September 23, 2022

MS. SARAH MEARON, PG
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California Regional Water Quality Control Board
San Diego Region
2375 Northside Drive, Suite 100
San Diego, CA 92108-2700
(*via email*)

Re: Lake San Marcos Interim Aeration Pilot Study Progress Report
[CIWQS ID: 771065; Geotracker Site ID: T10000003261:SMearon]

Ms. Mearon,

This letter has been prepared at the request of the San Diego Regional Water Quality Control Board (RWQCB) for inclusion in an Executive Officer's Report package to the RWQCB. The specific request was to present data documenting successful operation of the aeration system at Lake San Marcos (LSM, the lake) and its effect on temperature, dissolved oxygen and nutrients. The aeration system was activated in April of 2022 as part of a pilot study that will extend through the end of this month. Since the final monitoring results for the pilot study have not been obtained or evaluated, the information and conclusions presented herein should be considered preliminary in nature. For purposes of this submittal, we have endeavored to assess the data from Station A (the deep lake station closest to the dam), as it is generally representative of deep lake conditions where the effects are likely to be most relevant and significant. The aeration pilot study report is due December 31, 2022. That report will include a full assessment of the available aeration pilot test data.

INTRODUCTION

One of the remedies for the Lake San Marcos and Upper San Marcos Creek project is the operation of an aeration system. The objective of the system is to vertically mix waters to prevent thermal stratification, ensure the water column is aerobic, and thus reduce the internal loading of nutrients from lake sediments. The Joint Parties (Citizens Development Corporation, the Cities of Escondido and San Marcos, and the County of San Diego) have deployed Phase 1 of the aeration system as a pilot study in the deepest part of Lake San Marcos; the system has been operational since April 5th, 2022. Monitoring events were conducted over the course of the pilot study as described in the pilot study workplan submitted to, and approved by, the RWQCB earlier this year.

PILOT STUDY GOALS AND OBJECTIVES

The aeration system pilot study is configured to release air from 10 dual-port diffusers located in the deeper portion of Lake San Marcos. The aeration pilot study is intended to mix deep lake waters, which is expected to have several benefits:

- Mixing prevents the formation of thermally stratified lake conditions, and thus prevents the formation of a cold, stable bottom layer (the hypolimnion) where anoxic conditions result in nutrient releases from sediments (internal loading);

- The plume of air bubbles released from the diffusers at the lake bottom entrains water in the upward flow, which results in greater exposure of lake water to atmospheric air (and oxygen); and

- The upward entrainment and downward movement of displaced shallow waters together result in a circulation pattern which a) discourages algal growth at the surface by reducing water residence time in the photosynthetically active zone and b) is generally less hospitable to algal nuisance conditions (e.g., formation of algal mats and growth of cyanobacteria species generally).

PILOT STUDY METHODS

Configuration

Phase I of the aeration system has been installed and is comprised of a land-based propane-fueled generator and compressor system plus 10 diffusers located in the deeper portion of Lake San Marcos (Figure 1). The compressor pressurizes the system and pumps filtered air to the diffusers. Diffusers are positioned along a 1500-foot stretch of Lake San Marcos centerline (extending from the dam northwards). The diffusers are roughly coincident with historical deep-lake monitoring locations (i.e., inclusive of Stations A, AB, and B; see Figure 2). The 2019 workplan cites the total flow capacity of the aeration system (Phase I and II) as 40-50 cubic feet per minute (CFM); the pilot scale effort (Phase I) is comprised of diffusers with a maximum capacity of 10 CFM each. Thus, if fully deployed, the pilot system could theoretically operate at approximately twice the 2019 design capacity. (Note: flow rates cited above occur at the static pressure at the bottom of the lake. The flow rates under atmospheric pressure as the injected air reaches the surface of the lake would be approximately twice these values.)

