when the Speece cone is operating. The oxygen required to raise hypolimnion dissolved oxygen to saturation while satisfying the oxygen demand exerted by its parts is 863 kg O_2/d, resulting in a total calculated HOD of 1,541 kg O_2/d. The HOD value is in close agreement with other HOD analyses and resolve uncertainty between these studies.

Introduction

Accurate calculation of HOD is the foundation of design for the oxygenation system. Data obtained in 2023 provides key insight into design HOD. The whole lake experiment turned off the Speece cone on August 7th. Afterward, the hypolimnion was fully anoxic for about one month. During this time there was solubilization of iron, manganese, and ammonia-nitrogen from sediments, all of which exert an oxygen demand that can calculated from the chemistry of re-oxidation. Also, Chl-*a* measured in the hypolimnion can be translated to sediment oxygen demand (SOD) because it is a way to measure how settled phytoplankton can deplete oxygen at the lake bottom. From these parameters, HOD can be calculated.

Defining the Hypolimnion

From the perspective of calculating HOD, defining the hypolimnion is not simple. The hypolimnion is the area or volume under the thermocline. The HOD is calculated from the area or volume under the thermocline. Both area and volume perspectives of the hypolimnion are helpful to calculate HOD, depending on the data used for the calculation.

Defining the depth of thermocline requires careful consideration of the 2023 data. Looking at temperature data, the thermocline would be set at about 4 meters (m) depth in spring, 5 m early summer, and in late summer it is diffuse starting at about 5 m and ending around 8 m (Figure 1). It is tempting to pick 4 m because it is the most conservative choice. The area and volume under the 4 m depth curve is most of the lake, however. Choosing 4 m to calculate HOD would result in a needlessly high design HOD and unnecessarily higher expense.

Looking at dissolved oxygen (DO) saturation data helps define the hypolimnion with more clarity for the purposes of calculating HOD (Figure 2). The oxycline is the depth at which DO drops precipitously. Oxygenation must meet the oxygen demand below the oxycline. Above it, wind mixing of the epilimnion satisfies oxygen demand. The bottom of the oxycline is at about 6 m depth early in the summer. Late in summer, the thermocline erodes, but is still strong at the end of August. At that time, the bottom of the oxycline is at about 7 to 8 m. From an oxycline perspective the HOD volume or area calculation would be under the 6 to 8 m curve. A conservative calculation sets it at 6 m.

The choice of oxycline depth can be refined by looking at iron (Fe) and manganese (Mn) data. There is no significant difference for total Fe at the mid-lake station between the middle of the water column (5 m) and the surface (Figure 3). At 5 m, iron is just as oxidized as at the surface. At the north and south stations there is solubilized Fe at the bottom (6 m) (Figure 4, Figure 5). Thus, there is an oxycline between 5 and 6 m.

For HOD calculation the hypolimnion volume from 6 to 10 m is approximately 3,236,000 cubic meters (m^3). The area under the 6 m curve is approximately 1,975,000 square meters (m^2).

