CLEARLAKE OAKS COUNTY WATER DISTRICT

NOTICE OF A SPECIAL MEETING OF THE BOARD OF DIRECTORS

Date: April 11, 2024
Time: 2:00 PM

Clearlake Oaks County Water District - Administration Building
12952 E. Hwy. 20 Clearlake Oaks, CA 95423

AGENDA

A. CALL TO ORDER

- Pledge of Allegiance
- Roll Call

☐ Mr. Stanley Archacki, President ☐ Mr. Michael Herman, Vice President ☐ Mr. Samuel Boucher, Director
☐ Mr. James Burton, Director ☐ Mr. William McHugh, Director ☐ Mrs. Dianna Mann – General Manager
☐ Mrs. Olivia Mann – Board Secretary

B. PUBLIC COMMENT ON ITEMS NOT ON THE AGENDA

The public may comment on items not on the agenda within the Board's jurisdiction. Speakers are limited to three (3) minutes each.

NEW BUSINESS

1. Presentation on the Hypolimnetic Oxygenation Pilot Project in the Clearlake Oaks Arm

Action Taken: ____________________

2. Discussion and consideration of allowing the Clearlake Oaks County Water District to participate in the Hypolimnetic Oxygenation Pilot Project

Action Taken: ____________________

ADJOURNMENT **Time:** ________

Where appropriate or deemed necessary, the Board may take action on any item listed on the agenda, including items listed as information items. Public documents relating to any open session item listed on this agenda that are distributed to all or a majority of the members of the Board of Directors less than 72 hours before the meeting are available for public inspection in the customer service area of the District's Administrative Office at the above address.

The public may address the Board concerning an agenda item during the Board's consideration of that agenda item. The President will call for comments at the appropriate time. Comments of individual speakers are limited to three minutes per agenda item.

In compliance with the Americans with Disabilities Act, if you have a disability, and you need a disability-related modification or accommodation to participate in this meeting, then please contact Clearlake Oaks County Water District Secretary to the Board at 707-998-3322. Requests must be made as early as possible, and at least one full business day before the start of the meeting.

Clear Lake Blue Ribbon Committee
HYPOLIMNETIC OXYGENATION PILOT PROJECT IN THE OAKS ARM
May 5th, 2022

Project Title: Hypolimnetic Oxygenation Pilot Project in the Oaks Arm

Project Description:

1. *Background of the Project*: Historical monitoring data and more recent monitoring, experiments, and modeling by UC Davis TERC have shown that periods of low dissolved oxygen (hypoxia) next to the lake bed sediments are a major factor in the poor water quality and ecological health of Clear Lake (Fig. 1, App. 1). These periods of depleted dissolved oxygen (DO) occur when the lake thermally stratifies in summer. The absence of DO during the summer months (typically June to September, but occasionally May to November) leads to:

- *Release of sediment-bound phosphorus (internal loading).* Field and laboratory studies confirm that internal loading is responsible for over 80% of the phosphorus in the lake water (Fig. 2, App. 1).
- *Phosphorus (P) is a major driving factor in the formation of harmful algal blooms (HABs).* HABs are an issue that threatens public health and many beneficial uses of the lake. Recent measurements have shown that neurotoxins produced during Clear Lake's intensive HABs travel through treatment plants and are present in human drinking water at levels in exceedance of state and federal standards.
- *Facilitation of methylmercury release (MeHg).* MeHg accumulates in fish tissue and produces nervous system effects in humans. The linkage between low DO and high MeHg release rates has been established in numerous systems around the country, and the USGS and US EPA have been studying this at Clear Lake in the decadal long remediation program of the Sulphur Bank Mercury Mine (Fig. 3, App. 1).
- *Release of other metals.* Metal ions (e.g. iron) also result from episodic periods of hypoxia that impose expensive water treatment costs on water purveyors.
- *Loss of fish habitat with the potential for summer fish kills.* Extended hypoxic events stress fish populations and negatively impact the lake ecology and the economic viability of the sports fishery.

Hypolimnetic Oxygenation (HO) (Fig. 4, App. 1) is a technique that has been used nationwide (and in California) to ameliorate such conditions. It entails the direct injection of pure oxygen to the lake's hypolimnion (the lower stratum of the lake). Appendix 2 provides background details.