Figure 1. Aeration Diffuser Location

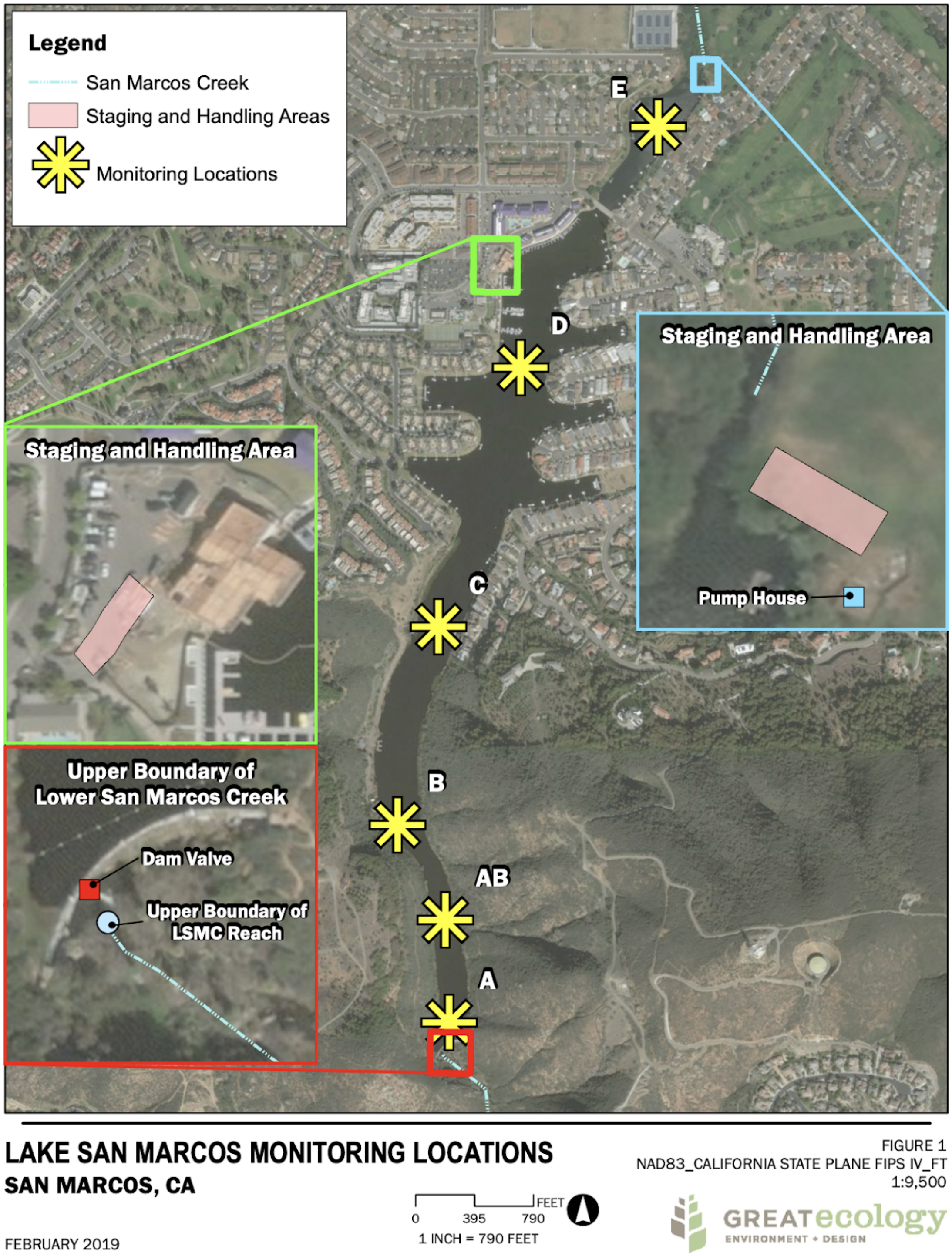

Figure 2. Lake San Marcos Monitoring Stations Map

Timing/Schedule of Operation

Diffusers have been operated at a less-than-maximum capacity during the pilot study. To date, the system has been programmed to run during weekdays (Monday through Friday) for a 10-hour period (approximately 7am to 5pm).

When the aeration system startup occurred on April 5, the system began operating at a time when the lake was already thermally stratified. Although Lake San Marcos was expected to be in a destratified condition at start-up, the pre-monitoring data indicated stratification was present. As a result, the system startup procedure was modified to sequentially activate diffusers starting with the six shallowest diffuser arrays, and then adding 2 additional diffuser arrays over the course of a week (ending with activation of the two diffusers in the deepest part of the lake, closest to the dam). Monitoring during this period indicated that this strategy worked: after two weeks, Lake San Marcos was mixed without indications of anoxic waters at the surface of the lake during that time, and without any negative effects on lake ecology (e.g., fish kills, algae blooms).

