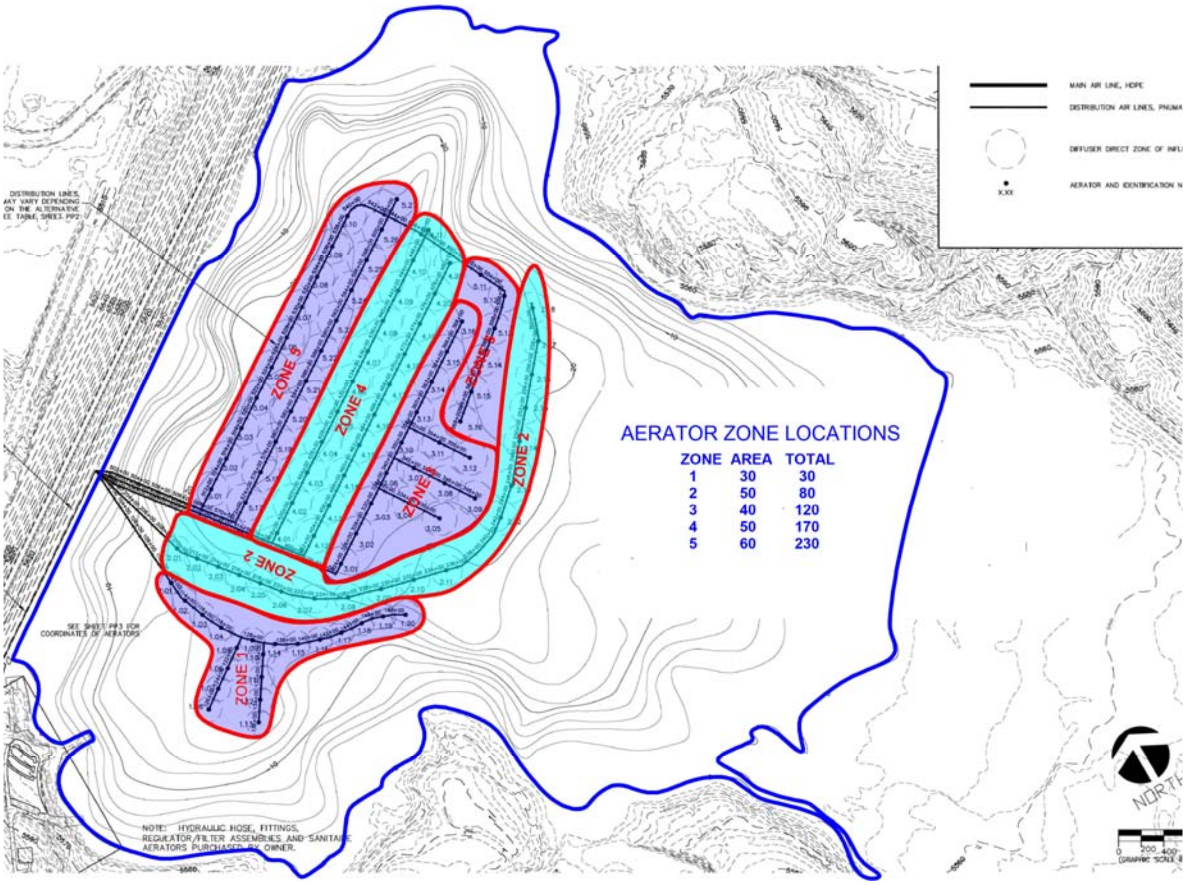
EVALUATION OF IN-RESERVOIR TREATMENT AT CHERRY CREEK RESERVOIR

For Cherry Creek Basin
Water Quality Authority

January 2020



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EXECUTIVE SUMMARY

Wright Water Engineers, Inc. (WWE) performed an evaluation of several approaches to in-reservoir treatment at Cherry Creek Reservoir (the Reservoir). An evaluation of the operations of the existing aerated destratification system provided "lessons learned" for use the possible expansion of the system. There are several issues with the existing system with the overheating and shut down of the air compressor as primary concerns. However, the primary issues with the existing destratification system are that the chlorophyll α concentrations and dissolved oxygen conditions in the Reservoir have not shown a marked improvement since the implementation of the system.

WWE investigated the approach for expanding the existing destratification system. Hydros Consulting simulations (Hydros, 2019) using a bubble plume model showed only a modest improvement in the Reservoir water quality with a significant expansion of the aerated destratification system. Out of the scenarios with additional diffusers, doubling the number of diffusers in the existing footprint (for a total of 232 diffusers) had the greatest return in terms of reduction of chlorophyll α, compared to the scenarios of 3 times, 4 times, and 5 times the diffusers receiving diminishing returns.

Based on the results of the model simulations, WWE did a conceptual design of doubling the size of the existing destratification system. The expansion was based on doubling the diffusers to a total of 232 and keeping the air flow to each diffuser at 2.4 scfm/diffuser, thereby doubling the air flow. The expansion to 232 diffusers would result in meeting the chlorophyll α limit for 2 out of the 6 years that were simulated by Hydros and reduce the number of hypoxic days by more than 50 percent compared to the existing system. The costs of expanding the existing system was estimated at $2.1 million. Annual O&M costs were estimated at $120,000.

Based on research and successes of in-reservoir treatment systems, WWE performed an evaluation of a side stream liquid oxygen system (SSLO) to improve the water quality in the Reservoir. This scenario would require additional water quality model simulations to determine the possible effectiveness. This approach would result in higher dissolved oxygen concentrations to the bottom portion of the Reservoir and the means to add a chemical (e.g.alum) during periods when there is a higher influx of dissolved phosphorus to the Reservoir water column. Based on a conceptual design, the SSLO system would include an in-reservoir intake with an air burst cleaning system, pump station to pump water from the reservoir, an oxygen saturation system, a chemical feed system (e.g. alum), and oxygen storage. The conceptual level opinion of probable costs for a SSLO is approximately $6.9 million (with assumptions). Annual O&M costs were estimated at $97,000.

Other in-reservoir treatment approaches are discussed. The whole-lake single dose aluminum sulfate (alum) treatment to inactivate phosphorus in lake sediments has been used as an effective method to reduce dissolved phosphorus concentrations and chlorophyll α concentrations in many lakes and reservoirs. The evaluation of the proper use of alum in the Reservoir may represent the most effective and efficient approach to reducing dissolved phosphorus and chlorophyll α concentrations.

Sediment removal from Cherry Creek Reservoir is not a new consideration. The sediment removal approach assumes that the release of phosphorus and nitrogen from the Reservoir sediments can be reduced by removing the layer of the most highly enriched material near the top of the sediment layer. The layered sediments in reservoirs are typically removed by either draining the reservoir and excavating or hydraulic dredging. The sediment removal could also be extended into an approach for further deepening of the Reservoir, below the originally designed bottom elevation. This would not only remove the enriched sediment, but a deeper Reservoir would also result in a more efficient mixing with using the existing destratification system. A deeper Reservoir would allow for additional water to be entrained into the plume as it rises through the water column, thus moving a larger volume of water for the same air flow rate.

This report is not intended to be a comprehensive alternatives analysis for the in-reservoir treatment of the Cherry Creek Reservoir. While several approaches to expanding the existing destratification system are presented in this report, a more thorough analysis may be warranted prior to pursuing a specific alternative. Since none of the alternatives modeled by Hydros met the required water quality standards, WWE did not perform further analysis of one of the modeled scenarios to consistently meet the water quality goals as prescribed by the Scope of Work. However, WWE did perform assessment of alternative approaches for further consideration.

1 INTRODUCTION

In 2008, the Cherry Creek Basin Water Quality Authority (the Authority) directed that a compressed-air destratification system be installed in Cherry Creek Reservoir (the Reservoir) with the intention of increasing dissolved oxygen concentrations at the bottom of the Reservoir to reduce internal water column loading of nutrients. This reduction in nutrients would result in lower chlorophyll α concentrations. The destratification system was operated from 2008-2013 (roughly April through November each year) and in the spring of 2017, 2018, and 2019. Because water quality monitoring results indicated that the destratification system has been unsuccessful to consistently increase dissolved oxygen concentrations at the bottom levels of the Reservoir, and the chlorophyll α levels have not been markedly reduced, the Authority identified a need to study the system to identify possible improvements.

As an initial step, the Authority authorized the consulting firm Hydros Consulting, Inc. (Hydros) to conduct water quality modeling simulations using the CE-QUAL-W2 water quality model to better understand the causes of the chlorophyll a standard exceedances, evaluate the impacts of the destratification system, and to provide a tool to help predict the effects of future management strategies. Key findings from this report indicated that the current system was under sized and had minimal to no effect on algae. The model runs from this 2017 study indicated that "a destratification system with three times the vertical mixing effect of the current destratification system is needed to meet the original design target dissolved oxygen of 5 mg/L at the bottom of the reservoir" (Hydros, 2017). Hydros stated in this report that a separate study would be needed to appropriately size and design a system to meet the three times vertical mixing objective. In 2019, the Authority requested that Hydros apply a coupled bubble-plume and water-quality model to Cherry Creek Reservoir to allow a mechanistic representation of the mixing induced by the destratification system. The 2017 water quality model was modified to add a "bubble plume" component to better simulate the conditions of the existing destratification system and simulate the effects of different modifications to the existing system. The results of this modeling effort have been presented by Hydros in a **DRAFT** Technical Memorandum dated April 30, 2019 (Hydros, 2019).

As a next step, the Authority engaged Wright Water Engineers, Inc. (WWE) to apply the results of the Hydros studies and investigate the engineered improvements that would be required to the existing destratification approach to result in better water quality, as modeled. The Authority also requested that WWE evaluate the shortcomings of the existing destratification system with the intent of applying the lessons learned to a modified destratification system. In addition, the Authority requested that WWE identify and research possible alternative technologies for in-lake systems with the goal of improving water quality in Cherry Creek Reservoir. WWE performed a site visit at the existing destratification system in October 2018 to obtain detailed information and interview staff.

This report is not intended to be a comprehensive alternatives analysis for the in-reservoir treatment of the Cherry Creek Reservoir. While several alternatives to expanding the existing destratification system are presented in this report, a more thorough analysis may be warranted prior to pursuing a specific alternative. Since none of the alternatives modeled by Hydros met the required water quality standards, WWE did not perform further analysis of one of the modeled scenarios to consistently meet the water quality goals as prescribed by the Scope of Work. However, WWE did perform assessment of alternative approaches for further consideration.

A. Background

The Reservoir is typically operated at a water level that corresponds to a surface area of 876 acres and a volume of 13,522 Acre-Feet. The average depth of the Reservoir is approximately 15.4 feet and it has a maximum depth of approximately 27 feet (Absolute Natural Resources, LLC., 2013).

Water quality in the Reservoir has been monitored for many years at three in-reservoir water quality sampling locations: CCR-1, CCR-2, and CCR-3, as shown in Figure 1. The deepest of these sampling points is CCR-2.

1. In-Reservoir Treatment Studies

There is a history of evaluation of in-reservoir treatment options for the Reservoir. A 1988 study performed at the request of the Authority evaluated in-reservoir control options (CDM,1988). In 1990, the Authority published a Feasibility Plan for Pilot Scale In-Reservoir Phosphorus Control at Cherry Creek Reservoir which suggested alum addition and dredging of bottom sediments (Annual Report, 1990). Although considered, destratification of the Reservoir was not a priority option during these studies.

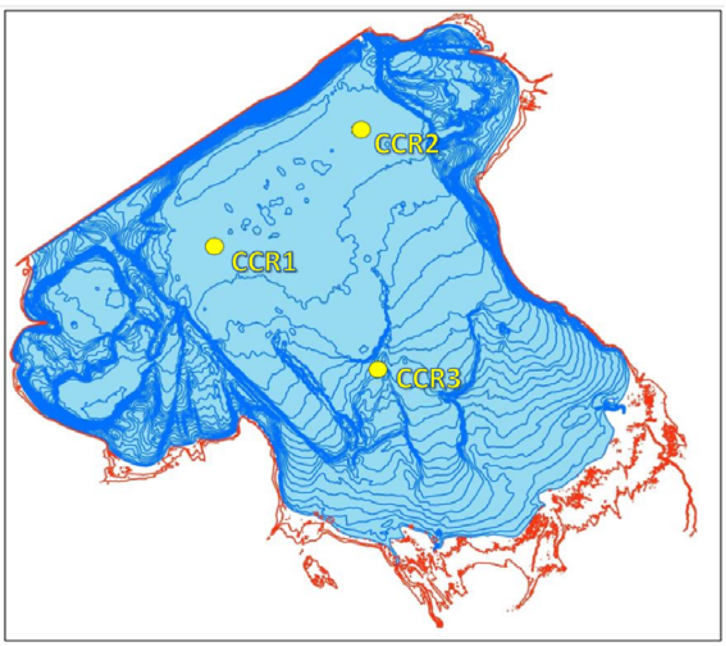


Figure 1. Bathymetry of Cherry Creek Reservoir (1foot contours), and sample point locations CCR-1, CCR-2, and CCR-3 (Hydros, 2017)

2. Destratification

In 2004, Dr. William Lewis issued a report to the Authority that stated that the Reservoir stratified temporarily for a period of several days at a time with erratic patterns of oxygen concentrations in the deeper water, with some periods of complete anoxia. However, the stratification is lost during windy weather (Lewis, et.al., 2004). These temporary stratification periods result in low bottom oxygen and release of sediment nutrients to the water column. These nutrients become available to algae in the photic zone layers and algae can proliferate, as exhibited by an increase in chlorophyll α.

Following Dr. Lewis' report, an investigation of Reservoir destratification was performed (Brown & Caldwell, 2004). This May 4, 2004 Report stated that "Dr. Lewis suggested destratification (mixing) as a method to address internal loading and other factors that increase algal growth and therefore, chlorophyll α and phosphorus and nitrogen concentrations." In addition, the 2004 Report suggested that a feasibility economic analysis of 2 or 3 mixing destratification alternatives be prepared.

In late 2005, a feasibility report to address Reservoir destratification was submitted to the Authority by AMEC Earth and Environmental (AMEC, 2005). AMEC was assisted with this feasibility report by Alex Horne Associates, and Dr. Alex Horne, a well-known specialist in the field of limnology. Hydrosphere Resource Consultants was also a part of the consulting team for this report. The AMEC Report evaluated several reservoir mixing approaches and recommended an aeration destratification system. The AMEC Report included design criteria and proposed equipment for the system.

The recommended destratification system was designed by AMEC with design plans submitted on October 27, 2006. The aeration destratification system was constructed in 2007 and startup occurred in April 2008.

Problems with overheating of the air compressor were experienced early after the startup of the destratification system. The compressor overheating resulted in periodic shutdowns of the system. In 2012, an assessment of the overheating of the compressor was performed by Eaton Energy Solutions, Inc. (Eaton, 2012). The assessment offered conclusions and recommendations to address the system shutdowns.

The performance of the aeration destratification system was investigated by evaluation of the water quality data obtained during the period of system operation. Hydros performed this evaluation and summarized the performance in a technical memorandum dated April 5, 2017 (Hydros, 2017). Hydros concluded that the system was not effectively reducing anaerobic internal loading of nutrients and there was not a noteworthy reduction in cyanobacteria since installation of the destratification system.

2 EVALUATION OF THE EXISTING DESTRATIFICATION SYSTEM

The AMEC design drawings that were made available to WWE are dated October 27, 2006. Since a Basis of Design Report was not made available, WWE relied on the AMEC references listed in the Reference Section of this report and on the design information that was included on the 2006 design drawings.

Since there have been problems with the existing system, WWE performed the evaluation with the goals of identifying the problems and determining how the existing system could be improved.

A. Description of the Destratification System

The original design of the destratification system consisted of a single air compressor that delivered air to 102 circular membrane disc diffusers heads that were spread across an area of approximately 250 acres of the 876-acre reservoir operating area. Each diffuser creates a bubble plume that is intended to provide the energy to mix the Reservoir bottom water and carry the water to the surface for exposure to air. The diffusers were divided into five separate aeration zones with each zone having a separate air distribution pipeline. The approximate locations of the air diffusers and the five lateral air distribution lines are shown in Figure 2 (Hydros, 2019).