While many reservoirs are successfully utilizing this technique, Clear Lake has a large surface area (150 km^2) and is naturally highly productive (hypereutrophic), which results in a very high oxygen demand at the sediment-water interface (approx. 0.9 g O_2/m^2/day). For these reasons, we propose a pilot project on the Oaks Arm (14.1 km^2) to fine-tune the technology for Clear Lake before a whole-lake implementation is designed. **An important advantage that Clear Lake possesses over smaller lakes is that it has high water current velocities resulting from longer distances winds can blow across the lake.** This feature will be utilized through the model-based design to help distribute the oxygen over a larger area both in the Oaks Arm and into the other two Arms.

Importantly, although internal loading accounts for a majority of the lake P-budget, watershed inputs are important, especially at longer time scales (e.g. decadal and centennial), and activities to reduce external nutrients are still critical to the long term health of the lake.

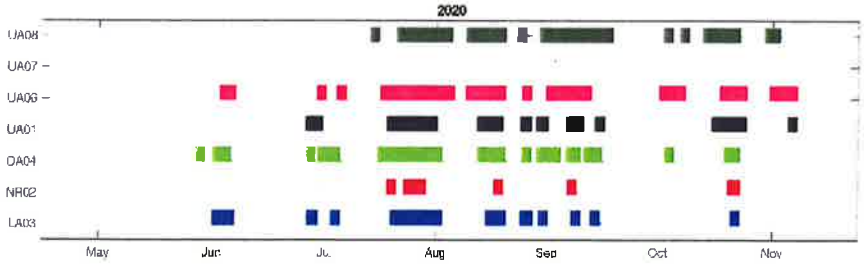
2. *Project Purpose:* This pilot **research** project consists of the design, construction, implementation, monitoring, water testing, and scenario testing of Hypolimnetic Oxygenation (HO) in the Oaks Arm of Clear Lake, CA. The **Oaks Arm** was selected as it is the smallest basin (14.1 km^2, 0.125 km^3), is affected by long-term mercury issues, and is the site of many of the largest HAB blooms. Preliminary results from our 3D lake model suggest that the added oxygen will be readily transported throughout the Oaks Arm within days of injection at the site, depending on current velocities and sediment uptake rates.

The HO will occur through the direct injection of oxygen via a set of diffusers installed at the bottom of the lake from an external oxygen supply onshore during the summer months (see further details about timing in the section below). Pure oxygen (five times more effective than air) is injected at low flow rates through a porous diffuser line that is elevated a short distance above the sediments (Fig. 5, App. 1). The released fine bubbles dissolve rapidly in the hypolimnion, without significant lake mixing. Sediment disturbance will also be minimal given the low oxygen flow rates and the suspension of the diffuser slightly above the sediments. This design is largely self-cleaning, and the whole system need only be floated to the surface in the unlikely event of a line break. This operation can be simply performed on-site if needed.

3. *What does "Success" Look Like?* Our objectives are to 1) quantify rates at which oxygen is dispersed and taken up after injection; 2) quantify the impact of oxygenation on P-release from sediments; and, 3) monitor the effect of oxygenation on water quality. Success of the pilot project is necessarily more targeted than the eventual lake-wide implementation goal of reducing HABs. Here, success will be defined as quantifiably increasing DO in bottom waters and having such oxygenation result in a measurable reduction in P-release from sediments, and validating predictions made using our 3D lake model.

The pilot project will target maintaining daily average hypolimnetic DO concentrations above 3.5 mg/L, and maintaining hypolimnetic orthophosphate concentrations below 0.05 mg/L. As a point of reference, DO can currently be at zero for 2-3 weeks at a time, and orthophosphate can be in excess of 0.6 mg/L. Monitoring of methyl mercury concentrations in the Oaks Arm (by USGS) will also be made and compared to measurements taken in previous years and other Arms.

Success also includes optimizing the HO to deliver the precise amounts of oxygen only when they are needed. The figure below shows the periods in 2020 when anoxia existed at our monitoring stations. At OA-04 in the Oaks Arm (OA04 - light green) anoxia occurred for less than 3 months. Using a hypoxia prediction model already developed for Clear Lake (Cortés et al. 2021), we can modify it and test the system's ability to efficiently start and stop the oxygenation as needed.