As this is a pilot-scale study, the system is not fully instrumented to operate in response to monitored environmental variables on the scale of minutes-to-hours. Manual programming and control of the system is needed to start the system. Therefore, the system has been operating using best professional judgement based on bi-weekly to monthly monitoring data (e.g., measured lake thermal stratification), historical patterns (from prior years' monitoring), and environmental variables (e.g., storm conditions, prolonged high air temperatures).

Once activated, the equipment did go through a 'troubleshooting' period and a variety of modifications and/or fine-tuning settings was necessary over the first few months of the pilot study (April-June). However, these issues were resolved, and the system has been running smoothly from late June through July and August. The Aeration system operating time log describes this in greater detail below. Additionally, the flow rate to individual diffusers has been adjusted occasionally over the course of the season to address site-specific conditions (i.e., to ensure that all diffusers were generating similar bubble plumes). With the exception of the phased startups described above, all diffusers have been activated throughout the course of the pilot study to optimize the performance of the system.

Deactivation

Under natural conditions, destratification at Lake San Marcos generally occurs in the fall, usually in the late September or October timeframe. This typically occurs after 3 or more consecutive days with daily low temperatures below 60 ° Fahrenheit, or following prolonged windy conditions. It is anticipated that operation of the aeration system will not be necessary after approximately September, since thermal gains during the day are typically insufficient to produce thermal stratification through the late fall and winter. The aeration system pilot operations will likely be completed around September 30, and the aeration system put into a standby mode for the 2022-2023 winter season.

MONITORING & RERPORTING PROGRAM METHODS

Monitoring began before aeration system startup, was conducted on a bi-weekly frequency immediately following system startup (for one month), and then on a monthly basis (which will continue through September 2022). Monitoring was undertaken following provisions of the pilot study workplan, including for physical, chemical and biological parameters. For the purposes of this interim report, only data collected at Station A is presented. Station A is located in the deepest portion of Lake San Marcos where the aeration system's efficacy is most important (the final report will comprehensively discuss all available data).

A valuable interpretive tool is the assessment of nutrient masses in Lake San Marcos, which enables more meaningful integrative assessments and comparisons to historical conditions. This method converts concentration data and established lake volumes into nutrient masses for different volumetric “cells” of the lake, which can then be considered in part or for the whole lake. The methodology of these calculations used the same methods that have historically been used to track nutrient masses in Lake San Marcos for previous pilot studies (e.g. for phosphorus inactivation treatments). Historically, assessment of the deep lake conditions included calculations based on hypolimnion and epilimnion masses based on the stratification boundary. However, since the purpose of the aeration pilot study was to eliminate stratification, the method was modified. In April, May, and June, while Lake San Marcos was thermally mixed, an oxycline was observed and so dissolved oxygen could be used as a proxy to establish the upper and lower volumes of the lake and in turn calculate the nutrient masses for the upper and lower volumes of the lake. In July and August, the lake was thermally mixed and there was no oxycline. In July and August, the same depth from the previous months were used as the boundary to 1) simplify the calculations, 2) enable consistent time-series comparisons for the duration of the pilot study, and 3) enable direct comparisons for water masses between 2021 (when the lake was stratified) and 2022 (when the lake was not stratified due to the aeration system).

To assess whether the aeration system affected water quality at Lake San Marcos relative to prior years, Station A data from 2022 was compared to Station A data from 2014 and 2021. The 2014 data was used as a no-aeration, no phosphorus inactivation case year (discussed below). The 2021 data was used to compare 2022 conditions with aeration to a year when a phosphorus inactivation treatment was applied. All three years (2014, 2021, and 2022) had similar low annual rainfall conditions in the previous wet season (i.e., below-average annual rainfall, though the timing and magnitude of storms differed between years).