A process schematic of the destratification system is presented in Figure 3. The air from the compressor is delivered in a 4-inch diameter HDPE pipeline to five manifold manholes that are located on the face of the dam embankment. Each of the five manholes were designed to contain a valve, flow meter, and a pressure gauge for each distribution pipeline and aeration zone. However, the air flow meters have been removed. Further detail of the system is presented in Table 1.

In 2009, fourteen membrane disc diffusers were added to the system. Ten diffusers were added to Aeration Zone 4 and four diffusers were added to Zone 1 (Eaton, 2012).

The diffusers were expected to move about 1,000,000 gallons of water per minute (approximately 4,400 acre-feet per day) resulting in a “turn-over” of the mixing zone about once per day (www.cherrycreekbasin.org).

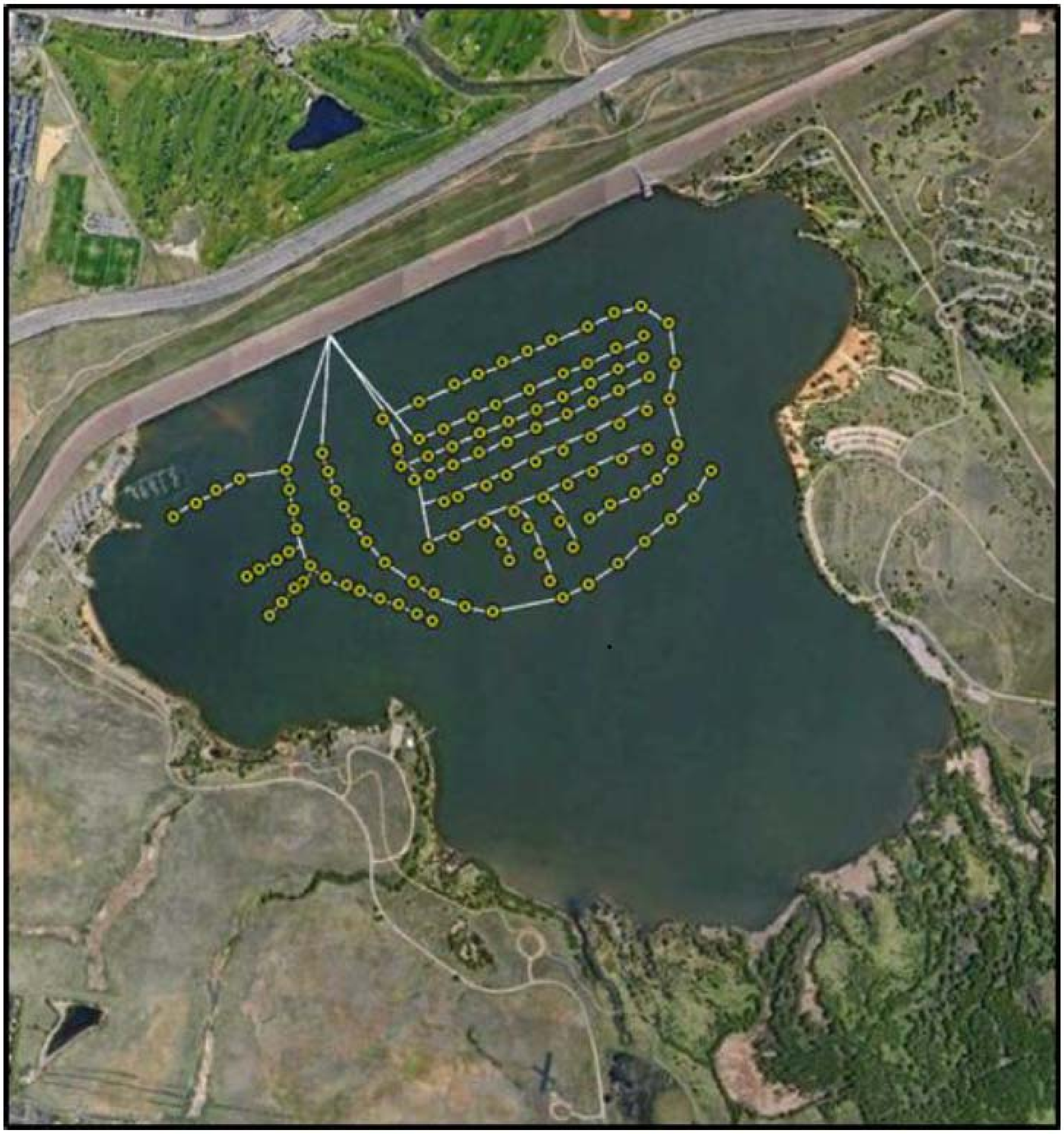


Figure 2. Existing Cherry Creek Reservoir and Destratification System Footprint. - Background aerial image from Google Earth, May 13, 2017. (Hydros, 2019).

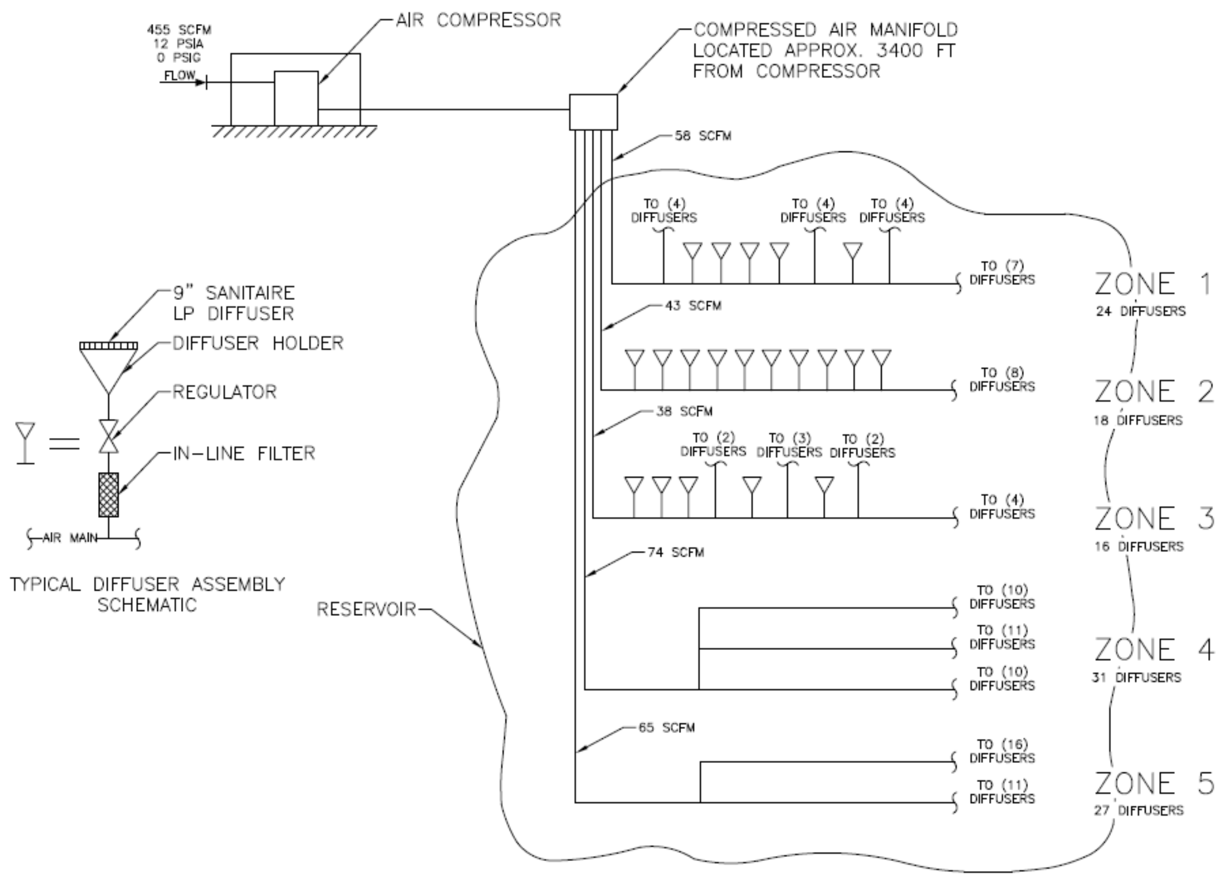


Figure 3. Process Flow Diagram for Existing System (Modified from Eaton, 2012)

Table 1. Summary of Existing Destratification System Components

Component	Model/Material	Amount	Notes
Compressor	Atlas Copco Model #ZE3F350	1	Has been shutting down due to overheating. Creates intrusive noise in surrounding park. 54.4 psig max, 455 SCFM max.
Main Airline	4" HDPE	3,025 LF	Lengths of pipe based on 2006 construction drawings. Information was not available on the lengths/locations of pipe in the current configuration.
Manifold Manholes	4' Dia. Manholes	5	Each manhole originally had a valve, air flow meter, and pressure gauge. The air flow meters have since been removed.
Diffuser Pipe	1.25" SAE 100R2 AT	10,300 LF	Lengths of pipe based on 2006 construction drawings. Information was not available on the lengths/locations of pipe in the current configuration.
Diffuser Pipe	1.00" SAE 100R2 AT	25,800 LF	Lengths of pipe based on 2006 construction drawings. Information was not available on the lengths/locations of pipe in the current configuration.
Diffusers	Sanitaire 9" LP Diffuser w/ Regulator and Filter	115	Originally 102 diffusers in 2008. In 2009, 14 heads were added for a total of 116 diffusers. In 2018, one diffuser head was removed. Operating range of 1-10 SCFM per head, with ideal range for constant use of 2-5 SCFM.

1. Air Compressor

Some of the destratification equipment was procured by the Authority and was installed as directed in the 2006 AMEC design. The air compressor was specified and purchased separately from the AMEC 2006 design drawings. The separate specification for the compressor was issued in July 2006.

The air compressor is a fixed speed rotary screw compressor manufactured by Atlas Copco with a 125-horsepower motor. This compressor is a "load/unload" type that relies on an air distribution system that can operate between two pressure limits. There was no variable frequency drive provided with the compressor.

The compressor was selected per the original aeration system design that consisted of 102 diffuser heads receiving either 2.2 standard cubic feet per minute (SCFM) or 3.3 SCFM per head, depending on the diffuser depth. AMEC specified the required air flow to the original system as 386 SCFM, which includes an additional 50% of reserve capacity, and the required delivery pressure of this system as 51 psig (corresponding to the largest pressure requirement of the system, then found in Zone 5). These compressor requirements are within the 455 SCFM (at 5550 feet) and 54.4 psig max pressure offered by the existing compressor (AMEC, 2009).

2. Compressor Building

The existing compressor building has concrete masonry unit (CMU) walls and a metal roof with interior sound board. The building measures approximately 17.5 feet by 15.3 feet and houses the compressor, controls, and ventilation system, shown schematically in Figure 4. In 2012, Eaton Energy Solutions, Inc. field verified the dimensions of the existing compressor building and concluded that the building has adequate service clearances around the compressor unit.

The building currently employs a forced air ventilation system for cooling the compressor. The building ventilation system is comprised of an approximately 16 inches diameter propeller exhaust fan and three louvers that draw air into the compressor building. Two of the louvers are 29 inches by 57 inches door louvers and the other louver is a 15 inches by 16 inches louver above the door. The compressor has an internal exhaust fan that discharges through a 54 inches by 24 inches exhaust louver under the building propeller fan.

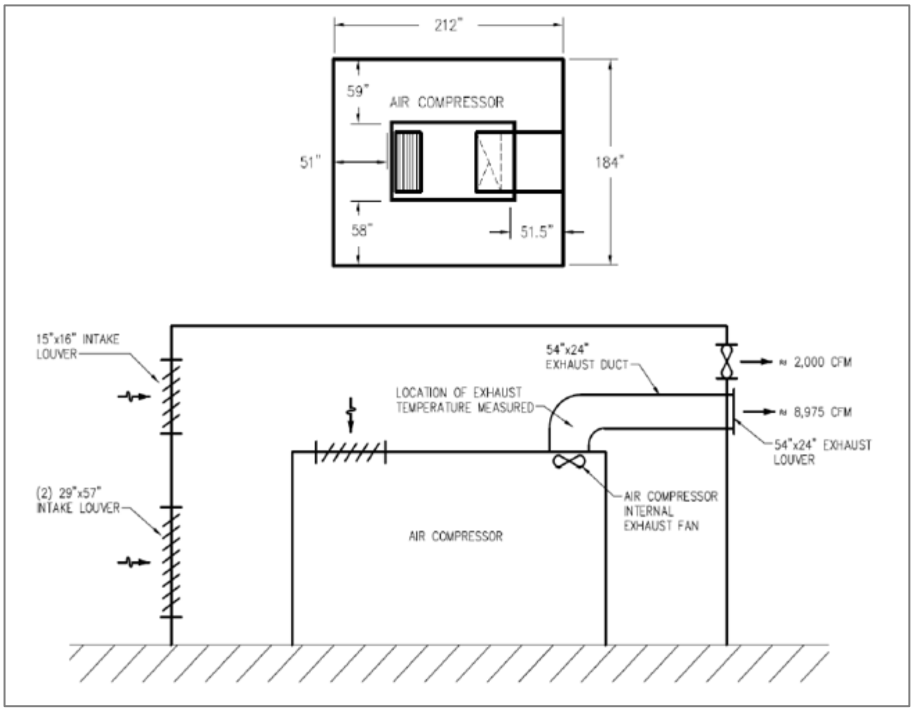


Figure 4. Existing Compressor Building Configuration. The top figure shows a plan view of the compressor building, including service clearances and building dimensions. The lower figure shows a side view of the compressor building, illustrating the relative location of the intake louvers and exhaust fan (Eaton, 2012).

3. Air Diffusers

Each air diffuser currently installed in the Reservoir is membrane disc type Sanitaire 9 inch LP diffuser, series 2802. The diffuser assembly includes an AMEC patented air flow regulator and a filter. The air flow regulator controls the flow to each diffuser between 2.4 and 2.8 SCFM, depending on the air pressure delivered to the assembly. The diffusers release air bubbles approximately 2.5 feet above the Reservoir bottom.

The diffuser assemblies are spaced with an average distance of 250 feet to 350 feet. This spacing was specified by the "Diffuser Direct Zone of Influence", as shown in the original 2006 AMEC design drawings, Sheet PP4. There are 115 diffusers as of September 2019 in the destratification system.

B. Issues and Performance of the Existing System

The performance of the existing destratification system has been evaluated by Hydros and the results of the evaluation are summarized in this Section. The existing destratification system has experienced several mechanical issues with the compressor.

1. Air Compressor

The existing air compressor has experienced shorter than recommended cycle times and frequent episodes of overheating and shutdown. High temperature shutdowns were experienced in 2009 (TC Consulting Services, 2010) and have continued over the years. For example, the compressor experienced 36 “high temperature shut-down occurrences” in 2018 during the May to August operation period (JRS Consultant, 2018).

The Atlas Copco compressor is a “load/unload” type that relies on a distribution system that can operate between two pressure limits. The compressor first pressurizes the system to the upper pressure limit, and then an unloading valve closes to create a vacuum at the compressor inlet while the motor continues to run. The system pressure can then drop by supplying air to the reservoir diffusers to the lower limit. The unloading valve then opens, starting the cycle again. Atlas Copco recommended a **minimum** of 9 psi between the upper and lower pressure limits. However, the system pressure tends to vary only between 6 psi (between 49 psi and 55 psi) (55 psi is the maximum rated outlet pressure of the current compressor). Atlas Copco data cautions that the minimum upper/lower pressure differential of 9 psi in conjunction with a properly selected receiver tank should result in a **minimum** compressor cycle time of 30 seconds. The small pressure differential (currently 4-6 psi) and the lack of an air receiver contribute to the current cycle time of approximately 13 seconds. According to Eaton, in order to compensate for the low pressure differential, the required air receiver tank for the system would need a total volume of 4,874 gallons. The current 4-inch main pipe (acting as a receiver tank for the system) has a volume of 2,112 gallons, so an air receiver volume of 2,762 gallons would be required to provide the additional air volume.

Another contributing factor to the shorter than recommended cycle times is the fact that the air compressor is oversized for the air flow requirements of the system. The original design included a factor of safety of 1.5 to allow for 50 percent reserve capacity in the compressor air flow. Instead of selecting a compressor based off the actual original 257 SCFM requirement, the design applied a requirement of 386 SCFM (which includes 50 percent reserve capacity). To compound this issue, a compressor was selected that could deliver 455 CFM at the Cherry Creek Site, which results in a reserve capacity of 77 percent.