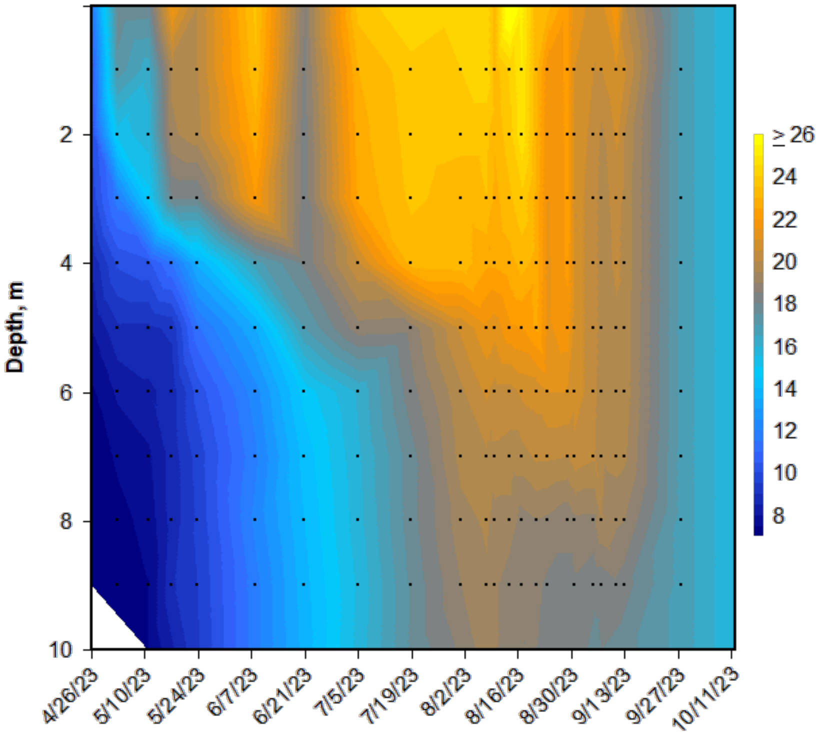

Figure 1. Temperature (°C) Profile at the Mid-lake Station

Dots are sample points (same for DO below).