[Note: Total water year precipitation was 5.2 inches in 2013-2014, 5.8 inches in 2020-2021, 7.0 inches 2021-2022 (not including September 2022). These years were all relatively dry in comparison to the 20-year average of 10.5 inches for the dataset (NOWData, NOAA Online Weather Data, Carlsbad McClelland Palomar Airport Station, www.weather.gov).]

Results

An inherit assumption of this report is that Station A is representative of the deep lake in 2022, 2021 and 2014. This was verified to a limited extent based on the physical characteristics of the lake water. Photographic data of Lake San Marcos were also reviewed, however meaningful changes in conditions were not readily apparent across the different time periods.

Operating Log

The approximate number of days and hours the aeration system was operated for each month are indicated in Table 1 (no correction factor was applied to account for the number of workdays per month).

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Table 1. Summary of Aeration System Monthly Operations

Month	April	May	June	July	August
Days	19	19	14	21	23
Hours	142	156	134	210	230

Water Temperature

As described previously, Lake San Marcos typically becomes thermally stratified in the spring. The stratification persists throughout the summer until destratification occurs in late September or early October. Figure 3 below illustrates how stratification develops at Station A in a normal year without an aeration system (2021). Surface water temperatures increase at a greater rate than bottom water temperatures; this results in progressively larger temperature gradients within the water column as stratification intensifies throughout the summer months. In July and August, a temperature difference of roughly 8°C was observed between the shallow and deep waters at Station A (Figure 3).

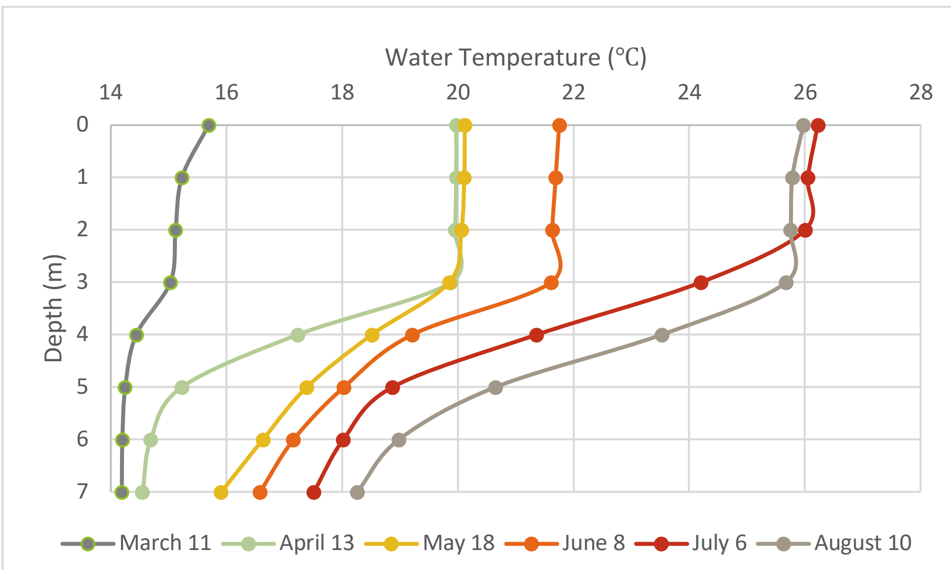

Figure 3. 2021 Station A Water Temperature Profile

Figure 4 presents the water temperature profiles at Station A for 2022. In contrast to 2021, Lake San Marcos was thermally stratified in March prior to start-up of the aeration system. The aeration system was activated on April 5. Data from the two-week post-start-up monitoring event (April 19) illustrates that, as the aeration system was activated, the temperature gradient was reduced dramatically at Station A (from 4.83 to1.87°C). The April through June data indicate that the temperature gradient was <2°C (Figure 4). In July and August temperatures are relatively uniform throughout the water column. Since the threshold for thermal stratification is generally a 3°difference, Lake San Marcos can be considered thermally mixed for the period from April through August 2022.