This technology, combined with the operational experience from the pilot project and the 3-D lake model, **will allow for the design of a future whole-lake system** and its efficient local operation.

4. *Project Tasks*

Task 1 - Permitting: We will contract with an experienced local consultant to conduct the CEQA environmental review, planning, and construction permits. This will be for the pilot project, but the knowledge gained will streamline the future permitting process.

Task 2 - Design: We will contract with an experienced HO designer for the pilot HO system. TERC staff will assist by the running of the 3-D lake model (see Appendix 3) under separate funding. The siting of the land-based part of the system is included in the design. Preliminary design calculations call for two oxygen diffuser lines, each 4,400 feet long. The assumed sediment oxygen demand is 0.9 g/m^2/day, and with a factor of safety of two, the design capacity of the system should be ~33 tons of oxygen per day. Deliveries to a liquid oxygen storage tank can come from a number of suppliers in Sacramento or the Bay Area.

Task 3 – Outreach: The TERC project manager will be responsible for conducting community outreach for the project. Working collaboratively with all community stakeholders from around the lake and with guidance from the BRC Socio-Economic Sub-Committee, the outreach will be conducted during both the planning, design, and construction phases (Year 1) and the operational phase (Year 2). Workshops, school visits, public meetings, attendance at local events, and social media will be part of the approaches to be used. Special emphasis will be given to Oaks Arm stakeholders initially. Real-time data access from the monitoring buoys will be used as part of the outreach.

Task 4 - Construction: An RFP for HO construction and installation of the designed system will be developed. The Contracting process and the award will be managed by UC Davis Purchasing.

Task 5 - Operation: The system will be operated by the Construction contractor under guidance from TERC. Three specific goals will guide the operation:

1. Achievement of the performance standards detailed above and based on the ongoing monitoring;
2. Testing of the high efficiency model-guided operating system; and,
3. Testing of the system response to "worst-case scenarios" such as wildfire evacuations, or anchor dragging breaking a diffuser line. The system requires no power, so power failure is not a concern.

Tasks 6A and 6B – Monitoring: This program will be a partnership between TERC and the USGS.

TERC Monitoring: Three real-time monitoring buoys will be deployed in the Oaks Arm to gather continuous real-time DO and temperature data every 5 minutes at multiple depths above the lake bottom. Operation will commence in Year 1 when permitting, design and construction are taking place, to provide background data, and continue in Year 2 to monitor the impacts of hypolimnetic oxygenation. The data will be telemetered in real-time and a web portal created to allow the public access to the high-frequency data. With these data, the immediate response of the system will be available to the HO operator, researchers, and stakeholders. Water samples will be taken every 2 weeks at 4 depths at all three stations. The full suite of phytoplankton identification/abundance and nitrogen and phosphorus forms (as currently being measured in the lake) will be analyzed. On up to 10 occasions surface samples for cyanobacteria will be sampled (if bloom conditions are present) and analyzed for total anatoxin-a, total microcystin/nodularin, and total saxitoxin. Comparisons will be made with historical data and other Arms and with the existing shoreline cyanobacterial detection program conducted by the Big Valley Band of Pomo Indians. An acoustic Doppler current profiler will be deployed for the pilot HO operation in Year 2 to better understand the movement of oxygenated water in the Oaks Arm and to assist with model calibration. An autonomous underwater vehicle (AUV) will be deployed to map the distribution of dissolved oxygen in the hypolimnion prior to the commencement of oxygenation and on two occasions during oxygenation to show the spatial distribution of oxygen and other variables. Sediment cores, that are being analyzed on behalf of Lake County, will continue to be collected and used to help determine the impacts of oxygenation on phosphorus partitioning. We do not expect measurable changes at higher trophic levels (fish) because of the short duration of the oxygenation in the Pilot Project.

USGS Monitoring: Water samples for Methyl mercury analysis will be taken on six occasions (before, during, and after HO). One profiling sonde will be incorporated into one of the real-time buoys, and a second sonde will be used for distributed profiling. The development of the sondes will be separately funded by the US EPA.