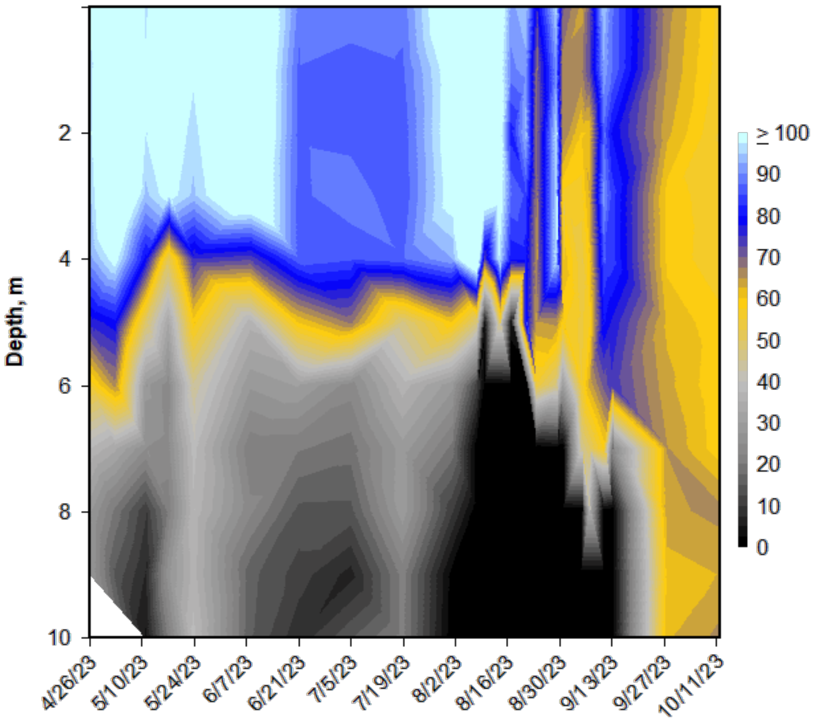

Figure 2. DO Saturation at Mid-lake Station

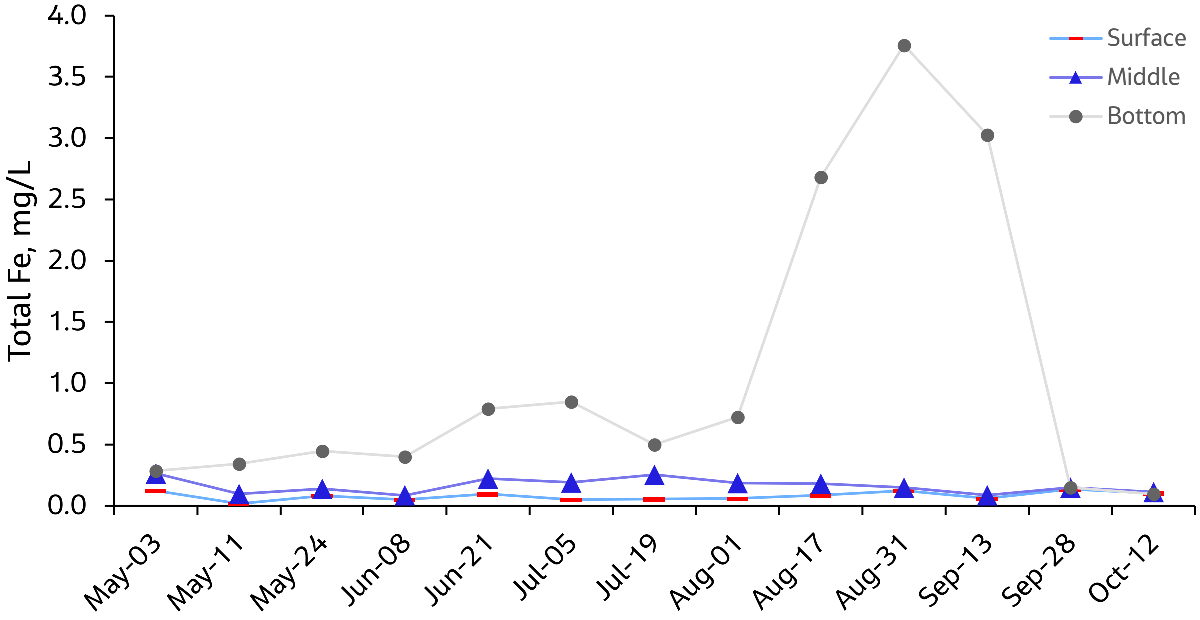

Figure 3. Mid-lake Station Total Fe

Oxygen demand of iron

There is solubilization of iron at the bottom of the north and south monitoring stations. station (Figure 4, Figure 5). Bottom total iron at these stations (5 m) is about five times greater than at the bottom of the mid-lake station (10 m). It is important to note that turning off the Speece cone does not affect bottom total iron concentrations as it did at the bottom of the mid-lake station. Thus, at 5 m depth there is little geochemical influence of the hypolimnion. There is sufficient oxygen transfer from wind-induced mixing to oxidize most iron at 5 m. This effect is also observed at 5 m in the mid-lake station (Figure 3).

The clear conclusion from these findings is that 5 m is not the correct depth to mark the top of the hypolimnion. It must be deeper.

There is no iron data between 5 and 10 m depth, but it is possible to observe the effect of iron on oxygen depletion rates. Ferrous iron reacts abiotically with oxygen. Any iron mixed up from the hypolimnion into contact with oxygen-rich surface water oxidizes within minutes. Depletion rates of oxygen at a transition zone between the epilimnion and hypolimnion will vary chaotically. At a stability stratified zone, the rates will tend to be more stable. The DO depletion rates are 6 m depth are far less stable than at 7 and 8 m (Figure 6). Thus, 6 m is a conservative choice for the top of the hypolimnion to calculate HOD.

The specific rate of iron solubilization was 0.1 milligrams per liter per day (mg/L/d) from the time the cone was turned off until mixing lowered Fe (Figure 7). The Fe mass solubilization rate for the hypolimnion volume is 324 kilograms per day (kg/d).

The oxygen required to re-oxidize the iron is 2.26 g Fe^{2+}: g O per complete oxidation to magnetite (Equation 1). Thus, the iron HOD is 124 kg/d.