Because the selected compressor is a fixed speed compressor, it can only operate at 100 percent capacity. Therefore, when the compressor pressurizes the system to the upper pressure limit, the system reaches the limit quickly because the air flow provided by the compressor is far greater than the system demand. The system also depressurizes very quickly because, while the air flow demand is far less than what the compressor is providing, it is still a large air flow. Ideally, the compressor could have been downsized in flow capacity to meet the system air flow requirement, which would significantly increase the compressor cycle times. Typical design of compressor systems suggests that the compressor delivery air flow be within 30 to 35 percent of the system requirements to have longer cycle times, compared to the 77 percent provided in the existing system.

As a further issue, the addition of the 14 diffuser assemblies in 2009 increased the system demand from the original design pressure at 51 psig (largest pressure requirement of original system found in Zone 5) to 67 psig, with this largest pressure requirement shifted to Zone 4. This pressure is beyond the pressure capabilities of the existing compressor. Therefore, the existing compressor cannot deliver the required pressure at all outlets and would need to be replaced to achieve adequate delivery pressure to all parts of the existing aeration system. To WWE's knowledge, this increased pressure requirement was not recognized when the 14 diffusers were added.

In 2012, Eaton evaluated the compressor and concluded that the overheating and shutdowns could be remedied by installing a 2,762-gallon receiver tank in conjunction with adding either evaporative or mechanical cooling to the building. However, the compressor is undersized for the pressure demands of the aeration system, which would not be fixed with the additional air storage (receiver tank) or cooling.

2. Compressor Building Ventilating and Air Conditioning

Eaton provided an analysis of the cooling required for the existing Atlas Copco compressor and the existing building ventilation cooling capacity.

According to manufacturer's data, the existing Atlas Copco compressor can operate in ambient temperatures up to 104 degrees Fahrenheit (F). Outdoor temperatures at the Reservoir often exceed 93 degrees F. The Eaton analysis reported the airflow requirements for the compressor ventilation grids results in an 11-degree F temperature rise above outdoor temperatures, as shown in Figure 5.

In order to ensure that the building ambient temperature is always below 104 degrees F, the building would require either evaporative or mechanical cooling.

Eaton also observed that the air compressor internal exhaust fan was undersized. Eaton field measured exhaust air temperatures to perform a heat balance calculation to determine the exhaust air flow rate. Eaton concluded that the compressor ventilation system is moving less air than design and at a higher temperature, which is the main cause of the compressor overheating.

3. Air Diffusers

In the design development of the system, AMEC assumed that very little direct transfer of oxygen would be achieved from the bubbles developed by the diffusers. Therefore, the most important design parameter, as stated by AMEC, was the flow of water generated by the bubble plume. They assumed that the majority of the oxygen transfer would be by uptake of oxygen at the air-water surface interface (AMEC, 2005The primary design criterion to address the needed flow of water generated by the rising bubbles from each diffuser was the spacing of the diffusers. To address this criterion, AMEC relied on explanations of work by Goossens (1979) and by Smith, et.al. (1982). These researchers suggested that a mixing cylinder radius equal to 5 times to 7 times the depth of the Reservoir "for effective mixing to leave no quiescent areas or, more precisely, to provide a fully homogenized water column."

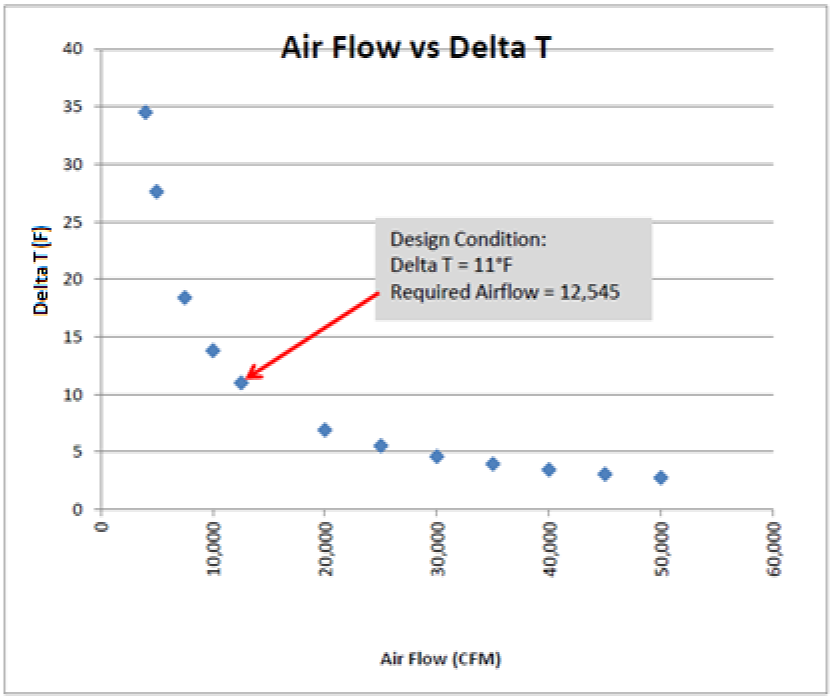


Figure 5. Energy Balance Graph of Compressor House Ambient Air. This graph was developed by Eaton Energy Solutions Inc. based on their field measurements and mass balance calculations (Eaton, 2012).

AMEC recommended the installation of 102 individual diffusers with a cylinder radius of mixing for each diffuser assumed at 7 times the water depth to achieve mixing. This would result in a diffuser spacing of about 280 feet (7 times 20 feet depth times 2. The depth used was 20 feet as the majority of the diffuser heads reside within the 20 foot contour). The installed spacing of diffusers was from between 250 feet and 350 feet.

The total aeration rate of 1.5 cubic feet per acre per minute was used as the design condition.

The existing Sanitaire diffusers must be cleaned, adjusted, or replaced on a yearly basis. The 2018 JRS Engineering Annual Report indicated that, of the 115 diffusers, 18 had to be fully replaced or have components replaced. All the diffusers needed to be cleaned, and a few required adjustments.

4. Water Quality Impact

The most important issue with the current destratification system is that the water quality in the Reservoir has not significantly improved. Hydros assessed the performance of the existing destratification system in their report dated April 5, 2017. A summary of the relevant issues is presented below.

The current aeration system has been unsuccessful in consistently meeting the chlorophyll α and dissolved oxygen goals, or even improving the conditions for these parameters. The summer chlorophyll α concentrations range from 1 µg/L to 57 µg/L, with an average of 20 µg/L for years 2003-2013. During the initial six-year operation period of the aeration system (2008-2013), the site-specific standard for chlorophyll α (18 µg/L) was only met in two years, as shown in Figure 6.

Reservoir bottom dissolved oxygen levels have not consistently increased since implementation of the destratification system. Dissolved oxygen data from 1 meter depth and the bottom most depth is plotted from CCR-2 and CCR-3 in Figure 7. The data indicates that the Reservoir has experienced anoxia or hypoxia (<2mg/L) at the bottom of the Reservoir at CCR-2 every summer since the system start up. Since initiation of the Reservoir destratification system, bottom dissolved oxygen concentrations have decreased slightly at CCR-2 and increased at CCR-3. According to the 2017 Hydros report, the decrease at CCR-2 is likely due to the induced sediment oxygen demand.

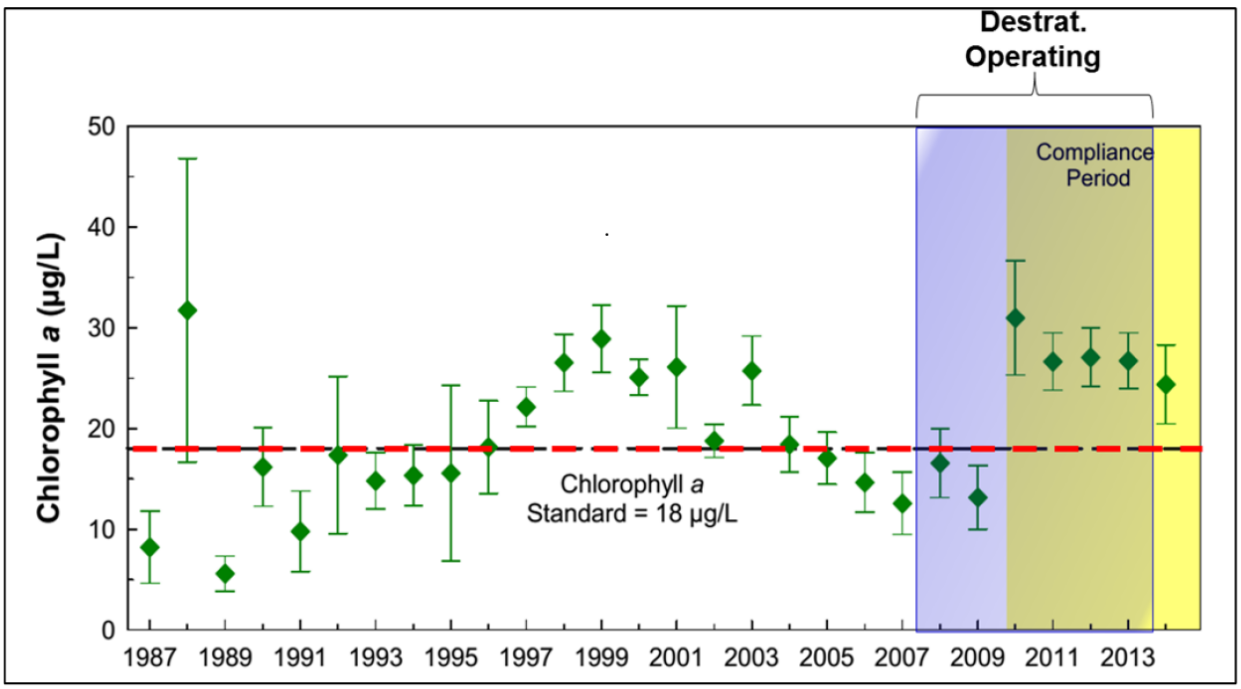


Figure 6. Cherry Creek Reservoir Average Summer Chlorophyll α Compared to the Standard (in Red), 1987-2013 (Hydros, 2017; GEI, 2015)

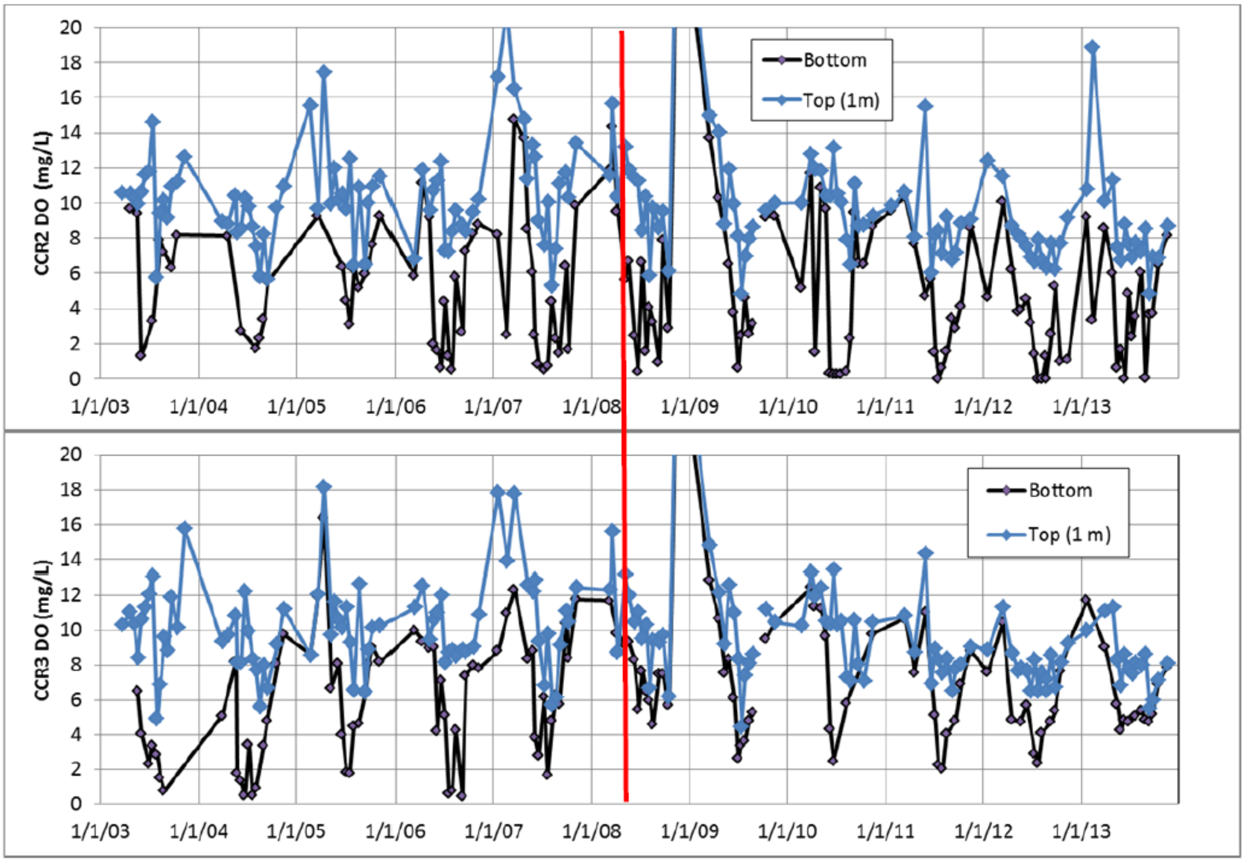


Figure 7. Dissolved Oxygen Concentrations at 1 Meter and Near the Bottom of the Reservoir at Sample Points CCR-2 and CCR-3. The Red Line Indicates the Commencement of the Destratification System (Hydros, 2017)

As discussed in the previous sections, the current destratification system at Cherry Creek Reservoir is under-sized to achieve the mixing required to maintain oxic conditions at the bottom of the reservoir and to meet summer chlorophyll α requirements. In addition to the analysis of the current system performance, Hydros Consulting Inc. conducted modeling to determine the increased destratification system mixing required to meet the dissolved oxygen levels and chlorophyll α standard. From the modeling performed in the 2017 Hydros study, it was reported that a destratification system with a "3X vertical mixing" effect of the current destratification system would result in at least 5 mg/L of dissolved oxygen. at the bottom of the reservoir at nearly all times from 2003 through 2013. The model also indicated a corresponding decrease in chlorophyll α in all years (although the 18 µg/L limit would be exceeded in 2010).

As explained by Hydros representatives, the "3X vertical mixing" value is based on a simple multiplier available in the original CE-QUAL-W2 modeling used for the 2017 Hydros study. In the modeling, the 3X multiplier was applied to each of the three vertical mixing processes: wind, currents, and existing destratification system. While the "3X vertical mixing" was intended to provide perspective on the relative magnitude of increased mixing required by <u>all</u> of the mixing processes affecting the Reservoir, it does **not** indicate a direct estimate of energy or compressor needs for an improved system. The 3X value does not directly correspond to a multiplier on air flow or number of diffuser heads. The 3X vertical mixing simulated by the Hydros model to meet the dissolved oxygen levels and site-specific summertime chlorophyll α standard cannot be attained by simply expanding the existing destratification system.

Therefore, WWE did not use the "3X vertical mixing" in any of the assessments presented in this report.

C. Existing Destratification System Conclusions

Based on the available information and the assessment described in this Section, the following are conclusions regarding the existing destratification system.

1) Based on the 2017 Hydros study, the current aeration destratification system has been unsuccessful in consistently meeting the chlorophyll α and dissolved oxygen goals, or even improving the conditions for these parameters. Potential benefits of the system to the Reservoir benthos, fishery, and other recreation activities were not specifically addressed by Hydros.
2) The existing air compressor was initially designed to provide air flow and pressure to the original grid layout consisting of 102 diffusers. The sizing included a reserved capacity of 77% without a variable speed drive or receiver tank. This reserve capacity could result in pressurizing the system too fast and increasing the cycle operation of the compressor which overheated the unit and resulted in system shutdown.
3) The ventilation system in the existing building is insufficient for the existing compressor, building size, and diffuser design. An evaporative or mechanical cooling system would have addressed the overheating of the air compressor.
4) The number of diffusers was increased by 14 in 2009, for a total of 116. At that time, the air compressor capacity was re-calculated for air flow; however, apparently the pressure requirements were not re-evaluated. The greater airflow through the distribution pipe increased the pressure required from the compressor to above the capability of the compressor. The result is that the required airflow could not be met for all of the new diffusers. More importantly, since the air compressor could not meet the pressure differential, the operation cycle times decreased and resulted in more compressor overheating.
5) The shortcomings of the existing aeration portion of the destratification system could be improved by implementing the recommendations in the Eaton 2012 Report and replacing the existing air compressor due to the pressure issue discussed above.