Task 7 - Final Report: A final report detailing the project outcomes, access to the data, and recommendations for the use of hypolimnetic oxygenation will be provided. The report will also include the details of the system design, construction, and operation.

5. *The Longer-Term Vision*

Assuming that the pilot project achieves its scientific, water quality, and ecological goals, it will be a relatively straightforward task to quantify the **capital cost and running cost** of a full-scale system. We are optimistic that with the experience gained, efficiencies in operation will translate into reduced oxygen consumption, and will allow for long-term reductions in costs.

What we would recommend to parallel this very large effort would be a quantitative assessment of the **long-term benefits** that an improvement in water quality and ecological health will provide to the entire community. This should take into account the economic benefits across all sectors, and include human health benefits and the opportunities for building human capacity. This is a task that would benefit from the leadership and inclusiveness of the Blue Ribbon Committee.

It is only when the true costs and benefits have been determined that a long-term, sustainable financing model can be developed.

Project Timeline:

- **Year 1:** Permitting, design, outreach, construction, monitoring
- **Year 2:** summer oxygen injection), monitoring, final report

Projected Budget:

		Performed By	Year 1	Year 2	Total	Percentage of Budget
Task 1	Permitting	Consultant	$200,000		$200,000	9.1%
Task 2	Design	Contractor	$150,000		$150,000	6.8%
Task 3	Outreach	TERC	$30,000	$20,000	$50,000	2.3%
Task 4	Construction	Contractor	$850,000		$850,000	38.6%
Task 5	Operation	Contractor		$300,000	$300,000	13.6%
Task 6 - A	Monitoring	TERC	$330,000	$180,000	$510,000	23.2%
Task 6 - B	Monitoring	USGS		$120,000	$120,000	5.5%
Task 7	Final Report	TERC		$20,000	$20,000	0.9%
All Tasks			$1,560,000	$640,000	$2,200,000	100%

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Additional Information:

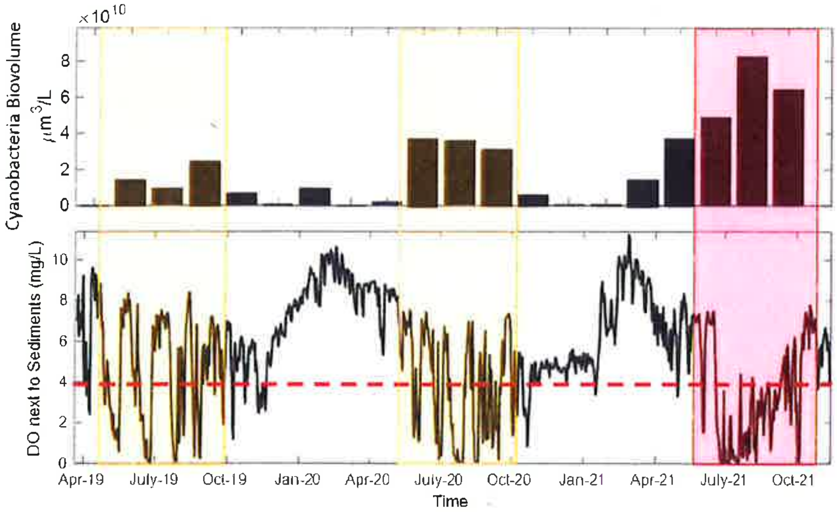

Fig. 1. (Top) Cyanobacteria biovolume from our in-lake sampling every 6-8 weeks in the Oaks Arm. (Bottom) Continuous-time series of benthic dissolved oxygen in the Oaks Arm. The red dashed line marks one of the possible DO thresholds to define hypoxia. The squares mark the summer periods when the cyanobacteria biovolume increases and the DO decreases