Equation 1. $3Fe + 2O_2 \rightarrow Fe_3O_4$

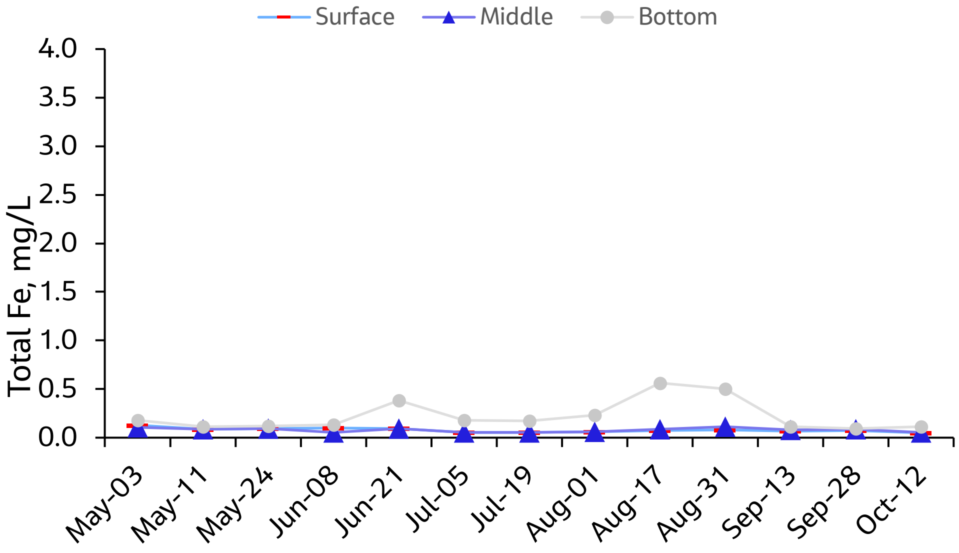

Figure 4. North Station Total Fe

Note that the vertical axis scale is the same as at the mid-lake station.

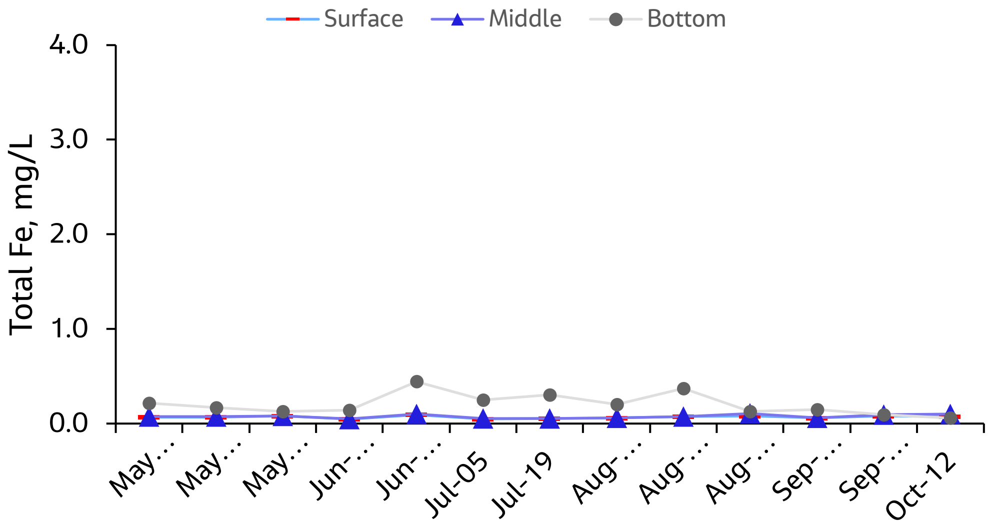

Figure 5. South Station Total Fe

Note that the vertical axis scale is the same as at the mid-lake station.