3 EXPANDING THE EXISTING DESTRATIFICATION SYSTEM

WWE investigated an approach for expanding the existing destratification system. The results of the 2019 Hydros modeling (reported in the April 30, 2019 DRAFT technical memorandum) were used by WWE to develop a specific scenario for an expanded destratification system in the Reservoir.

A. Hydros Reservoir Modeling - 2019

In 2019, the Authority requested that Hydros conduct additional reservoir water quality modeling in order to evaluate the potential performance of an expansion to the existing destratification system. The 2019 modeling used a coupled CE-QUAL-W2 and bubble plume water-quality model with the goal of providing a more mechanistic simulation of the existing system. The improved model was used to simulate the water-quality response to specific design modifications of the destratification system.

Hydros used this model to determine the effectiveness of the current destratification system assuming that the compressor shutdowns were avoided, as well as simulate the system response to an increase in diffusers, an increase in air flow rates, and a combination of an increase in diffusers and an increase in air. Ultimately, the goals of the study were to determine the benefits regarding summertime chlorophyll α concentrations and dissolved oxygen concentrations at the bottom of the Reservoir. In addition, the model simulations were done to determine if the chlorophyll α limit could realistically be met with an expanded destratification system. The following scenarios were modeled by Hydros.

1. Scenario 1 – No Compressor Shutdowns

To determine if solving the compressor shutdown issues would allow the destratification system to benefit the dissolved oxygen and chlorophyll α conditions, Hydros modeled the existing system response to a properly functioning compressor. This scenario was evaluated with two runs of the coupled model: the first run simulated the destratification as it was actually operated from 2008 to 2013, and the second run simulated the system without unplanned shutdowns over the same period. Results from the two runs were nearly identical, indicating that even if the air compressor were to operate without shutdowns, little additional benefit would be realized regarding the dissolved oxygen and chlorophyll α conditions.

2. Scenario 2 – Increased Air Flow to Existing Diffusers

Two model scenarios were evaluated with increased air flow rates to each of the 116 diffusers: 10 SCFM per diffuser (4 times airflow) and 24 SCFM per diffuser (10 times airflow). Simulation results indicate that there was limited benefit to bottom dissolved oxygen and average chlorophyll α concentrations with additional airflow, even with as much as 10 times the existing system airflow.

3. Scenario 3 – Additional Diffusers

Four model runs were conducted to simulate the installation of additional diffusers, each with a flow rate of 2.4 SCFM/diffuser. The scenarios considered were: 232 total diffusers (2 times existing), 348 total diffusers (3 times existing), 464 total diffusers (4 times existing), and 580 total diffusers (5 times existing). In the scenario of 2 times the diffusers, the additional diffusers were added to the existing aeration system footprint (Hydros, 2019). However, in the 3 times, 4 times, and 5 times the diffuser scenarios, the diffusers were added between the reservoir dam and CCR-3. This was not based on any spacing constraint. Simulation results indicate that increasing the number of diffusers (while maintaining 2.4 SCFM per diffuser) resulted in increased bottom dissolved oxygen concentrations and decreased summertime chlorophyll α concentrations, although not to the required levels. The system of 5 times the diffusers was required to maintain bottom dissolved oxygen levels above 2 mg/L in most years and, even then, there were a few days each year where bottom dissolved oxygen levels were hypoxic. Chlorophyll α concentrations were reduced on average by 3.1 µg/L, but simulated concentrations were still above the 18µg/L in 4 of the 6 simulated years with 580 total diffusers.

The coupled model does suggest that, for a given increase in air flow capacity to the system, the simulated chlorophyll α levels had a larger response to the additional diffusers rather than increased airflow to the existing system. The scenario with 464 diffusers (4 times airflow to the system) demonstrated a chlorophyll α reduction of 3.0 µg/L on average, whereas the scenario with 10 SCFM (4.2 times airflow to the existing diffusers) demonstrated a chlorophyll α reduction of 2.1µg/L on average. Therefore, expansion of the system by additional heads was a slightly more efficient method for increasing the system mixing than increasing the airflow.

4. Scenario 4 – Additional Diffusers and Increased Air Flow to Each Head

Twenty-two model runs were conducted by Hydros to simulate the installation of additional diffusers with increased airflow rates to each diffuser. Shown in Table 2, the additional diffuser heads and increased flow from each of these simulations would elicit lower chlorophyll α concentrations, though there were apparent diminishing returns for larger and larger systems. None of the simulated model scenarios would be able to meet the chlorophyll α limit of 18µg/L in all years, even with 5 times the diffusers and 50 times the air flow.

Table 2. Hydros Model – Simulated Reduction in July-September Average Chlorophyll α Additional Diffusers and Increased Air Flow to Each Diffuser

Scenario		Minimum (µg/L)	Average (µg/L)	Maximum (µg/L)	Air Flow Capacity Relative to Existing System
Total Heads	Flow per Head (SCFM)				
116	10	-0.2	-2.1	-4.5	4.2x
	24	-0.3	-2.7	-5.4	10x
232	2.4	-0.3	-2.5	-5.0	2x
	5	-0.3	-2.9	-5.5	4.2x
	7.5	-0.4	-3.0	-5.8	6.3x
	10	-0.4	-3.1	-6.1	8x
	24	-0.4	-3.4	-6.5	20x
348	2.4	-0.4	-2.8	-5.6	3x
	5	-0.4	-3.0	-6.0	6.3x
	7.5	-0.4	-3.2	-6.4	9.4x
	10	-0.5	-3.2	-6.4	12.5x
	24	-0.5	-3.4	-7.2	30x
464	2.4	-0.4	-3.0	-6.1	4x
	5	-0.5	-3.2	-6.6	8.3x
	7.5	-0.5	-3.3	-7.2	12.5x
	10	-0.5	-3.4	-7.3	16.7x
	24	-0.5	-3.6	-8.0	40x
580	2.4	-0.5	-3.1	-6.6	5x
	5	-0.5	-3.3	-7.3	10.5x
	7.5	-0.5	-3.5	-7.6	15.6x
	10	-0.5	-3.5	-7.9	20.8x
	24	-0.6	-3.7	-8.3	50x

A system with 580 diffusers and 24 SCFM per diffuser (i.e. 50 times the air flow) would be required to ensure bottom dissolved oxygen levels are above 2 mg/L in all 6 simulated years.

The modeling conducted by Hydros only evaluated the expansion of the current system via additional heads and increased airflow. The modeling did not include simulation of alternative approaches, such as side stream pure oxygenation, deepening the Reservoir (lowering the designed bottom of the Reservoir), chemical addition, or dredging the Reservoir (removing accumulated sediment, but keeping the same elevation of bottom of the Reservoir).

It is evident from the coupled bubble-plume water quality model that the required bottom dissolved oxygen and summertime chlorophyll α concentrations are unattainable through expansion of the existing system. The "3X vertical mixing" factor described in Section 2.B.4 cannot be achieved through the addition of as many as 464 (for a total of 580) diffuser heads with an airflow of 24 SCFM per head.

The modeling conducted by Hydros evaluated only the expansion of the current system via additional heads and increased airflow. The modeling did not include simulation of alternative technologies, such as a side stream liquid oxygenation system, deepening the reservoir, or dredging the reservoir.

B. Approaches for Expanding the Existing System

1. Extent of Expansion – Number of Diffusers and Air Flow Capacity

None of the scenarios modeled by Hydros for expanding the existing system were predicted to result in the chlorophyll α concentration limit of 18 µg/L to be consistently met. However, the Hydros modeling did show that expanding the existing system would somewhat improve water quality conditions at the Reservoir. The modeling results also predicted markedly diminishing incremental improvements of water quality (e.g. dissolved oxygen) as the destratification system was incrementally expanded.

The modeled results show that, for a given increase in air flow capacity to the system, the simulated chlorophyll α concentrations would decrease by a larger amount with the additional diffusers than with only increasing air flow to the existing diffusers, as shown in Figure 8. Note that increasing the number of diffusers to a total of 232 results in a modeled chlorophyll α change of -2.5 µg/L while increasing the number of diffusers to 464 would only increase this change to -2.8 µg/L. Therefore, in considering the simulated reduction in chlorophyll α concentrations, the more efficient expansion of the system would be to increase the number of diffusers to 232 heads.

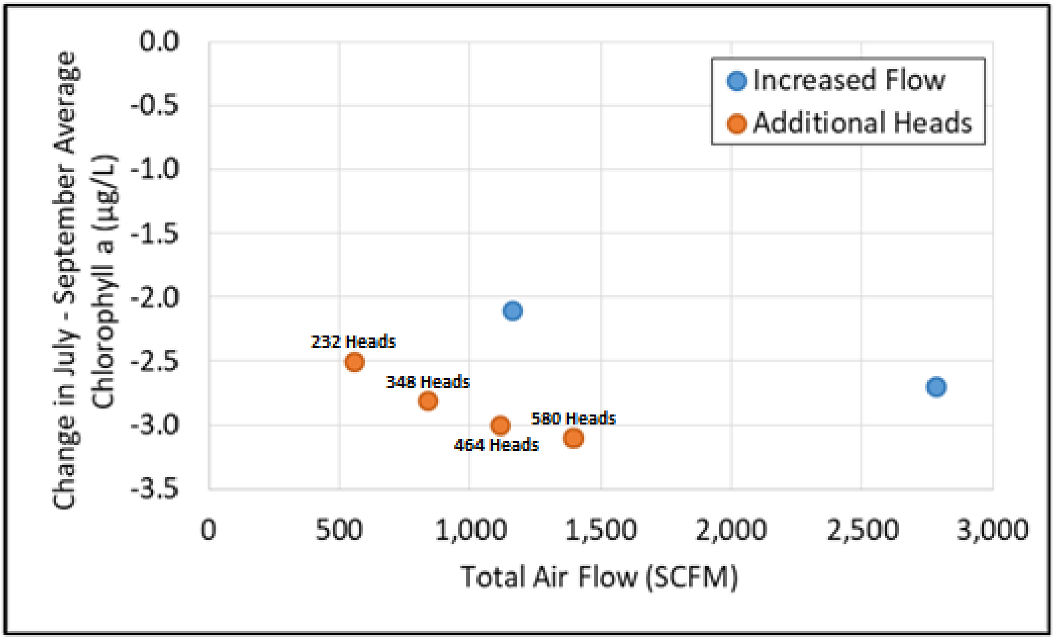


Figure 8. Comparison Between Simulated Changes in July – September Average Chlorophyll α (Years 2008 – 2013) for Scenarios with Increased Airflow to the Existing 116 Diffusers and Additional Diffusers at 2.4 SCFM Each. (Hydros, 2019)

This observation is also demonstrated when comparing the simulation for each year. Out of the scenarios with additional diffusers, doubling the number of diffusers in the existing footprint (for a total of 232 diffusers) had the greatest return in terms of reduction of chlorophyll α, compared to the scenarios of 3 times, 4 times, and 5 times the diffusers receiving diminishing returns, as shown in Figure 9.

Therefore, the scenario with 232 diffusers and 2.4 SCFM per diffuser resulted in an average model simulated decrease (in the six years modeled) of 2.5 µg/L in chlorophyll α levels, and a maximum decrease (in the six years modeled) of 5.0 µg/L in chlorophyll α concentrations (see Table 2).

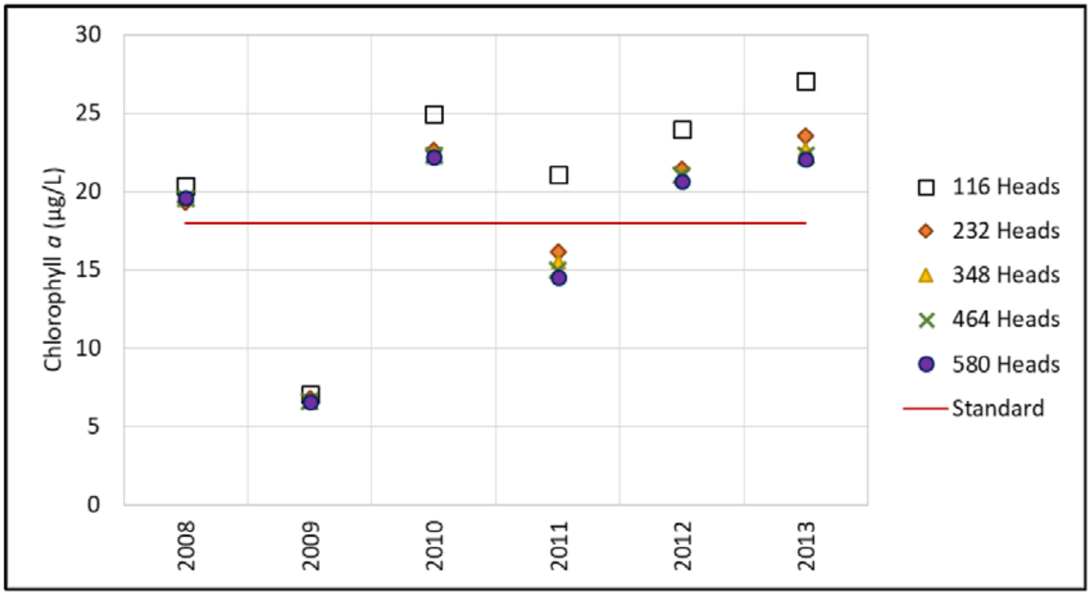


Figure 9. Simulated July – September Average Chlorophyll α for Scenarios with Additional Diffusers at 2.4 SCFM Each (Hydros, 2019)

Because of the greater return from additional diffusers and the diminishing returns for more than 2 times the diffusers in terms of chlorophyll α concentrations, WWE selected the scenario to expand the destratification system to a total of 232 diffusers. Also, because going beyond the 2.4 SCFM criteria for air flow to each diffuser did not have commensurate reductions in chlorophyll α concentrations, WWE determined that the air flow to each diffuser in the selected scenario be 2.4 SCFM. This would improve the water quality conditions. However, the chlorophyll α limit would be met for only 1 additional year (2011) as shown in Figure 9. Thus, based on the model simulations, the expansion to 232 diffusers would result in meeting the chlorophyll α limit for 2 out of the 6 years.

2. 232 Diffusers and 2.4 SCFM - Dissolved Oxygen Model Simulations

The coupled model simulation for the Reservoir bottom dissolved oxygen concentrations for this scenario also showed that there would be a benefit to expanding the existing system by doubling the number of diffusers. A system with 232 diffusers would experience more than 50% fewer hypoxic days per year than the simulated existing system of 116 diffuser heads, as shown in Figure 10.