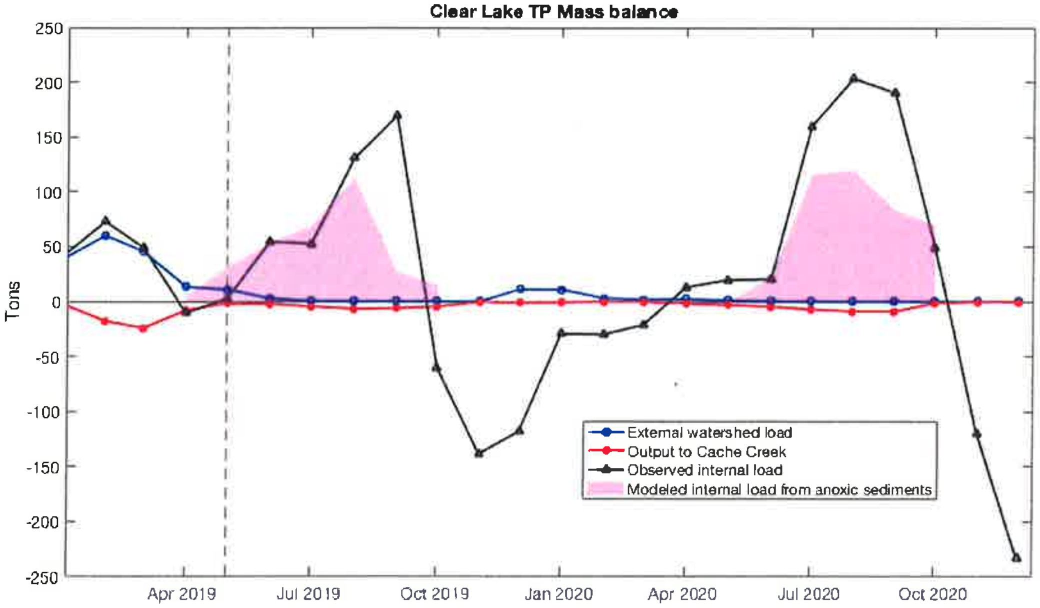

Fig.2. Total phosphorus mass balance for Clear Lake (2019-2020) with external input and output loads, and observed and modeled internal load from anoxic sediments using laboratory P-release rates. Dashed vertical line indicates the start of the UC Davis Lake monitoring program

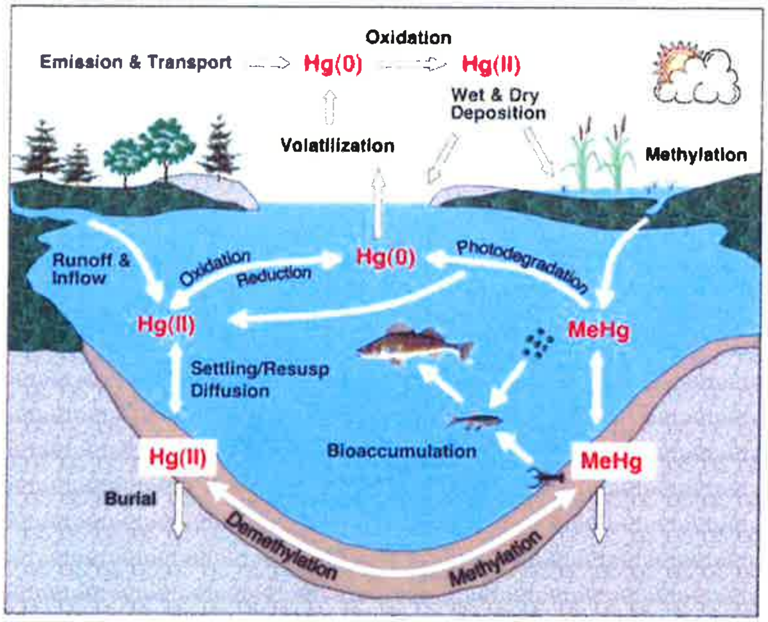

Fig. 3. Diagram of mercury (Hg) cycle in a water body. A small portion of Hg(II) is converted to the more toxic form of methylmercury (MeHg). Methylation of mercury is a biologically mediated process known to be facilitated by some strains of sulfate- and iron-reducing bacteria (anaerobic conditions). Wetlands and lake sediments are important environments where methylation occurs. Methylation can also occur in anoxic bottom water. If we keep the overlying water oxygenated, concentrations of MeHg are likely to be lower in sediment, bottom water, and the food web.