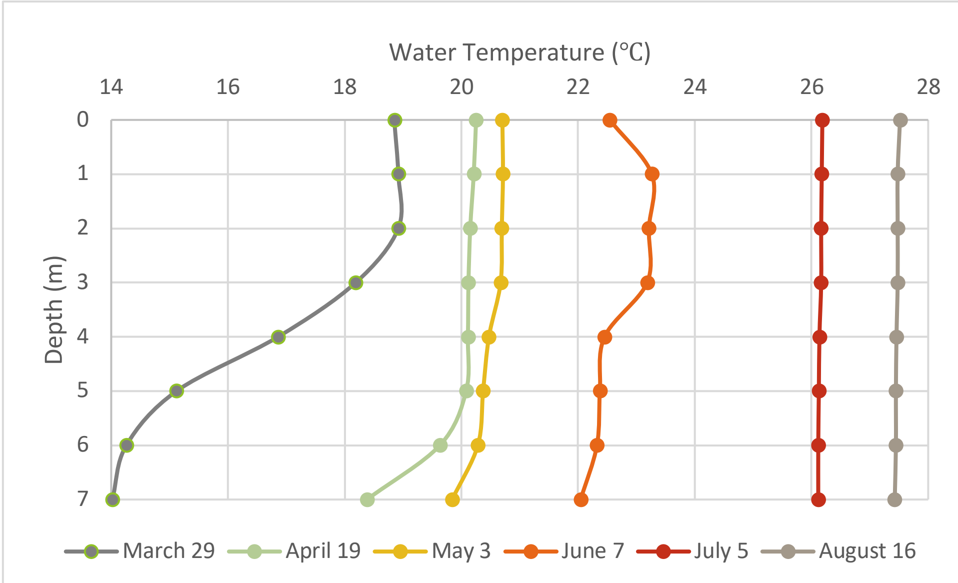

Figure 4. 2022 Station A Water Temperature Profile

The arithmetic differences of the surface and bottom water temperatures at Station A from 2021 and 2022 are displayed in Figure 5. The temperature data shows Station A was stratified in March 2022 but not in March 2021. After March 2021, in the absence of water column mixing with aeration, the thermocline became established and the 3°C difference threshold was exceeded throughout the summer (ranging from 4 to 8°C from April-August). The 2022 temperature data reflects stratification at Station A in March before the aeration system was started. Post-aeration start-up, the difference between the surface and bottom temperatures decreased below the 3°C threshold for the remainder of spring and summer in 2022 (April-August). As the months progressed, the water temperature difference from the surface to the bottom decreased to <1°C in July and August 2022 (Figure 5).

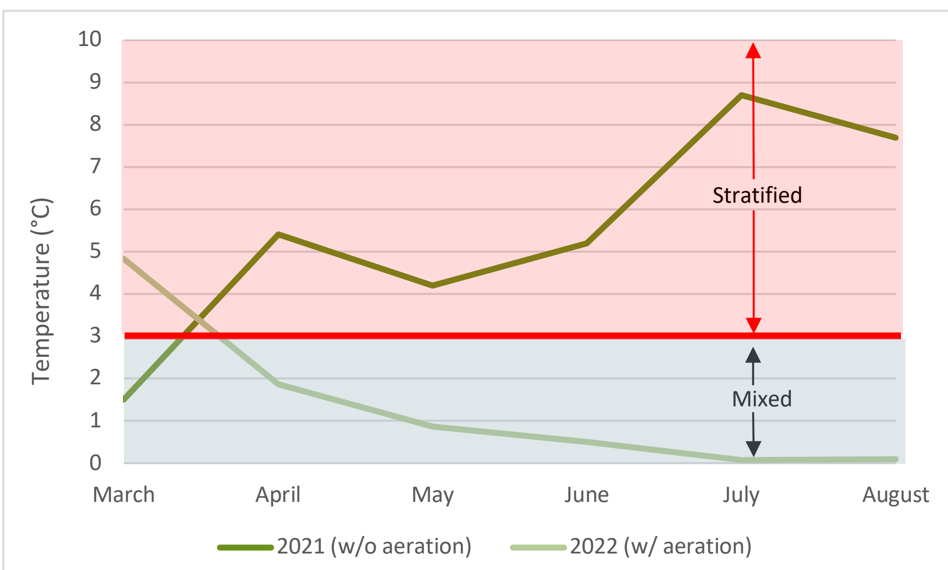

Figure 5. 2021 vs 2022 Surface-Bottom Water Temperature Difference at Station A

Dissolved Oxygen

Without mechanical mixing (e.g. in 2021), Lake San Marcos becomes thermally stratified in late spring and low dissolved oxygen levels were observed in the hypolimnion. Figure 6 presents dissolved oxygen (DO) profiles in 2021 (without water column mixing) and illustrates how thermal stratification (Figure 3) coincides with low dissolved oxygen in the hypolimnion. As the year progressed, DO levels in the hypolimnion fell to an essentially anoxic level (< 1.0 mg/L). (Note: the surface DO levels follow a different pattern due to [1] wind-driven mixing of surface waters and [2] diurnal changes in DO due to photosynthetic activity).