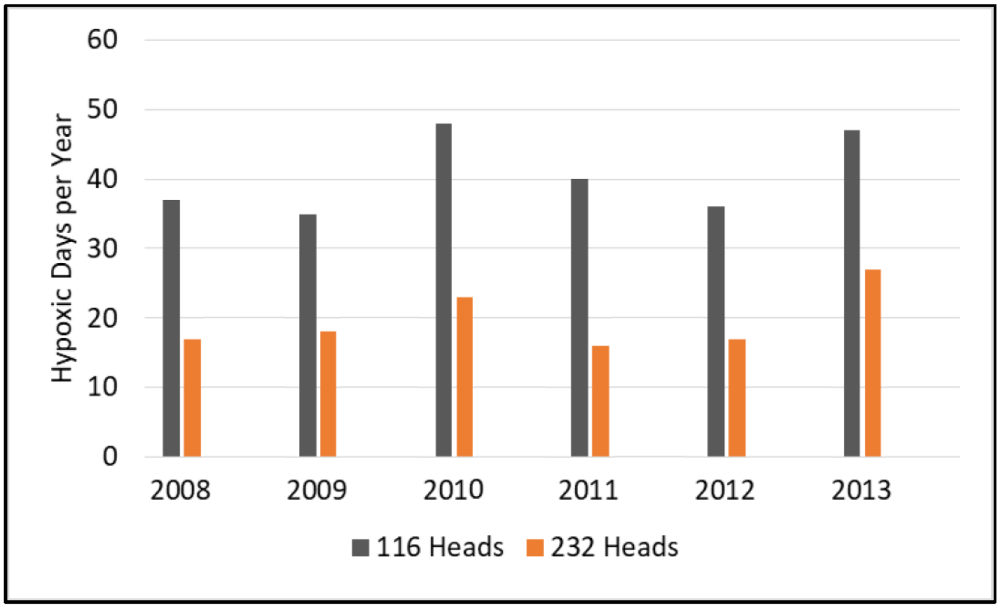


Figure 10. Comparison of Simulated Number of Hypoxic Days per Year for 116 and 232 Diffusers (Hydros, 2019)

C. Concepts for Design - 232 Diffusers at 2.4 SCFM per Diffuser

In order to expand the current system to include 232 diffusers in the current footprint, the system would need a new compressor, piping, and additional diffusers. In this scenario, WWE assumed that 117 additional Sanitaire diffusers would be proportionally spread across the existing destratification system footprint. It should be noted that, if the Authority chooses to expand the existing system with Sanitaire diffusers, Sanitaire would assist in the design by conducting modeling to determine the exact spacing and location of each of the additional 117 diffuser heads. Placement of heads in the Hydros modeling and the concept calculations assume that the diffusers are spaced so that there is no bubble plume overlap or interference.

1. Diffusers

There are currently 115 Sanitaire 9 inch LP diffusers (with regulator and filter) installed in the existing Cherry Creek Reservoir destratification system. For the new scenario, WWE assumed that 117 additional LP diffusers will need to be purchased and installed for a total of 232 diffusers.

However, the Sanitaire diffusers are specifically designed for wastewater treatment biological reactors. WWE, or Sanitaire representatives, could find no other lake installations that use Sanitaire diffusers.

According to Sanitaire representatives, the Sanitaire 9-inch LP diffuser currently utilized at the Reservoir was intended for use in wastewater treatment. Sanitaire recommends that the spacing between these diffuser heads be no more than 4 feet in a wastewater treatment reactor. Conversations with Sanitaire representatives indicate that the use of the Sanitaire 9-inch LP diffusers in this reservoir setting is unusual, with no contacted representative able to recall another project that uses the LP diffusers in reservoir aeration.

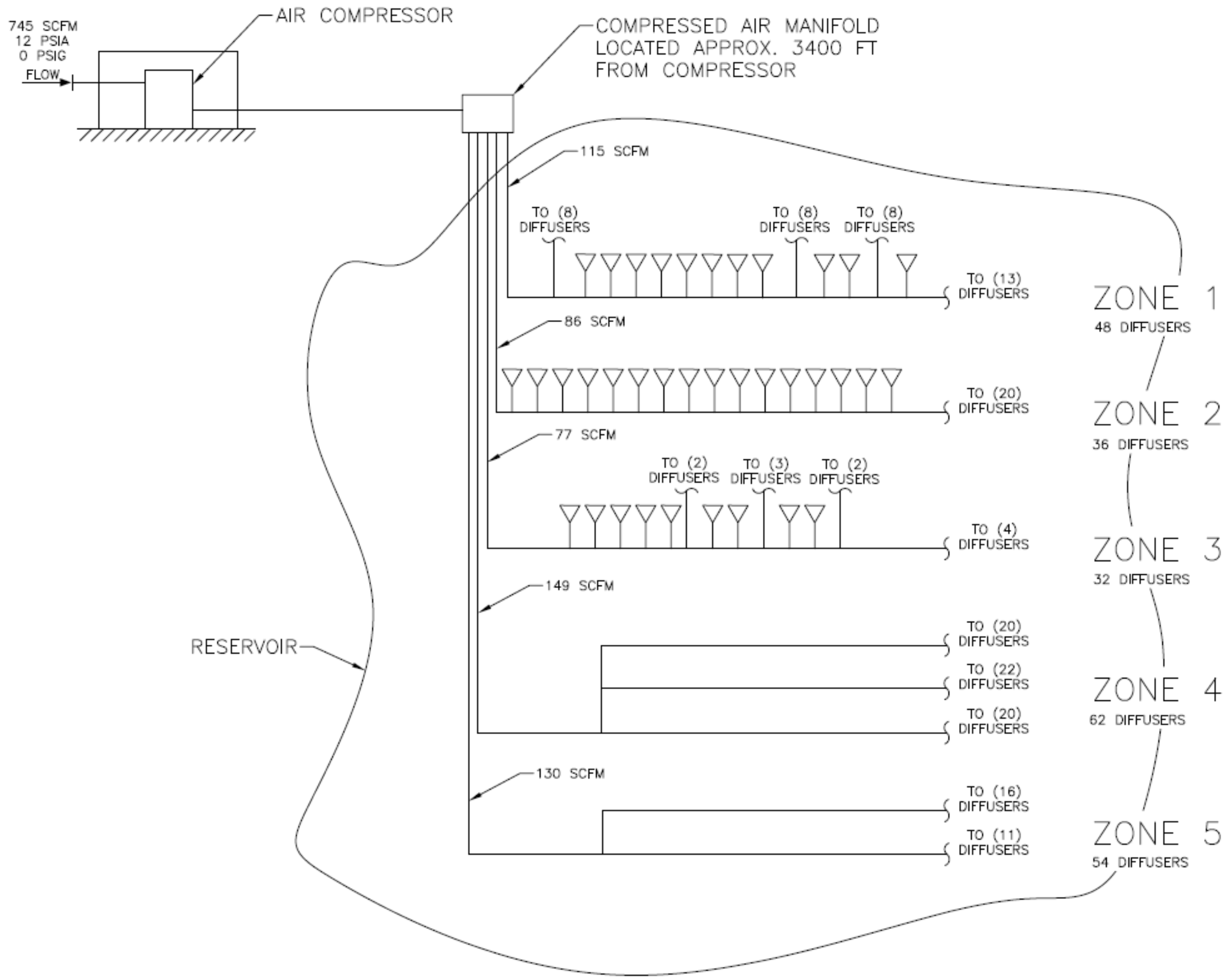


Figure 11. Process Flow Diagram of the Expansion of the Existing Destratification System

A standard diffuser type used for lake aeration destratification systems is a line diffuser. This type is often used in reservoir diffuser systems for bubble plume upwelling and side stream super-saturation. The porous diffuser lines are often more than a mile long. The oxygen bubble plume is spread out over the long lines to provide localized or widespread dissolved oxygen improvements without disturbing the sediment. The holes are oriented along the porous hose to promote lateral mixing across the sediments and uniform mixing through the water column. The line diffuser system can be deployed and maintained without the use of divers due to the buoyancy lines on each line diffuser, and can be used with compressed air, gaseous oxygen, or super-oxygenated water. The system uses long lines of flexible porous hose to avoid clogging and other maintenance issues associated with other diffuser heads.

Typically, line diffuser systems do not require annual maintenance, with most systems needing no maintenance for 10 years. The porous hose is less prone to clogging than ceramic diffuser lines or heads due to the flexibility in the rubber holes. Unlike rigid holes in ceramic diffusers, the rubber holes in the porous hose allow for the hole to flex and bend, which makes it easier to unclog during normal start up procedures after periods of inactivity. Rigid holes (such as the holes in the ceramic diffuser heads currently utilized at CCR) are less flexible and may require high pressure cleaning and regular maintenance after periods of inactivity.

The line diffuser system does not have the diffuser head assembly that protrudes into the water column and that could get hooked on boat anchors, which is what lead to the damage of several existing diffusers in the Reservoir in 2018. The porous hose in the line diffuser system is attached to an HDPE pipe anchored to the reservoir bottom by concrete anchors. The porous hose is installed in fifteen foot increments so that, even if there were to be damage caused by a boat anchor, only that fifteen foot portion of the line would be affected. Line diffuser systems are used in successful destratification systems across the U.S., with installations in Colorado including the Aurora Reservoir and several Denver Water projects off the Platte River.

In addition, the line diffuser system would probably result in a lower capital cost for expanding the existing aeration destratification system when compared to adding the Sanitaire diffusers. Therefore, the line diffuser system may be more effective than the existing type of diffusers.

If the Authority decides to move ahead with the expansion of the destratification system, then the type of diffuser should be further investigated. Note that changing diffusers should be modeled with a bubble plume model as a first step to justify the continued consideration of a line diffuser system. Modeling results would help quantify the additional mixing and water quality improvement associated with the different diffuser types.

2. Air Compressor

The existing air compressor is undersized for the expanded system and would need to be replaced. WWE performed pressure drop and air flow calculations to preliminarily size a compressor for the new scenario.

The new compressor will need to deliver 594 CFM (0% reserve capacity) to the expanded aeration system.

In order to calculate the pressure requirements of the system, it was assumed that the 117 additional diffuser heads would be proportionally added to each of the five branches of the existing system. Table 3 summarizes the total pressure drop for each branch from the compressor outlet to the diffuser assemblies.

Table 3. Summary of Expanded Aeration System Pressure

Expanded System - Total Pressure Drop - 2.4 SCFM per Head						
Zone	Number of Diffuser Heads	5" Main Pressure Drop (psi)	Manifold to Furthest Diffuser Pressure Drop (psi)	Pressure Drop from Diffuser Assembly (psi)	Static Water Pressure (psi)	Total Pressure Requirement (psi)
1	48	2.1	9.3	7.9	7.8	27.0
2	36	2.1	34.0	7.9	8.7	52.6
3	32	2.1	11.0	7.9	9.5	30.5
4	62	2.1	35.4	7.9	10.4	55.8
5	54	2.1	34.8	7.9	10.0	54.7

Based on the pressure requirements presented in Table 3, the new compressor would need to deliver 594 CFM at a pressure of 56 psi to the destratification system. A reserve air flow capacity of about 25 percent would be needed to be provided by the compressor, resulting in a required capacity of about 750 CFM.

For this concept design, WWE identified an Ingersoll Rand L200 Sierra oil-free rotary screw air compressor. This compressor can provide 745 CFM (at Cherry Creek Reservoir elevation) at a pressure of 100 psi, with a resulting reserve capacity of 25 percent. The compressor would be driven by a 200-horsepower motor and be a fixed speed compressor. This compressor can operate at ambient temperatures up to 115 degrees F.

WWE also included a 1,600-gallon air receiver tank to address the proper operation of the air compressor and prevent the overheating that is being experienced with the current compressor.

3. Compressor Building

The existing compressor building has sufficient space to house the new compressor, based on the conceptual level assessment. The building space will need to be re-evaluated during the final design to confirm this assumption.

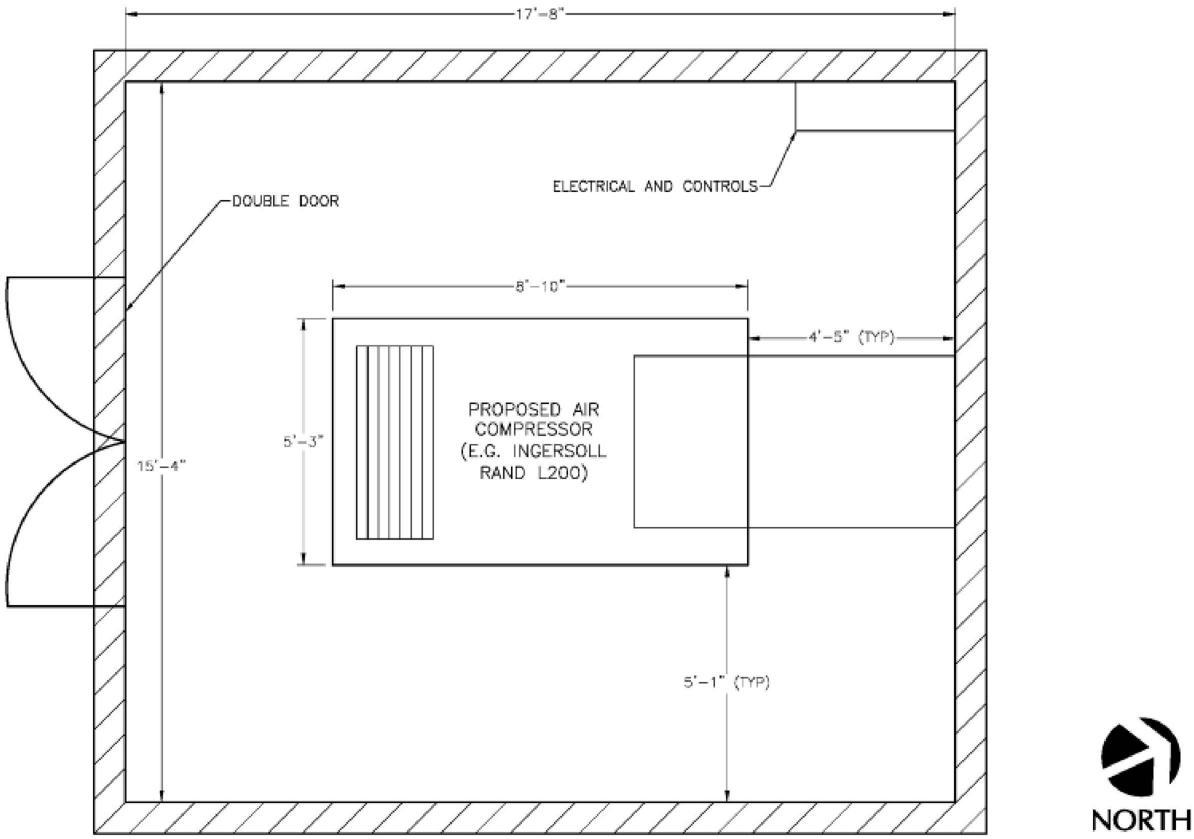


Figure 12. Conceptual Building Plan for Expanding the Existing System.

The existing building would need to be modified to accommodate the new compressor and equipment. This would include modifying the building access, electrical components, and the ventilation system. The need for air conditioning would be reassessed in final design, but the cost of air conditioning is not included at the time.

4. Distribution Piping

For the concept analysis of the air distribution piping for this scenario, the Authority provided a Google Earth KMZ file showing the GPS locations of each of the diffuser heads (Hydros, 2018). However, this file did not have the existing air distribution piping alignments. WWE used the 2006 AMEC Construction Drawings in conjunction with the 2012 Eaton Compressor Evaluation to estimate the current distribution piping layout and establish preliminary pipe lengths.

Much of the existing destratification piping is undersized to accommodate the increased air flow requirements of the expansion to a 232-diffuser head system. Specifically, the existing 4-inch diameter HDPE main line would need to be replaced with a 5-inch diameter HDPE main line. Due to the increased air flow requirements of the system, the existing 1.25-inch diameter diffuser lateral piping would need to be replaced by 2-inch diameter. Most of the 1-inch diameter piping can be reused, but diffusers would need to be added. A partial site plan of the expanded aeration destratification system is shown on Figure 13.

5. Opinion of Probable Costs for the Expansion of the Existing System

The estimated costs for the expansion of the existing destratification system are presented in Table 4. More detail regarding the estimates are provided in Appendix A. The engineering documentation used in the preparation of the estimates includes previous project experience, relevant construction project bids, input from the contractor bidding on the existing destratification system, and vendor information on major equipment items.

Estimated capital costs are often prepared at several points during the project planning and design. The expected level of accuracy is directly proportional to 1) the level of engineering effort applied and 2) known details. The estimated capital costs presented in this study are considered conceptual. Therefore, cost estimates have been prepared to a nominal accuracy of +50 to - 30 percent, reflecting the conceptual level of detail.

Indirect costs include project contingency, professional design fees (engineering, geotechnical, and surveying), and administrative/legal fees. Project contingency is based on the level of confidence in the scope of work, quantities, and complexity of the project. Contingency is intended to cover anticipated variances between the direct costs in the base estimates and the final actual project cost for the total estimated values to represent the most likely outcomes. The contingency sum does not cover changes to the stated design (scope changes) or the listed qualifications and exclusions. It is expected that the most likely outcome is that all contingency monies would be spent in the execution of the project. Engineering fees for design have been estimated at 10 percent, and engineering fees for construction administration have been estimated at 5 percent. Administrative/legal fees have been estimated at 5 percent.