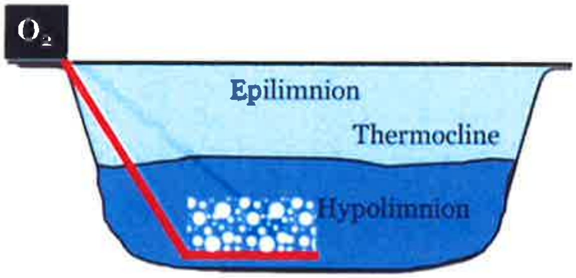

Fig. 4. Hypolimnetic oxygenation (HO) system schematic. The red line represents the pipe that transports the pure oxygen from the shore supply to the bottom of the lake

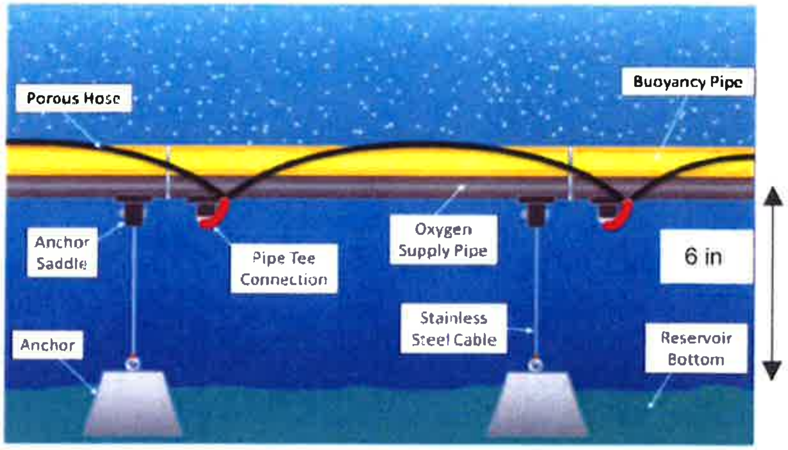

Fig. 5. Oxygen diffusers diagram. The yellow pipeline is very porous and it releases fine bubbles creating a crater that removes the sediments that may be covering it. The black pipe transports the oxygen and it is designed to float and keep the diffuser above the sediments

***Appendix 2**: Background of Hypolimnetic Oxygenation*

The foundation for use of oxygen as a restoration strategy of eutrophic lakes and reservoirs traces back to Mortimer (1942). The first application of artificially raising hypolimnetic oxygen to counter anoxia occurred in an Austrian aeration system. In the early years of HO, results were often variable, in part due to the availability of pure oxygen, design and performance issues, and oxygen storage logistics. As research on HO systems continued, technology improved, and pure oxygen became more readily available, HO has proven to be an effective technique with more predictive results. To date, more than 30 HO systems have been deployed in lakes and reservoirs worldwide (Gerling et al. 2014, Singleton and Little 2006).

Modern HO systems rely on oxygen either produced or stored adjacent to the lake. An on-site oxygen generator can be used to produce oxygen. These have a higher initial capital cost but lower operating costs in the long run. Liquid oxygen (LOX) can be delivered by a gas supplier. Such an arrangement has little or no maintenance expense but can result in a higher oxygen cost. Pure oxygen is preferred over the addition of air, as air is comprised of only 20% oxygen. It was envisaged for the Pilot Project that LOX be delivered, as the limited duration of the pilot project (less than 4 months) did not appear to warrant the extra capital costs. As part of the pilot project, a more detailed cost-benefit analysis of the oxygen supply could be conducted.

There are various systems used to transfer the oxygen from the storage or generation site into the lake and hypolimnion. HO transfer systems are generally categorized into three types: (1) direct injection via bubble plume diffusers (see for example Singleton et al. 2007) – in these systems a small bubble size ensures the oxygen quickly dissolves into the hypolimnion within a short distance from the injection depth; (2) in situ contact chambers such as the Speece Cone (see for example McGinnis and Little 1998) where oxygen dissolution occurs within a specially designed dissolution chamber housed at the bottom of the lake before releasing to the hypolimnion; and (3) side-stream saturation, for which water is withdrawn from the hypolimnion, oxygenated, and then returned (see for example Beutel and Horne 1999). Such systems have all operated for many years at a time, with a Speece cone system in Camanche Reservoir having been used for over twenty years. CA Waterboard currently has a hypolimnetic oxygenation study ongoing on Lake Hodges in San Diego. None of these systems have been found to cause the sustained disturbance of the sediments. A pilot study conducted by Dr. Horne in the 70s in the Oaks Arm used the aeration technique, and the goal was to mix the full water column instead of directly adding oxygen at the sediment-water interface.