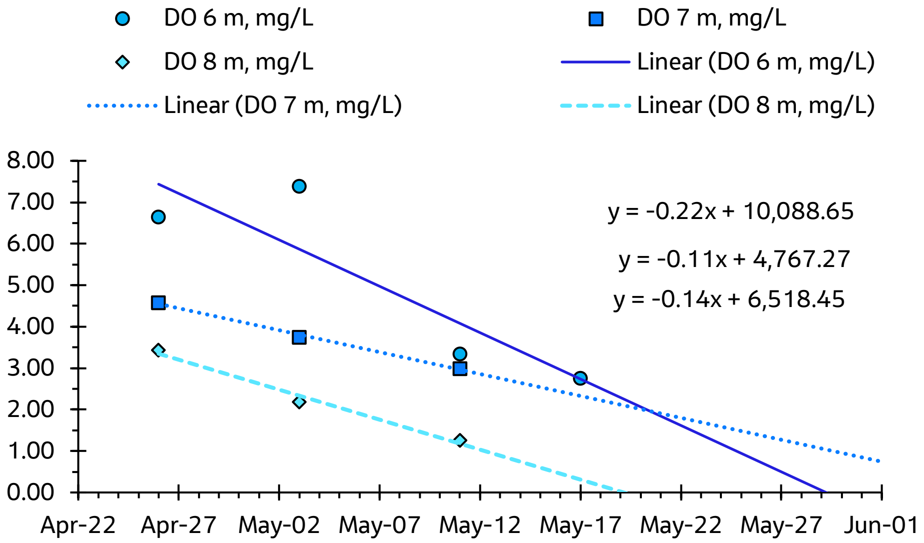

Figure 6. Dissolved Oxygen Depletion Rates In the Upper Hypolimnion

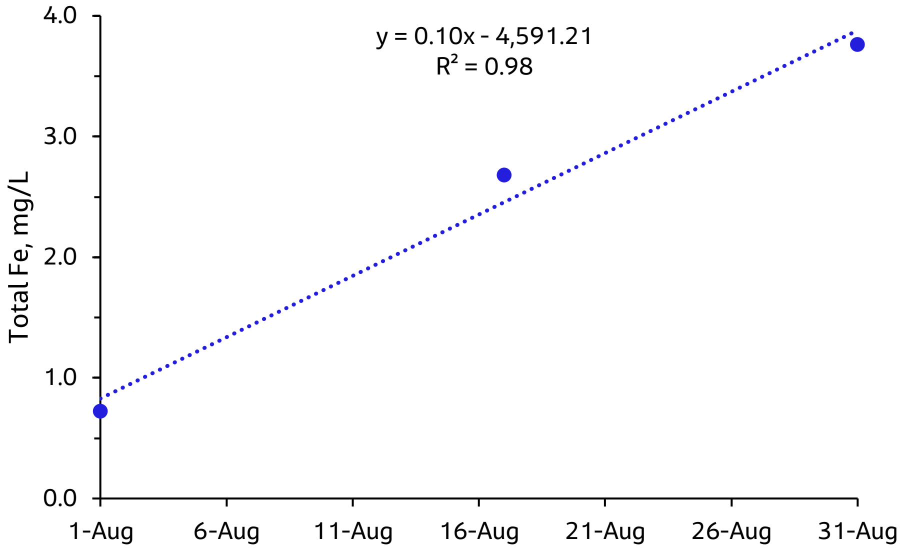

Figure 7. Iron Solubilization in August

The slope of the curve is the iron solubilization rate in mg/L/d.

Oxygen Demand of Manganese

Calculation of the oxygen demand exerted to oxidize Mn^{2+} to Mn^{4+} follows the same method as Fe oxidation. The specific rate of hypolimnetic Mn solubilization is 0.004 mg/L/d, or 13 kg/d for the volume of the hypolimnion (Figure 8), which exerts an oxygen demand of 5 kg/d per the mass ratio of 2.58 grams (g) Mn: g O as derived from (Equation 2).