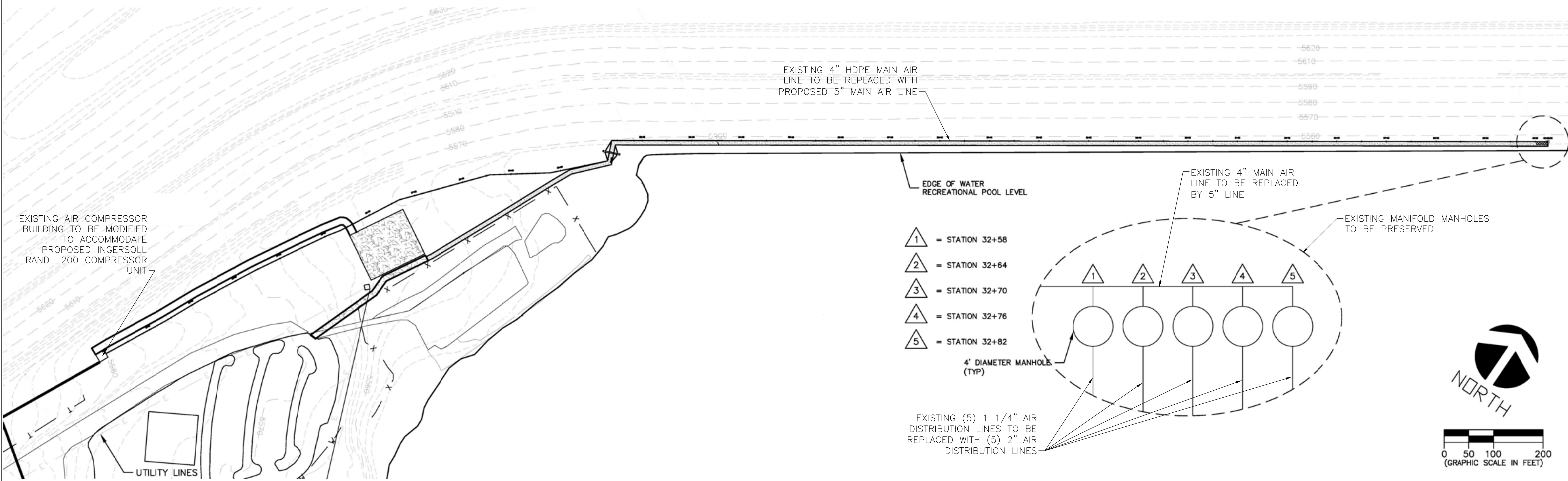
Table 4. Estimated Capital Costs of Expanding the Existing Destratification System

Item	Cost
Mobilization and Demobilization	$71,000
Demolition	$30,000
Building Modifications	$120,000
Compressor/Air Receiver	$320,000
Piping & Distribution Hose	$502,000
New Diffusers & Modifications	$373,000
Electrical and Instrumentation (5%)	$ 70,000
Subtotal	**$ 1,420,000**
Contingency (25%)	$ 360,000
Subtotal	**$ 1,780,000**
Engineering (15%)	$ 270,000
Administration/Legal (5%)	**$90,000**
TOTAL	**$ 2,140,000**

An estimate of the operation and maintenance (O&M) for each of the alternatives was developed. The annual O&M costs are presented in Table 5.

Table 5. Annual Operations and Maintenance Costs – Expanding the Existing Destratification System

Item	Cost
Operation & Labor	$20,000
Power	$80,000
Chemicals	$0
Subtotal	**$100,000**
Contingency (20%)	$20,000
TOTAL	**$120,000**



NOT FOR CONSTRUCTION

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WWE
WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211
(303)480-1700 FAX(303)480-1020

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EVALUATION OF IN-RESERVOIR TREATMENT AT CHERRY CREEK RESERVOIR

PARTIAL SITE PLAN EXPANSION OF EXISTING SYSTEM

JOB NO. 181-101.000

REVISION NO. 0

FIGURE NO. 13

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4 SIDE STREAM LIQUID OXYGENATION (SSLO) SYSTEM

WWE investigated the scenario where the existing destratification aeration system would be replaced with a side stream liquid oxygenation (SSLO) system. While several side stream options exist (see Section 5), WWE specifically investigated the SSLO system because of known successes in similar applications. SSLO systems are in use in many reservoirs, including at Marston Lake for Denver Water. Several of these SSLO installations are discussed in this Section.

A primary advantage for SSLO systems is that they have much greater oxygen transfer efficiencies than standard aeration systems, so dissolved oxygen concentrations at the bottom of the Reservoir can be much higher. For this reason, the SSLO approach has been shown to significantly reduce sediment oxygen demand when compared to aeration systems. SSLO (and other types of oxygenation systems) systems add oxygen to the water column to meet the existing oxygen demand in the sediment and water column. Data from other reservoirs show that sediment oxygen demand decreases in oxygenated lakes <u>over time</u> as a result of 1) oxidation of organic matter in the water column (due to the increased oxygen availability from an oxygenation system) before it is incorporated into the sediment, and 2) oxidation of organic matter that has already accumulated in the upper sediment layers.

Another advantage that may be very applicable to Cherry Creek Reservoir is that a small amount of chemical (e.g. alum) can be easily injected into the side stream system to precipitate dissolved phosphorus in the water column. This approach could be investigated to drive a phosphorus limited system in the Reservoir, rather than a nitrogen limited system. A further discussion of chemical addition is presented in Section 6.

In 2005, AMEC considered the use of a side stream liquid oxygenation (SSLO) system for application at Cherry Creek Reservoir (AMEC, 2005). The SSLO system was deemed feasible by AMEC and was determined to be the most cost effective of the three compared alternatives; however, it was not chosen due to the focused mixing aeration system scoring higher based on a decision matrix. According to the AMEC decision matrix, which ranked the alternatives (highest number score being the preferred alternative), the SSLO system was awarded 19 points as opposed to the destratification system (currently in use), which was awarded 20 points. Thus, the SSLO system was ruled out due to a slightly lower score on a very subjective decision matrix.

A. Overview

The technology behind the SSLO system is based on Henry's Law and works by trapping pure oxygen bubbles inside an oxygenation cone until they are dissolved. A side stream of water would be pumped from the Reservoir through the conical shaped oxygen transfer vessel, where gaseous oxygen would be fed and broken up into an intense bubble swarm by the velocity of the Reservoir water. This creates a large oxygen/water interface. The cone design provides enough contact time for the oxygen to fully dissolve in the water, allowing the oxygen saturator to achieve an oxygen transfer efficiency of over 90 percent, even at Front Range elevations. Depending on the pressure in the system, dissolved oxygen concentrations can be increased to 40-150 mg/L. Typically, the SSLO system approach has been used as a hypolimnetic oxygenation system that takes advantage of the naturally occurring stratification in reservoirs to confine the highly oxygenated water to the bottom, reducing the amount of oxygen needed to treat the reservoir and maintaining the natural stratification. However, due to the shallow and polymictic nature of Cherry Creek Reservoir, there is not consistent stratification of the Reservoir. If a SSLO system were installed at Cherry Creek Reservoir, the highly oxygenated water would be able to move freely through the entire water column. A schematic diagram of a side stream liquid oxygenation system is shown in Figure 14.

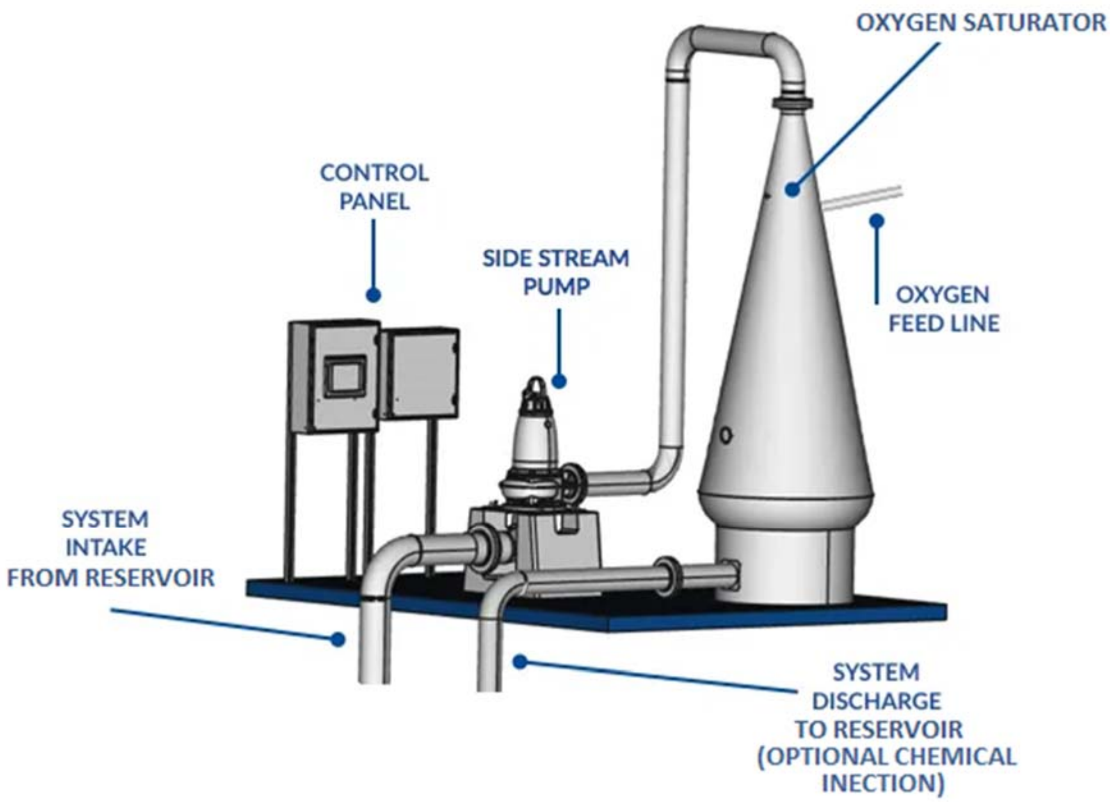


Figure 14. Typical Side Stream Liquid Oxygen System Schematic Diagram (modified from http://www.eco2tech.com/technology/). Raw water would be pumped from the bottom area of the Reservoir into the system intake. The raw water is mixed with the high purity oxygen in an intense bubble swarm, achieving an oxygen transfer efficiency of above 90 percent. The highly oxygenated water is then reintroduced to the bottom area of the Reservoir.

B. Example Installations

There are a number of SSLO system installations in the U.S. Included below are examples at Ottoville Quarry, Ohio; Gowanus Canal, New York; Barberton Reservoir, Ohio; and Marston Lake, Colorado.

1. Ottoville Quarry, Ohio

In Ottoville Quarry, Ohio, a side stream injection system was installed to improve conditions for the trout fishery of the lake in the summer. Similar to Cherry Creek Reservoir, the SSLO system was used due to the shallowness of the lake that would not support a deep injection system. The system increased the dissolved oxygen of the side stream water to 30 mg/L and, after two months of operation, had increased bottom level dissolved oxygen in the lake from 0 mg/L to 8 mg/L (Williams, 2011).

2. Gowanus Canal, New York

The Gowanus Canal is a man-made mile-long (10 feet -15 feet deep) tidal basin that was constructed during the 1800's. Due to the configuration of the canal, natural circulation is poor and pollutants that enter the canal through combined sewer overflows during rain events accumulate at the bottom, thereby driving down the dissolved oxygen to very low levels. New York City identified a need to improve water quality conditions in the canal during a temporary shutdown, and tasked their engineers to design a system using pure oxygen to reach the required dissolved oxygen concentrations. The SSLO system consists of pumping 15 million gallons per day of water out of the canal and saturating it with over 1.5 tons of pure oxygen. The highly oxygenated water is evenly distributed throughout the upper end of the canal through a 2,500-foot-long submerged pipe with flow distribution nozzles. The flow distribution nozzles ensure that the oxygenated water mixes instantly with the canal water, resulting in zero production of off gases (Clear Waters Magazine, 2011).

3. Barberton Reservoir, Ohio

Barberton Reservoir in Barberton, Ohio is a 200-acre reservoir with a maximum depth of 26 feet. Barberton Reservoir implemented a side stream liquid oxygenation system to increase dissolved oxygen at the bottom of the reservoir. The system installed at Barberton Reservoir includes two conical oxygenation saturators that introduce 2,100 lbs/day of oxygen to the reservoir. The system has successfully increased bottom dissolved oxygen concentrations since start up.

Maintenance requirements have been relatively low, with the only exception being the airburst system compressor. The bearings on this compressor have had to be replaced on a yearly basis. The nozzles have not experienced any clogging, and the system operates in near silence.

4. Marston Lake, Denver Water

Marston Lake, owned by Denver Water and located in the southwest Denver metro area, stores 250 million gallons of water diverted from the South Platte River. The water is piped 12 miles to the reservoir, followed by treatment at the Marston Water Treatment Plant. The reservoir has only one low level intake, which results in anoxic water being piped to the Marston WTP during the peak summer usage months. Denver Water conducted an analysis of hypolimnetic treatment options that would fit Marston Lake. Denver Water selected a pure oxygen system because it was able to produce and maintain high dissolved oxygen, had efficient oxygen transfer even at Denver elevation, and had silent operations. However, the pure oxygen system that was designed and constructed placed the pump and the oxygenation saturator in the lake under submerged conditions. The submerged saturator system is sized for a maximum oxygen feed of 2,000 lbs/day and runs from May through the fall. Figure 15 shows the dissolved oxygen concentrations in the summer of 2008, prior to oxygenation, and the summer of 2009 with the system in use. Bottom dissolved oxygen concentrations increased from nearly 0 mg/L in 2008 to above 6 mg/L.

The overall costs of the system was $2.6 million, which included an unanticipated cost when muck at the bottom of the lake had to be removed to install the submerged oxygen saturator on a flat surface.

WWE has had conversations with operations staff at Marston and they have reported on maintenance issues with the system, but these issues relate to the submerged oxygen saturator and the submerged pump. The water treatment plant supervisor at Marston reported that, in retrospect, they would have preferred a side stream oxygenation system instead of a submerged oxygenation system to eliminate the high cost and maintenance requirements associated with the current submerged system.

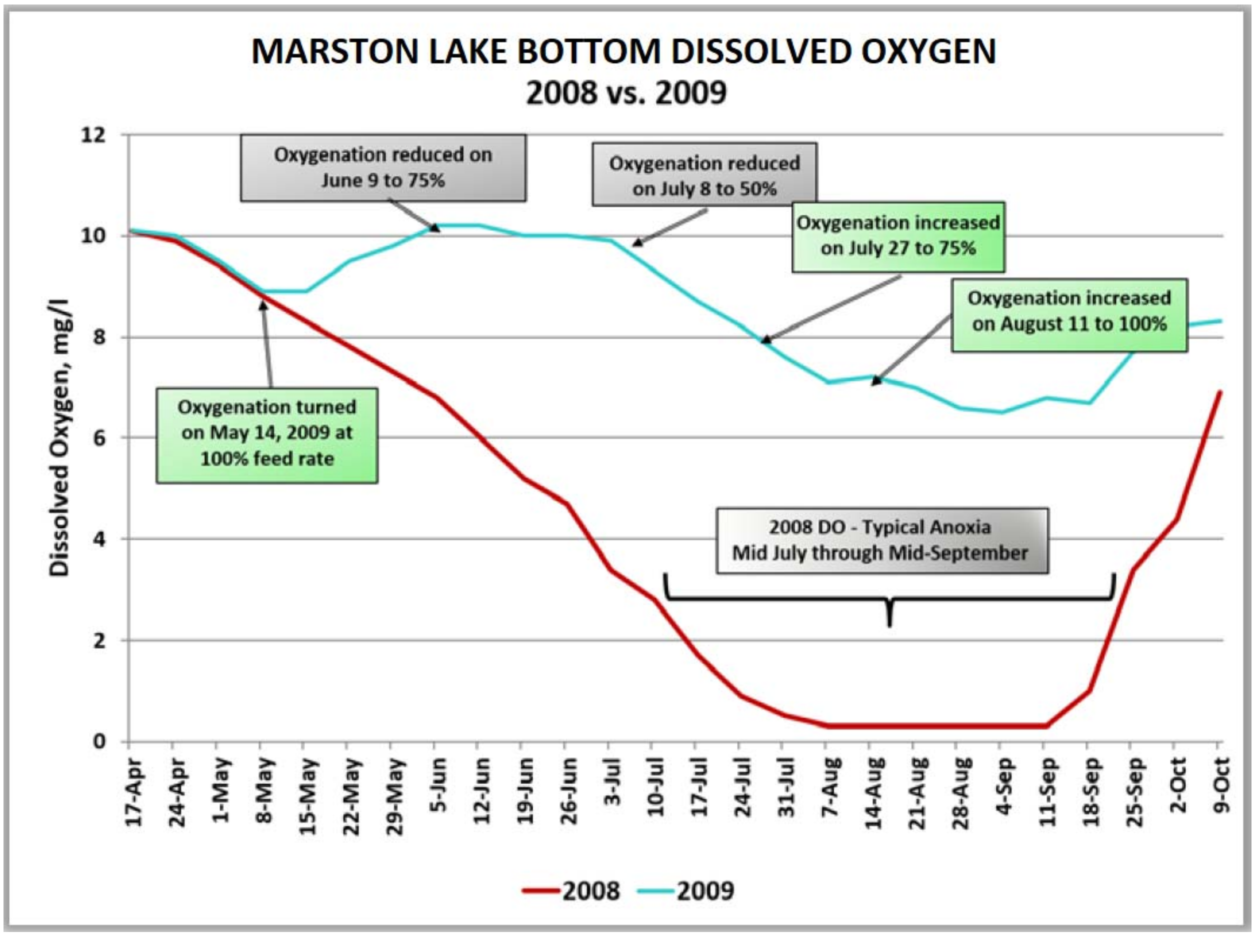


Figure 15. Marston Lake Bottom Dissolved Oxygen, Before and After Installation of the Pure Oxygen System (ECO2 Promotional Bulletin).