In 1999, the first review on HO was compiled, focusing on the first two decades of HO (Beutel and Horne 1999). A 2006 review summarized the state of system design (Singleton and Little 2006). A comprehensive review of HO in 2016 summarized HO applications to reduce cyanobacterial blooms (Bormans et al. 2016). A more recent review of HO was conducted in 2019, which concluded that HO was largely successful in improving water quality in the studies reviewed, although the conclusions must be tempered with the fact that other in-lake and watershed nutrient restoration efforts have often been implemented in conjunction with HO (Preece et al. 2019). The impacts of hypolimnetic oxygenation in three reservoirs in northern California specifically on mercury methylation are described in McCord (2016).

***Appendix 3**: In-lake Model Description and Progress*

During the past three years, the TERC team has been building, calibrating, and validating a three-dimensional (3-D) hydrodynamic lake model. A numerical lake model is a computer model that uses sets of mathematical equations to reproduce the different processes which are occurring in the lake (warming, mixing, stratification, inter-basin transport). The model is 3-D because it considers changes both in the horizontal and vertical directions. The processes the model simulates are organized into two groups: those that characterize how the water moves (i.e. *hydrodynamic*) and those that modify nutrients and algae in the lake (i.e. *water quality*). We have successfully completed the calibration/validation of the hydrodynamic model. The *calibration* process is a trial-and-error process in which we adjust the parameters of the mathematical equations to reduce the error between field observations and lake model results. During the *validation*, we use a different set of field data without changing any parameters, and we expect a good agreement between observations and model results.

Root mean square errors for temperature are less than 1°C between modeled and observed lake temperatures for a two-year simulation in all Clear Lake basins (Fig. 6).

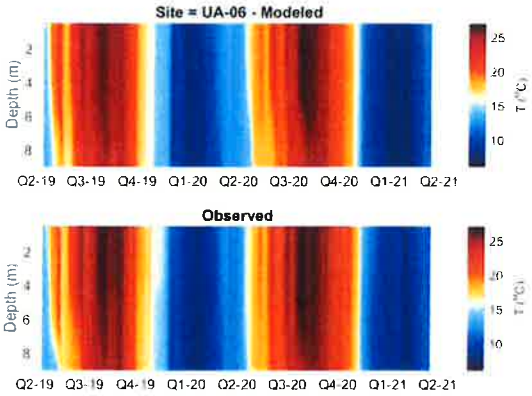

Fig. 6. Comparison of modeled (top) and observed (bottom) lake water temperatures between spring 2019 and spring 2021 in the Upper Arm (UA-06)

This lake model can also help us to better understand the transport of particles and dissolved constituents in the lake. The particles could be algae, phosphorus-rich sediment, or particulate mercury. Figure 7 shows the lake model results of the paths of three particles released in the Upper Arm. Each particle followed a completely different pathway, which highlights the complexity of the hydrodynamics or water movement in this system. Our field sampling plan is focused on improving our understanding of what are the factors affecting the different pathways.

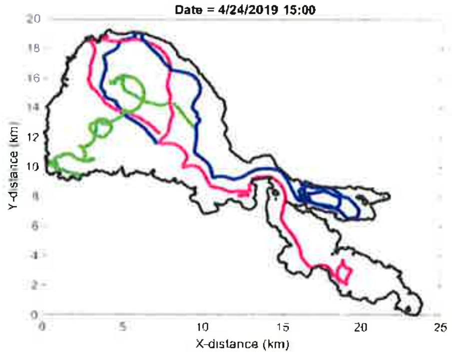

Fig. 7. Three-dimensional lake model results of possible pathways for particles. We used a different color to trace the path of each particle

We are concurrently developing a water quality or biogeochemical model to simulate the evolution of different constituents, such as dissolved oxygen, nitrogen species, phosphorus species, phytoplankton, and suspended solids. This model will include cyanobacteria as one of the phytoplankton groups. This module needs the same type of calibration/ validation described for the hydrodynamic module. Once the validation is completed, we are expecting to use the model to explore different questions regarding lake water quality (e.g. dissolved oxygen enhancement techniques, the fate of streams, and culvert loads). We have produced preliminary results of the dissolved oxygen changes in the water column without and with the hypolimnetic oxygen system (Fig. 8). These results suggest that dissolved oxygen next to the sediments can increase up to 80% when using hypolimnetic oxygenation.