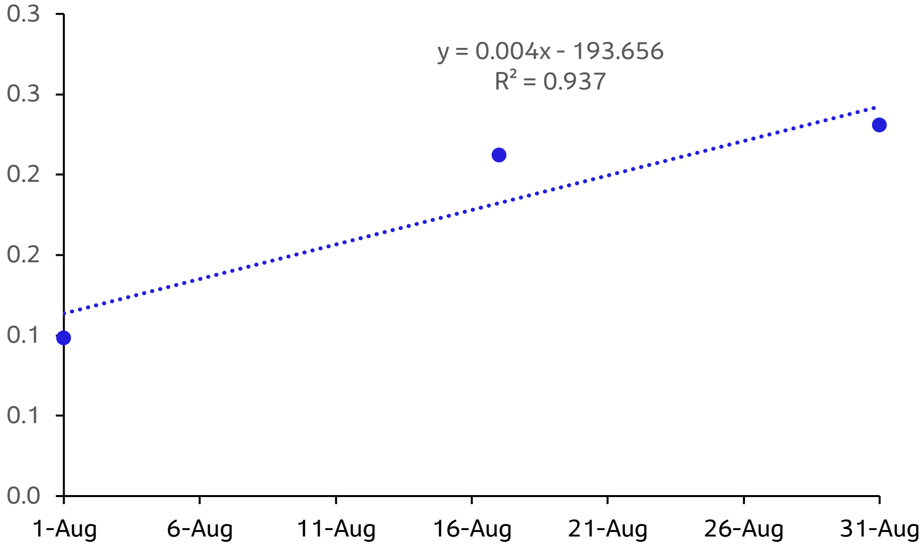

Figure 8. Manganese Solubilization in August

Equation 2. $3Mn + 2O_2 \rightarrow Mn_3O_4$

Oxygen Demand of Ammonia-Nitrogen

Ammonia-nitrogen (NH_3-N) has a high oxygen demand of 4.57 g O: g NH_3-N to fully oxidize to nitrate. Thus, the specific rate of NH_3-N accumulation (0.017 mg/L/d) in the hypolimnion (Figure 9) exerts a substantial oxygen demand of approximately 251 kg O_2/d.

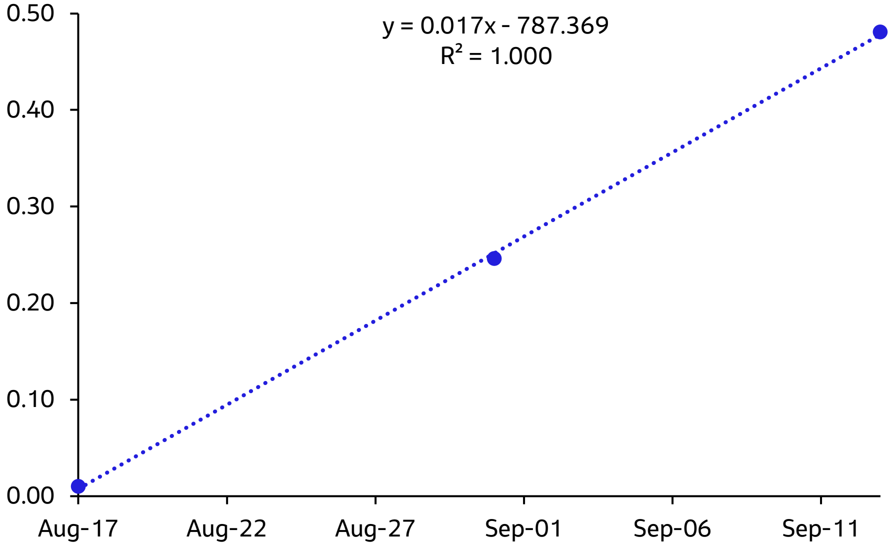

Figure 9. Rate of Ammonia-N Accumulation in the Hypolimnion

Oxygen Demand of Chlorophyll-*a*

Chlorophyll-*a* (Chl-*a*) is a pigment common to all phytoplankton. Decay of phytoplankton settled to the bottom exerts an oxygen demand at the sediment surface. Consequently, Chl-*a* can be a surrogate parameter for SOD per the Equation 3 (Walker Jr, 1985). Although Equation 3 is empirical and dimensionally inconsistent, experience has shown that it gives fairly accurate results for SOD in mg O_2/m^2/d.

Equation 3. $SOD = 219 Chla^{0.45}$

As noted in the water quality report, there is an accumulation of Chl-*a* in the bottom at all three sampling stations (Figure 10). The average rate of Chl-*a* accumulation is 0.44 mg/m^3/d at the bottom of all three sampling stations in July and August during the period of greatest Chl-*a* accumulation. Over the area of the hypolimnion rate of Chl-*a* accumulation exerts a specific oxygen demand of 0.15 g/m^2/d. Over the area under 6 m depth the HOD is 298 kg/d.