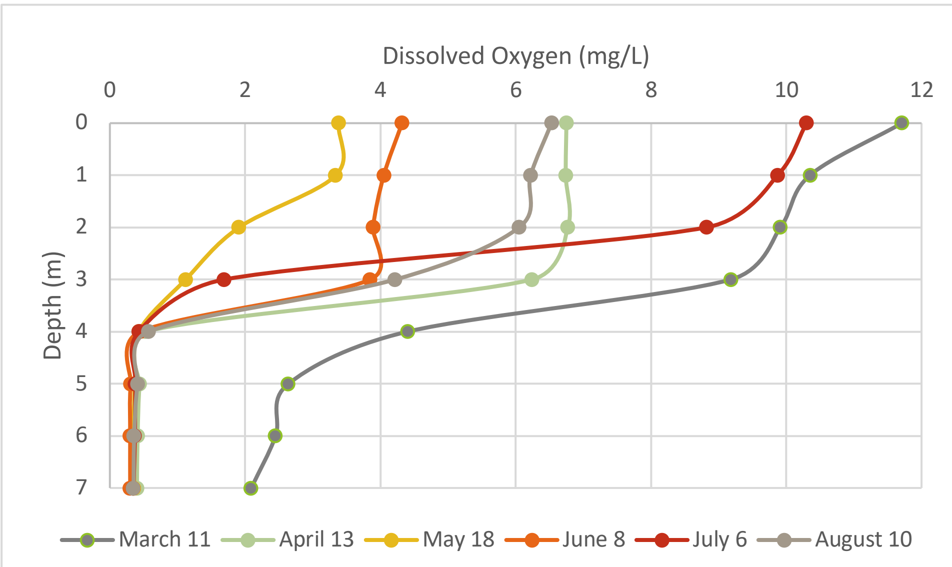

Figure 6. 2021 Station A Dissolved Oxygen Profile

The 2022 DO levels follow an irregular pattern (Figure 7), which can be attributed to various conditions, as described below:

- Pre-Aeration. Lake San Marcos was thermally stratified in March prior to aeration system startup;
- Troubleshooting Phase. Data collected in April (2-weeks post-startup), May (1 month post-startup), and June (2-months post-startup) reflect a period when the aeration system had been started, but the system was not operating at full capacity due to mechanical issues (see Table 1); and
- Operational Phase. Resolution of mechanical issues in mid-June resulted in a system operating as intended for the majority of June and all of July and August; data collected in July and August reflected the period when the system was operating as expected.

The impacts of these three conditions are reflected in the dissolved oxygen data: March data reflects the most stratified condition and the dissolved oxygen in the hypolimnion was at minimum for the water column below 4 meters in depth at Station A. When the aeration system was fully operational (i.e. past the 'troubleshooting' phase, in July and August), the data reflects a mixed water column: the difference between surface and bottom DO concentrations were <0.5 mg/L.