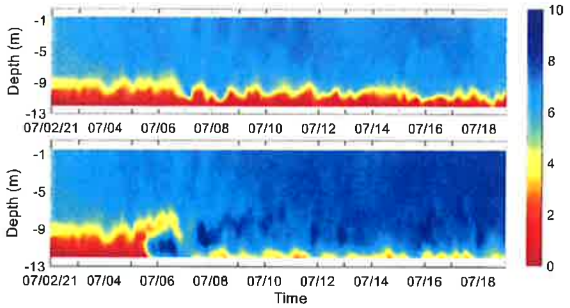

Fig. 8. Three-dimensional lake model results of dissolved oxygen without hypolimnetic oxygenation (top) and with the oxygen injection (bottom)

The large-scale manipulation that hypolimnetic oxygenation introduces, and the changes that it will set in motion, combined with the intensive monitoring that will track these changes, is an ideal scenario for a very robust calibration and validation of the biogeochemical model.

Appendix 4: References

Beutel MW, Horne AJ. 1999. A review of the effects of hypolimnetic oxygenation on lake and reservoir water quality. Lake Reserv Manage. 15(4):285–297. doi:10.1080/07438149909354124

Bormans M, Marsalek B, Jancula D. 2016. Controlling internal phosphorus loading in lakes by physical methods to reduce cyanobacterial blooms: a review. Aquat Ecol. 50(3):407–422. doi:10.1007/s10452-015-9564-x.

Cortés A, Forrest AL, Sadro S, Stang AJ, Swann M, Framsted NT, Thirkill R, Sharp SL, Schladow SG. 2021. Prediction of hypoxia in eutrophic polymictic lakes. Wat Resour. Res. 6: e2020WR028693. Doi: 10.1029/2020WR028693

Gerling AB, Browne RG, Gantzer PA, Mobley MH, Little JC, Carey CC. 2014. First report of the successful operation of a side stream supersaturation hypolimnetic oxygenation system in a eutrophic, shallow reservoir. Wat Res. 67:129–143. doi:10.1016/j.watres.2014.09.002.

McCord SA, Beutel MW, Dent SR, Schladow SG. 2016. Evaluation of mercury cycling and hypolimnetic oxygenation in mercury-impacted seasonally stratified reservoirs in the Guadalupe River watershed, California. Water Resour Res. 52(10):7726–7743. doi:10.1002/2016WR019061

McGinnis DF, Little JC. 1998. Bubble dynamics and oxygen transfer in a Speece cone. Water Science and Technology. 37:285-292, url: https://iwaponline.com/wst/article/37/2/285/7538/Bubble-dynamics-and-oxygen-transfer-in-a-speece

Mortimer CH. 1942. The exchange of dissolved substances between mud and water in lakes. Part III. The relation of seasonal variables in redox conditions in the mud to the distribution of dissolved substances in Esthwaite Water and Windermere, North Basin. Part IV. General discussion. J. Ecology. 30:147–201. doi:10.2307/2256691.

Preece, E. P., B. C. Moore, M. M. Skinner, A. Child & S.Dent. 2019. A review of the biological and chemical effects of hypolimnetic oxygenation. Lake and Reservoir Management. 35:3. 229-246, doi: 10.1080/10402381.2019.1580325

Singleton VL, Gantzer P, Little JC. 2007. Linear bubble plume model for hypolimnetic oxygenation: full-scale validation and sensitivity analysis. Water Resour Res. 43:W02405. doi:10.1029/2005WR004836.

Singleton VL, Little JC. 2006. Designing hypolimnetic aeration and oxygenation systems: a review. Environ Sci Technol. 40(24):7512–7520.