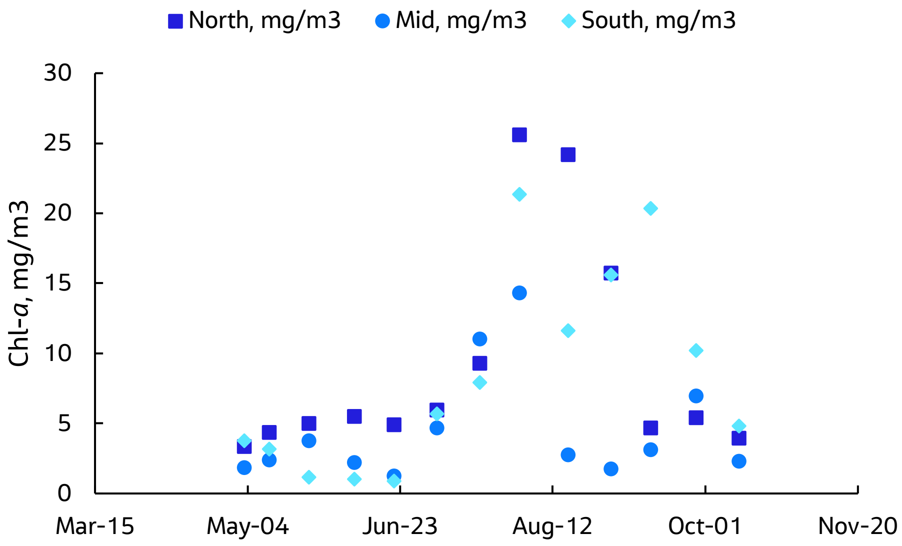

Figure 10. Chl-*a* Accumulation at the Lake Bottom

Total Hypolimnetic Oxygen Demand

The sum of the oxygen demand calculated for each parameter is 678 kg/d. This value is not the design HOD. It represents only enough oxygen to oxidize each parameter. There is no DO left over for habitat and to oxidize residual organic material in the sediment. To account for this additional HOD, there needs to be a calculation of the additional oxygen needed to bring the hypolimnion to a concentration of saturation, which is approximately 8 mg/L at the end of summer (~20°C).

To make this calculation, consider the oxygen demand if the hypolimnion is anoxic (DO = 0.0 mg/L) and the net balance of oxygen injected is equal to 678 kg/d. How much more oxygen over 678 kg/d is needed to raise DO to 8.0 mg/L in 30 days?

The data indicate that there is a DO crunch in about the last 30 days of summer, hence the 30-day reoxygenation criterion. Assuming a reoxygenation rate from 0.0 mg/L to 8.0 mg/L over 30 days, this rate of reoxygenation is an additional 0.27 g $O_2/m^3/d$ (mg/L/d). The volume of the hypolimnion is 3,236,000 m^3. Multiplying 0.27 g $O_2/m^3/d$ by this volume corresponds to 863 kg O_2/d additional oxygenation capacity.

The reoxygenation rate must be higher than the observed oxygen depletion rate (Figure 6). Calculation of DO depletion rates is done by plotting DO values at a set depth for starting values near 4.0 mg/L to end values greater than 1.0 or 2.0 mg/L. Lower DO values do not give reliable, linear depletion rates.

The slope of the curve fit to plotted date is the DO depletion rate in milligrams per liter per day (mg/L/d). Data from 6 m are somewhat chaotic because there is influent from mixing of surface waters. Data from 7 and 8 m are better behaved with less influence from vertical mixing. Deeper data begin with DO values too low for calculation. The average DO depletion rate observed from 6 to 8 m depth is 0.16 mg/L/d.

The reoxygenation rate of 0.27 mg/L/d is 41% higher than the depletion rate. Moreover, the reoxygenation rate is in addition to the oxygen demand exerted by iron, manganese, and settled algae.

The observed depletion rate is partially a function of these three factors. Thus, the reoxygenation rate is aggressive and provides a margin of safety.