C. SSLO System at Cherry Creek Reservoir

A SSLO system at Cherry Creek Reservoir would consist of a screened intake and piping from the Reservoir to the raw water pump, an intake screen air burst system with compressor, a raw water pump in a manhole pump station near the reservoir, an oxygen saturator, an ambient air vaporizer, a liquid oxygen storage tank, piping to deliver the oxygenated water, replacement of the existing diffuser heads with nozzles, and a new oxygenation building. A schematic graphic of a SSLO for Cherry Creek Reservoir is shown in Figure 16.

It should be noted that in many existing SSLO systems, the oxygenated water is confined to the lowest level of the reservoir by the natural reservoir stratification. Since Cherry Creek Reservoir does not have consistent stratification or strong hypolimnion during the summer, the oxygenated water introduced at the bottom of the reservoir may mix throughout the water column. This suggests greater potential for loss of oxygen to the atmosphere, which may require additional oxygenation capacity in the system beyond the 2,200 lb/day criterion used in the AMEC design. Should the Authority choose to pursue the SSLO option, modeling and further investigation should be conducted to investigate and determine if this criterion should be refined.

1. Intake

The intake would consist of a stainless-steel cylindrical wedge wire well screen that would be at least 10 feet deep in the Reservoir and away from the oxygenation line footprint, and a 24-inch diameter intake pipe that would convey raw water to a raw water pump station near the reservoir. The intake screen would have an air burst screen cleaning system. A partial site plan of a new SSLO for the Reservoir is shown in Figure 17.

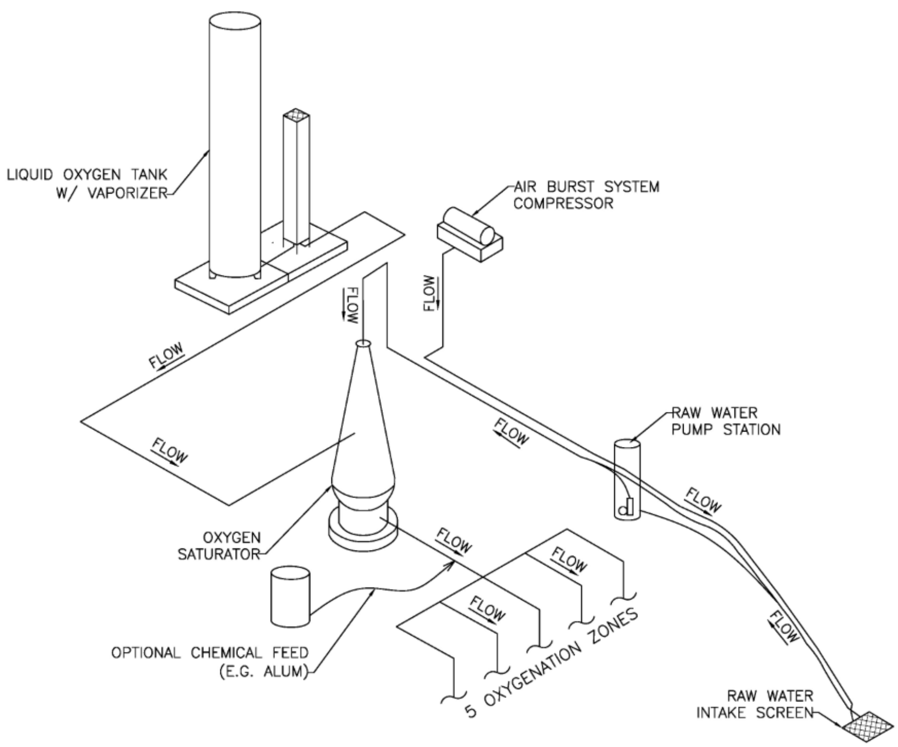
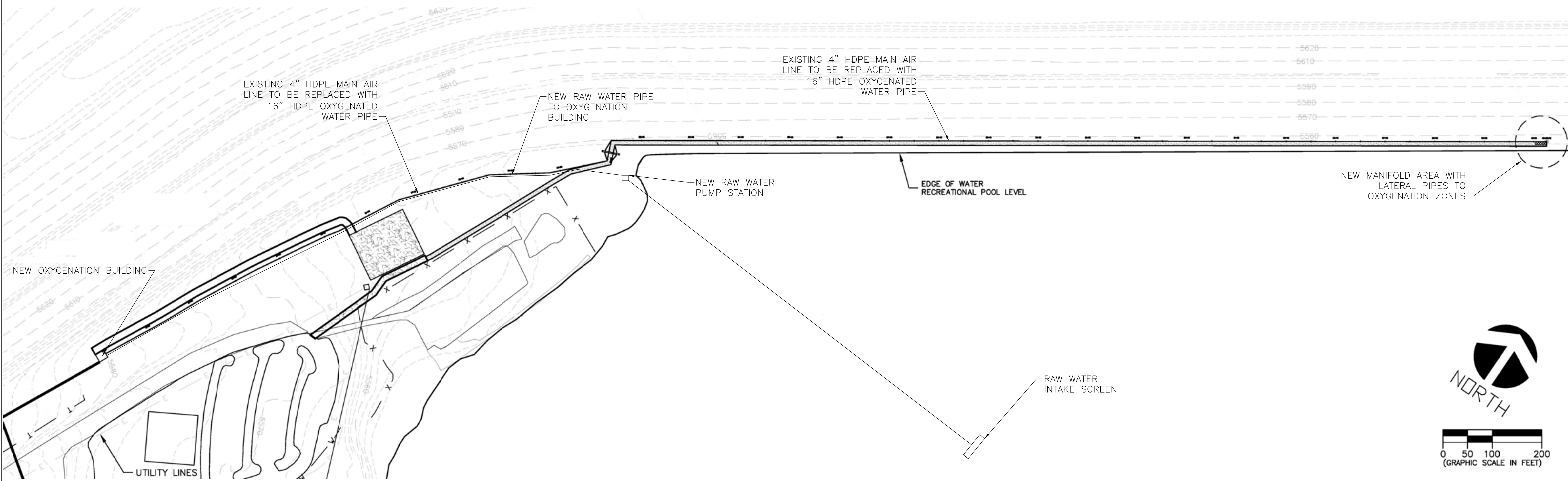


Figure 16. Conceptual Process Flow Diagram for the Side Stream Liquid Oxygenation System Alternative.



NOT FOR CONSTRUCTION

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Plot Date/Time: 10/03/2019, 12:09:31 PM; Z:\PROJECT FILES\18\181-101\181-101.000\CAD-GIS\CAD\SSO_SITE_PLAN.DWG-GENERAL SHEET LAYOUT

WWE WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211
(303)480-1700 FAX(303)480-1020

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EVALUATION OF IN-RESERVOIR TREATMENT AT CHERRY CREEK RESERVOIR

PARTIAL SITE PLAN NEW OXYGENATION SYSTEM

JOB NO. 181-101.000

REVISION NO. 0

FIGURE NO. 17

2. Airburst System

The airburst system would consist of a 25-horsepower compressor that supplies air through a 1.5-inch diameter airline to the cylindrical intake screen. The system would be used to clear accumulated sediment or debris from the intake screen.

3. Raw Water Pump Station

The side stream high purity oxygenation system would require a raw water pump to draw water out of the Reservoir and deliver the water through the oxygen saturator and into the nozzle distribution system. The pump was preliminarily sized to have a capacity of 3,000 gpm and the pump motor at 100 horsepower. One possible location for a raw water pump station is shown in Figure 17. Locating the pump station near the reservoir allows for gravity flow into the raw water pump station and minimal cover above the pump discharge pipe, minimizing excavation debris.

4. Oxygen Saturator

The SSLO system would require one conical oxygen saturator where the oxygen transfer to the Reservoir water occurs. The oxygen saturator is also known as a "Speece Cone" after the man who developed the technology. One main supplier of the oxygen saturator is ECO Oxygen Technologies, LLC (http://www.eco2tech.com) (ECO). The oxygen saturator would be cone shaped with a height of 16 feet and be 6 feet in diameter.

5. Piping

The existing aeration system piping could not be reused, since it is too small to accommodate the required 3,000 gpm system water flow rate. The existing 4 inch diameter HDPE main pipe would need to be replaced with a 16 inch diameter HDPE oxygenated water delivery pipe as shown in Figure 17. The 16 inch HDPE pipe carrying the oxygenated water would connect to a new piping manifold, where the existing 1.25 inch piping would need to be replaced with five branches of 8 inch diameter HDPE piping. The piping would reduce down to 2 inch diameter HDPE pipes at the end of each of the five branches to ensure proper pipe velocities. The alignment of the oxygenation lateral pipes would be further determined by modeling, prior to final design.

6. Nozzles

The SSLO system would include nozzles that would be installed on the new 8 inch diameter HDPE piping and 2 inch diameter HDPE piping. For the conceptual design, the nozzles would be spaced 15 feet apart across the entire length of the oxygenation lines, on alternating sides on the pipe. The nozzles would be installed to distribute oxygenated water horizontally and parallel to the bottom sediment of the Reservoir.

7. Oxygen

WWE assumed that the SSLO system would require approximately 2,200 lbs/day (1.1 tons/day) during the summer season based on the AMEC design criterion. If the Authority were to pursue the SSLO system at the Reservoir, the amount of oxygen required should be further investigated through additional modeling.

In order to provide the gaseous oxygen to the oxygen saturator, liquid oxygen needs to be delivered and stored on site, or oxygen must be generated on site. The local vendor Air Products and Chemicals, Inc. recommends using delivered liquid oxygen for oxygen rates lower than 25 tons/day. An on-site oxygen generator is applicable where the oxygen usage of 25 tons/day, or larger.

A liquid oxygen storage tank would be sized to accommodate six weeks of storage space and consist of a steel vertical, double walled tank. Based on the 1.1 tons of oxygen/day demand, the six-week demand would be 10,800 gallons. Therefore, the system would require an 11,000-gallon tank, or two tanks each with a volume of 5,500 gallons.

If the Authority were to pursue the SSLO system for the Reservoir, further investigation should be conducted to determine whether on-site oxygen generation should be considered over LOX Storage. Factors for consideration include safety and flood events.

Liquid oxygen is extremely cold and stores from -250 to -270 degrees F. A vacuum in the annular space between the two walls insulates the tank. The storage tank would function like a large thermos bottle to maintain temperature and prevent pressure build up. However, when a tank is not in use, the internal pressure will gradually increase as the liquid oxygen heats up. If the pressure rises to 225 psi due to lack of oxygen usage, the tank relief valve would open, and oxygen gas would vent to atmosphere. If liquid oxygen were not drawn from the storage tank for an extended period of time, up to 0.5 percent of the stored contents could be lost per day due to venting. If the SSLO system is further pursued, this aspect of the system would need to be addressed.

Vaporization assists in cooling the tank and would be used to maintain the low temperature. Liquid oxygen withdrawn from the storage tank must be vaporized and heated before reaching the oxygen saturator. The liquid oxygen storage tank would be followed by one or two ambient vaporizers. Ideally, two vaporizers would operate alternately in parallel. The vaporizers are simple tube and fin heat exchangers that use atmospheric heat collected at the fins to vaporize the liquid oxygen as it passes through the tubes. This process would slowly build ice on the vaporizers as moisture in the air freezes to the cold fins. Consequently, they must be thawed and operated in an alternating cycle, one unit vaporizing while the other unit defrosts.

A photograph of a liquid oxygen storage tank and vaporizers in a similar system is presented in Figure 18.

Figure 18. An Existing Liquid Oxygen Storage Tank and Vaporizers.

Liquid oxygen deliveries would include delivery of 20 tons of oxygen every two and a half weeks.

8. Oxygenation Building

A new building would be required to house the oxygen saturator and the air burst compressor. It is proposed that the new building would be constructed adjacent to the existing compressor building. At this conceptual level, the size of the new building would need to have approximately the same length and width dimensions as the existing building. However, the new building would have to be at a height to enclose the 16 feet high oxygen saturator.

The existing compressor building would be used to enclose the chemical feed equipment. The existing air compressor and appurtenances would be taken out of the building. Liquid chemical (e.g. liquid alum) would be delivered to this building and stored in tanks. The chemical feed pumps would also be housed in the existing building.

The oxygen storage tanks and vaporizers would be installed on the outside of the buildings on concrete pads. These components would not need to be housed in a building and can remain outdoors. A conceptual layout of the SSLO system buildings is presented in Figure 19.

9. Opinion of Probable Costs for the SSLO Alternative

The estimated costs for a new SSLO system for Cherry Creek Reservoir are presented in Table 6. More detail regarding the estimates are provided in Appendix A. The engineering documentation used in the preparation of the estimates includes previous project experience, relevant construction project bids, input from the contractor bidding on the existing destratification system, and vendor information on major equipment items.

Estimated capital costs are often prepared at several points during the project planning and design. The expected level of accuracy is directly proportional to 1) the level of engineering effort applied and 2) known details. The estimated capital costs presented in this study are considered to be conceptual. Therefore, cost estimates have been prepared to a nominal accuracy of +50 to - 30 percent, reflecting the conceptual level of detail.

Indirect costs include total project contingency, professional design fees (engineering, geotechnical, and surveying), and administrative/legal fees. Project contingency is based on the level of confidence in the scope of work, quantities, and complexity of the project. Contingency is intended to cover anticipated variances between the direct costs in the base estimates and the final actual project cost for the total estimated values to represent the most likely outcomes. The contingency does not cover changes to the stated design (scope changes) or the listed qualifications and exclusions. It is expected that the most likely outcome is that all contingency monies would be spent in the execution of the project. Engineering fees for design have been estimated at 10 percent, and engineering fees for construction administration have been estimated at 5 percent. Administrative/legal fees have been estimated at 5 percent.