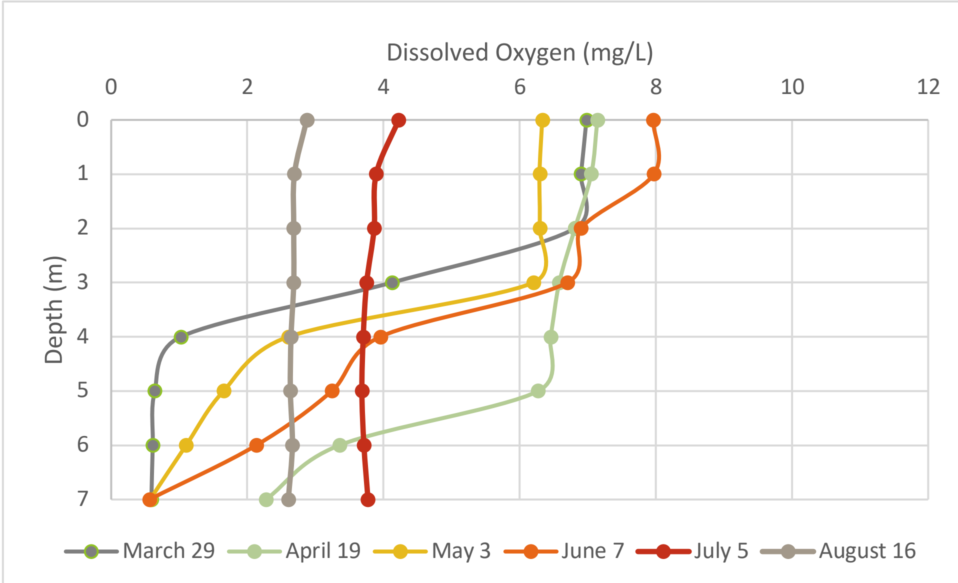

Figure 7. 2022 Station A Dissolved Oxygen Profile

Chlorophyll-a

Chlorophyll-*a* at the surface of Station A in 2022 were maintained within a range of 25 to 40 µg/L and appear to reflect the absence of algal bloom conditions (Figure 8). In 2021, variation was higher, and appeared to reflect bloom conditions in March and May. The phytoplankton taxonomic data will be assessed at wider spatial scales and compared to prior years' data in the final report.

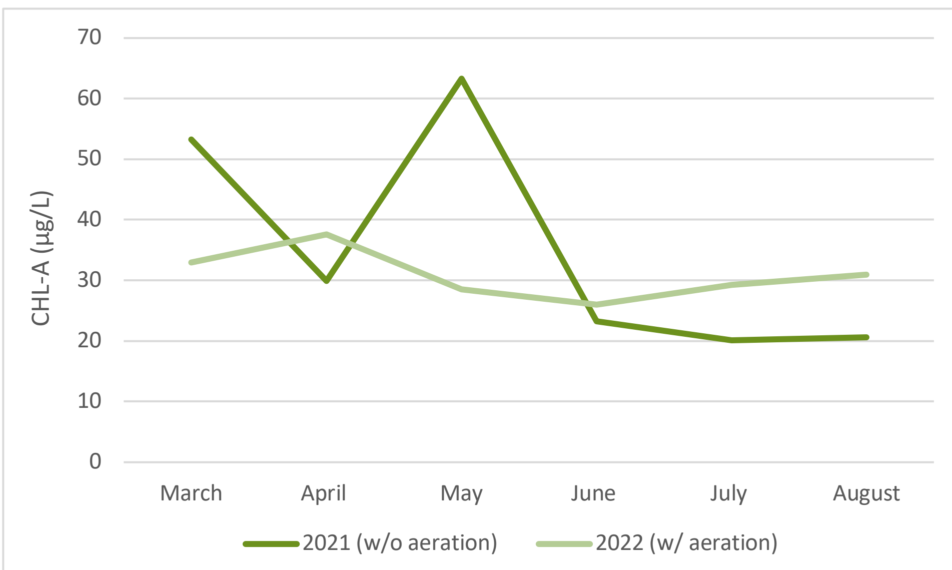

Figure 8. 2021 and 2022 Station A Surface Chlorophyll-*a* Concentrations

Nutrient Masses - Ammonia

2022 ammonia was assessed at Station A by comparing time-series masses with aeration to conditions in 2021 when no aeration system was present. Figure 9 below illustrates how ammonia loads accumulated in the deep lake (Station A) in 2021. Without aeration/mixing, the hypolimnion accumulated ammonia in the deep lake as stratification persisted throughout the summer of 2021.