Summing the measured oxygen demand and the reoxygenation rate gives a total calculated HOD of 1,541 kg/d. This HOD value should be compared to previous calculations of HOD (Table 1). The original design HOD was 1360 kg/L. Gantzer in his 2015 report recommended that 1360 kg/d be adopted as a conservative design criterion in view of the measured HOD of approximately 1000 kg/d. However, there was disagreement over the methods of HOD calculation between primary investigators in the 2015 report. In 2020, Gantzer systematically reanalyzed data from that study using four methods. That analysis yielded measured HOD values between 1,244 and 2,350 kg/d depending on the method of analysis used.

Table 1. Previous HOD Calculations

Study and Date	HOD, kg/d	DO Depletion Rate, mg/L/d	Depth of Top of Hypolimnion, m
Jacobs 2023	1,541	0.16	6.0
Gantzer 2020	1,244 1,547 2,011 2,350	0.156 – 0.219	5.5
Gantzer 2015	1,000	0.117	5.5
Moore 1991	1,360	Unknown	5 to 6

Discussion and Conclusions

Which HOD should be used for design? The median HOD between the studies is 1,452 kg/d, which is essentially Jacobs' result. None of the studies except Jacobs' had direct data from the hypolimnion from which to calculate the constituent parts of HOD. The 2023 water quality was able to more accurately define the hypolimnion. Gantzer defines it at a depth of 5.5 m. At 5.5 m, the hypolimnion volume is 4,686,430 m^3 which is approximately 1.45 times the volume at 6.0 m. Adjusted to a hypolimnion set at 5.5 m depth the Jacobs HOD would be 2,231 kg/d which is within 5% of Gantzer's maximum value of 2,350 kg/d. However, the 2023 data supports a 6.0 m depth of the top of the hypolimnion, not 5.5 m.

Additionally, in the 2020 analysis Gantzer cautions that calculation of the HOD with the pump running could result in an underestimation of the HOD because of induced mixing between the hypolimnion and the epilimnion. The 2023 calculation using data from when the pump was turned off supports this assertion. The specific oxygen demand rate (g O_2/m^3/d) from the 2023 study and Gantzer's 2020 analysis are essentially the same. The only difference in the HOD is that the 2023 data refine how the hypolimnion is defined by looking at oxidation of iron and manganese.

It is interesting that the HOD calculated from the demand exerted by the various parameters is a bit over the maximum oxygen transfer that the Speece cone is capable of (556 kg O_2/d). Considering the whole lake experiment, this makes sense. The cone prevented most solubilization of Fe and Mn, kept NH_3-N from sediment release, and prevented sustained anoxia from occurring. It did not, however, prevent hypoxia (DO of 0.5 and 2.0 mg/L) because it could not meet demand from constituent HOD factors. There needed to be substantially more oxygen injected into the hypolimnion to meet demand from parameters measured in the whole lake study, from SOD that was not measured, most likely legacy accumulated organic matter, and the need to maintain high dissolved oxygen after meeting these various parts of HOD.

An oxygenation system meeting 1,541 kg O_2/d will keep the hypolimnion in a highly aerobic condition. At least in the first year of operation, oxidation at this rate should start at or soon before ice-out. There is a legacy of insufficient oxygenation that needs to be overcome. Gantzer's 2020 analysis includes winter data, which has the highest oxygen demand. Under ice there is no wind mixing to periodically transport oxygen to the bottom. SOD completely dominates DO dynamics. It is therefore important to keep the hypolimnion near saturation (DO ≥ 8.0 mg/L) March to November to oxidize surficial sediments. The HOD is a function sediment oxygen debt, which is the decades-long accumulation of compounds in sediments that exert an oxygen demand. To date, oxygenation has never been high enough to retire the oxygen debt. Keeping the hypolimnion at DO saturation is likely to retire a large fraction of this debt. Thus, if the linear diffuser system is operated to design HOD, the HOD after 1 to 3 years of operation is likely to be lower than has been measured to date.

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