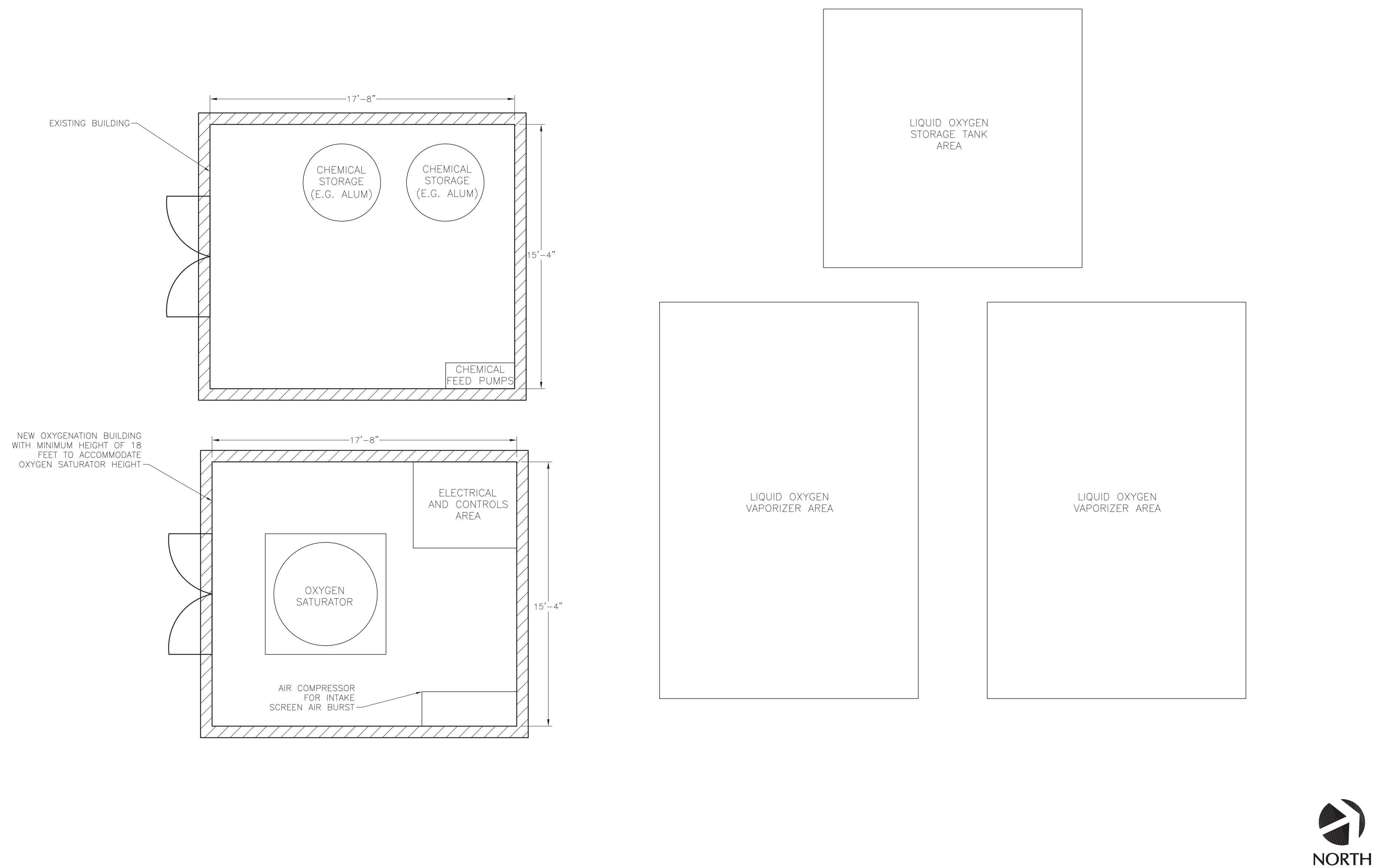
EXISTING BUILDING
17'-8"
15'-4"
CHEMICAL STORAGE (E.G. ALUM)
CHEMICAL STORAGE (E.G. ALUM)
CHEMICAL FEED PUMPS
NEW OXYGENATION BUILDING WITH MINIMUM HEIGHT OF 18 FEET TO ACCOMMODATE OXYGEN SATURATOR HEIGHT
17'-8"
15'-4"
ELECTRICAL AND CONTROLS AREA
OXYGEN SATURATOR
AIR COMPRESSOR FOR INTAKE SCREEN AIR BURST
LIQUID OXYGEN STORAGE TANK AREA
LIQUID OXYGEN VAPORIZER AREA
LIQUID OXYGEN VAPORIZER AREA
NORTH

Table 6. Estimated Capital Costs for the Side Stream Liquid Oxygen System

Item	Cost
Mobilization and Demobilization	$ 220,000
Demolition	$ 100,000
Intake	$950,000
Building	$72,000
Oxygen Saturator	$800,000
Liquid Oxygen System	$400,000
Chemical Feed System	$40,000
Piping and Oxygenated Water Distribution Lines	$1,620,000
Electrical and Instrumentation (10%)	$400,000
Subtotal	**$4,600,000**
Contingency (25%)	$1,150,000
Subtotal	**$5,750,000**
Engineering (15%)	$860,000
Administration/Legal (5%)	$290,000
TOTAL	**$6,900,000**

An estimate of the operation and maintenance (O&M) for each of the alternatives was developed. The annual O&M costs are presented in Table 7.

Table 7. Annual Operations and Maintenance Costs – Side Stream Liquid Oxygenation System

Item	Cost
Operation & Labor	$20,000
Power	$40,000
Chemicals	$21,000
Subtotal	**$81,000**
Contingency (20%)	$16,000
TOTAL	**$97,000**

5 OTHER APPROACHES

There are other approaches that may be considered for the improvement of water quality that may result in compliance with the chlorophyll α standard in the Reservoir.

A. Other Side Stream Treatment Systems

WWE investigated the SSLO system for Cherry Creek Reservoir since there are successful applications of the SSLO in other reservoirs. However, there are other side stream options that may be considered for treatment of Cherry Creek Reservoir

- A pumping station (or stations) that would be located on dry ground and would pump from the bottom of the reservoir (or the inlet areas) and recirculate the water, providing mixing and aeration
- A side stream water treatment plant (or plants) that would chemically treat and filter water from inflows (or the reservoir bottom) and return treated water to the reservoir

B. Mechanical Mixing

Rather than using bubble plumes to mix the Reservoir, WWE considered several approaches to mechanically mix the Reservoir. There are several propeller type mixers and other types that have been used successfully at other shallow discontinuous polymictic lakes. However, the typical lake mixing system has structures on the water surface. The concerns regarding the recreation impacts and public safety prohibit the use of this otherwise standard type of approach to mechanical mixing for the Reservoir.

C. Single Dose Alum Treatment

Whole-lake single dose aluminum sulfate (alum) treatment to inactivate phosphorus in lake sediments has been used as an effective method. In one analysis (Welch and Jacoby, 2001), over 80 percent of the projects proved successful, reducing internal loading by an average of 54 percent. However, these earlier projects typically did not supply a high enough dose of alum to fully inactivate the available phosphorus.

Another analysis of four lakes showed an average of 90 percent reduction in internal loading (Cooke, et. al., 2005).

A later comprehensive study (Huser, et. al., 2016) presented results of 83 lakes that had sufficient data after alum addition. Over 90 percent of these 83 lakes showed water quality improvement in the two years following the treatment. Many of these lakes were shallow, polymictic lakes.

The effectiveness and longevity of an alum treatment depends on the amount of external loading that continues to flow in from the watershed. Over time, continued high external loading will provide enough phosphorus to overcome the benefits of a single alum treatment. In addition, the alum floc layer gradually sinks deeper into the sediment and is no longer able to bind new phosphorus.

The evaluation of the proper use of alum in the Reservoir may represent the most effective and efficient approach to reducing dissolved phosphorus and chlorophyll α concentrations. Further studies such as bench scale work, microcosm work, toxicity testing, etc. should precede alum application in the reservoir.

D. Sediment Removal and/or Deepening the Reservoir

Over the years, sediment and organic rich material from Reservoir inflows have settled to the bottom of the Reservoir. This sediment layer contains nutrients that can be released to the water column during the anoxic periods (by a chemical reduction reaction). The nutrients become available for algae and results in more eutrophic conditions, especially an increase in chlorophyll α concentrations. The removal of this sediment could be advantageous for the Reservoir.

Sediment removal from Cherry Creek Reservoir is not a new consideration. In 1988, the concept was addressed in a report that estimated a volume of 2.7 million cubic yards to be removed, or about 2 feet of sediment removed over the entire area of the Reservoir. The 1988 cost estimate for this level of removal was $5.726 million (CDM, 1988). Today, this cost estimate would be approximately $14 million (based on Engineering New Record Construction Cost Indices).

The sediment removal approach assumes that the release of phosphorus and nitrogen from the Reservoir sediments can be reduced by removing the layer of the most highly enriched material near the top of the sediment layer. The layered sediments in reservoirs are typically removed by either draining the reservoir and excavating or dredging. The 1988 Report assumed hydraulic dredging and pumping the watery sediments to settling ponds on the banks on the Reservoir.

The sediment removal could also be extended into an approach for further deepening of the Reservoir. This would not only remove the enriched sediment, but a deeper Reservoir would also result in a more efficient mixing with using the existing destratification system. A deeper water column allows for additional water to be entrained into the plume as it rises through the water column, thus moving a larger volume of water for the same air flow rate.

Deepening the Reservoir could also result in more stable periods of stratification. In this scenario, a SSLO may be more effective which may be beneficial to the Reservoir water quality.

6 CONCLUSIONS

The following findings are based on WWE’s concept level evaluation of a possible engineered expansion of the existing aerated destratification system and assessment of other possible in-reservoir approaches. Please refer to Section 2.C for conclusions regarding the functioning of the existing system.

1. The expansion of the existing aerated destratification system will not meet the Reservoir chlorophyll α standard in all years, based on model simulations performed by Hydros (Hydros, 2019). However, additional diffusers would result in lower chlorophyll α. WWE selected a scenario to expand the destratification system to a total of 232 diffusers based on the model simulations. The expansion to 232 diffusers would result in meeting the

chlorophyll α limit for 2 out of the 6 years that were simulated by Hydros and reduce the number of hypoxic days by more than 50 percent.

2. The expansion of the existing destratification system would require a new compressor and air receiver, existing building modifications, new air distribution piping, additional diffusers, and replacement of a portion of the air diffuser piping laterals. The conceptual level opinion of probable capital costs for the expansion is approximately $2.1 million (with assumptions). Annual O&M costs were estimated at $120,000. Further detailed evaluation may impact these cost estimates.
3. A side stream liquid oxygenation (SSLO) system could provide greater water quality benefit to the Reservoir. The major potential benefits are higher dissolved oxygen concentrations to the bottom portion of the Reservoir and the means to add alum during periods when there is a higher influx of dissolved phosphorus to the Reservoir water column. A SSLO system for the Reservoir was investigated by WWE and would include an in-reservoir intake with an air burst cleaning system, pump station to pump water from the reservoir, an oxygen saturation system, a chemical feed system (e.g. alum), and oxygen storage and oxygenated water distribution lines with nozzles. The conceptual level opinion of probable costs for a SSLO is approximately $6.9 million (with assumptions). Annual O&M costs were estimated at $97,000. Further detailed evaluation may impact this cost estimate.
4. The evaluation of the proper use of alum in the Reservoir may represent the most effective and efficient approach to reducing dissolved phosphorus and chlorophyll α concentrations.

7 RECOMMENDATIONS

1. If the Authority decides to move ahead with the expansion of the destratification system, then the type of diffuser that should eventually be designed and installed should be further investigated. Note that changing diffusers should be modeled with the bubble plume model as a first step to justify the continued consideration of a line diffuser system.
2. If the Authority decides to pursue the SSLO system, then the next step would be to perform model simulations to assess the water quality benefits to the Reservoir with varying oxygen doses, particularly the reduction in chlorophyll α.
3. If the Authority considers alum treatment, then the next step would be to further investigate the applicability of this approach to the Reservoir. The investigation should include aquatic life effects, chemical compatibility evaluation based on historic water quality (e.g. alkalinity assessment, pH, and other parameters), jar testing, pilot testing, and other tasks.
4. WWE investigated and considered the performance of the destratification system in terms of its effect on chlorophyll α and dissolved oxygen. As such, the existing destratification system may be providing water quality benefits to the Reservoir that have not been fully addressed. The investigation of available information and data to determine benefits beyond chlorophyll α and dissolved oxygen was not in WWE's Scope of Work. The Authority should consider investigating other benefits (e.g. reduction of specific cyanobacteria) so that the existing destratification system can be operated during periods that will most benefit the Reservoir conditions.

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APPENDIX A

OPINION OF PROBABLE CAPITAL COSTS

Wright Water Engineers, Inc.

OPINION OF PROBABLE CAPITAL COSTS

Client:	Cherry Creek Basin Water Quality Authority
Project:	Cherry Creek Reservoir - Aeration Study Expand Existing System

Project No: 181-101.000	
Sheet: 1 of	1
By: JMN/GUS	Ckd:
Date: 10/4/19	Date:

Conceptual Level

DESCRIPTION	COMMENTS/REFERENCES	QTY.	UNIT MEAS.	UNIT COST	TOTAL COST
Mobilization and Demobilization		1	Ea	$71,000	$71,000
Demolition		1	LS	$30,000	$30,000
Existing Building HVAC and Electrical Modifications		1	LS	$120,000	$120,000
New Compressor	Ingersoll Rand	1	LS	$300,000	$300,000
New Air Receiver		1	LS	$20,000	$20,000
New 5" HDPE Air Transmission Line		3,400	LF	$30	$102,000
New 2" Air Distribution Hose		16,000	LF	$25	$400,000
New Diffuser Assemblies		117	Ea	$2,100	$245,700
Connections to Existing Manholes		5	Ea	$2,500	$12,500
Modifications to Existing Diffuser Assembly Locations		115	Ea	$1,000	$115,000
Electrical, Instrumentation and Controls		5%		$70,000	$70,000
Subtotal					$1,420,000
Contingency (%)		25%			$360,000
Subtotal					$1,780,000
Engineering (%)		15%			$270,000
Admin/Legal (%)		5%			$90,000
Total					**$2,140,000**
	Conceptual Level Range : +50% to -30%		$3,210,000	to	$1,500,000
Note:					
1. Assumes existing 1" air hose are reused.					
2. Assumes no building or electrical modifications for current code compliance.					
3. Assumes existing electrical service sufficient for new equipment.					
4. Construction dewatering excluded; underwater construction by divers assumed.					
Cherry Creek Reservoir - Aeration Study			$1,500,000	TO	$3,210,000

Wright Water Engineers, Inc.

OPINION OF PROBABLE CAPITAL COSTS

Client: Cherry Creek Basin Water Quality Authority	
Project: Cherry Creek Reservoir - Aeration Study Side Stream Oxygenation System	

Project No: 181-101.000	
Sheet: 1 of 1	
By: JMN/GUS	Ckd:
Date: 10/4/19	Date:

Conceptual Level

DESCRIPTION	COMMENTS/REFERENCES	QTY.	UNIT MEAS.	UNIT COST	TOTAL COST
Mobilization and Demobilization		1	Ea	$220,000	$220,000
Demolition		1	LS	$100,000	$100,000
Intake					
Cylindrical Screen		1	LS	$300,000	$300,000
24" DIP Raw Water Line		500	LF	$500	$250,000
Airburst System	Atlas Copco	1	LS	$50,000	$50,000
Intake Structure		1	LS	$250,000	$250,000
Side Stream Pump		1	Ea	$100,000	$100,000
Building	16'x18'	288	SF	$250	$72,000
Oxygen Saturator	ECO Oxygen Technologies, LLC	1	Ea	$800,000	$800,000
Liquid Oxygen System		1	Ea	$400,000	$400,000
Chemical Feed System		1	Ea	$40,000	$40,000
16" DIP Oxygenated Water Delivery Line		4,400	LF	$300	$1,320,000
Line Diffuser Piping and Nozzles	Mobley Engineering, Inc.	1	LS	$300,000	$300,000
Electrical, Instrumentation and Controls		10%		$400,000	$400,000
Subtotal					$4,600,000
Contingency (%)		25%			$1,150,000
Subtotal					$5,750,000
Engineering (%)		15%			$860,000
Admin/Legal (%)		5%			$290,000
Total					**$6,900,000**
	Conceptual Level Range : +50% to -30%		$10,350,000	to	$4,830,000

Note:
1. Assumes side stream pump and intake near marina at water edge and other components near existing building.
2. Assumes no building or electrical modifications for current code compliance and new building attached to existing building.
3. Assumes no required chemical feed system fire suppression or safety shower/eyewash.
4. Assumes existing electrical service sufficient for new equipment.
5. Construction dewatering excluded.

Cherry Creek Reservoir - Aeration Study		$4,830,000	TO	$10,350,000

EVALUATION OF IN-RESERVOIR TREATMENT AT CHERRY CREEK RESERVOIR

For CCBWQA

Submitted by
Wright Water Engineers, Inc.
2490 W. 26th Ave, 100A
Denver, CO 80211

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