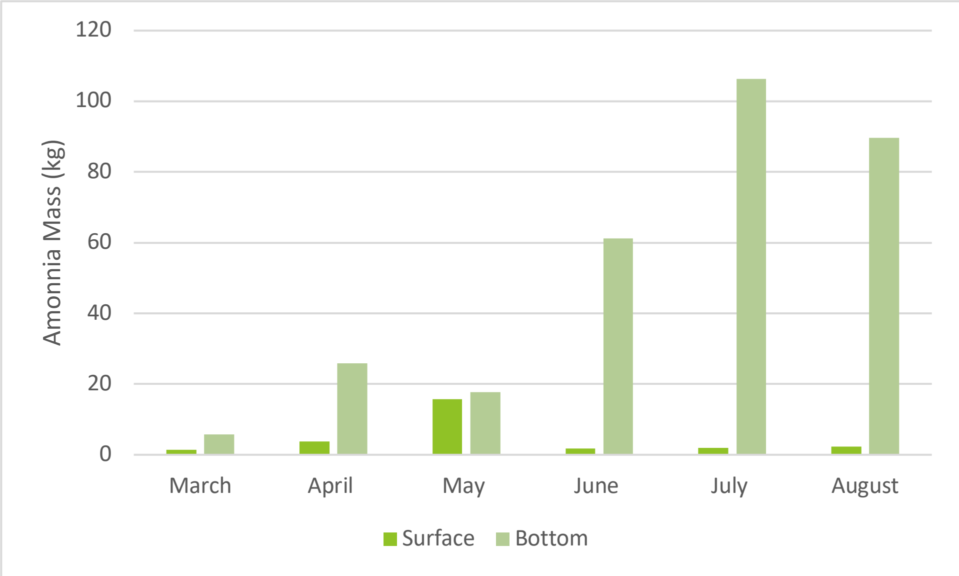

Figure 9. 2021 Ammonia Masses at Station A

In 2022, the aeration system increased the mixing of the water column at Station A and essentially maintained a mixed condition to the extent that dissolved oxygen did not decline to an anoxic condition (see Figure 7). As a result, ammonia formation was minimized and did not accumulate in deep lake (Figure 10). The highest mass of ammonia was observed in March, prior to aeration startup. After the aeration system was activated, the 2022 ammonia masses were maintained at low levels (relative to 2021 masses).

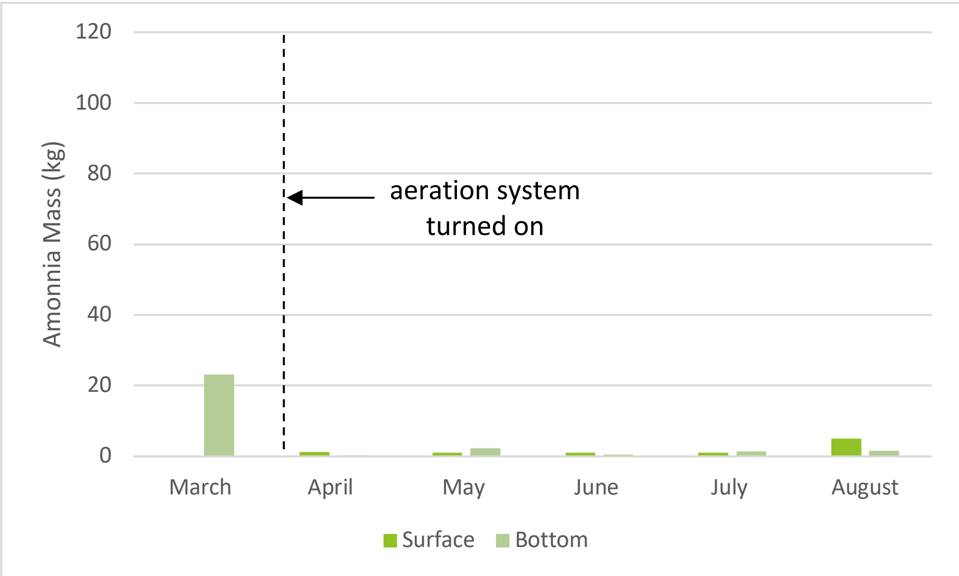

Figure 10. 2022 Total Ammonia Masses at Station A

Figure 11 illustrates that the 2021 total ammonia mass (hypolimnion and epilimnion, or sum of water column) at Station A was greater under stratified conditions in 2021 compared to the 2022 when the aeration system was active and mixing the lake (thermally, April-August, see Figure 5).

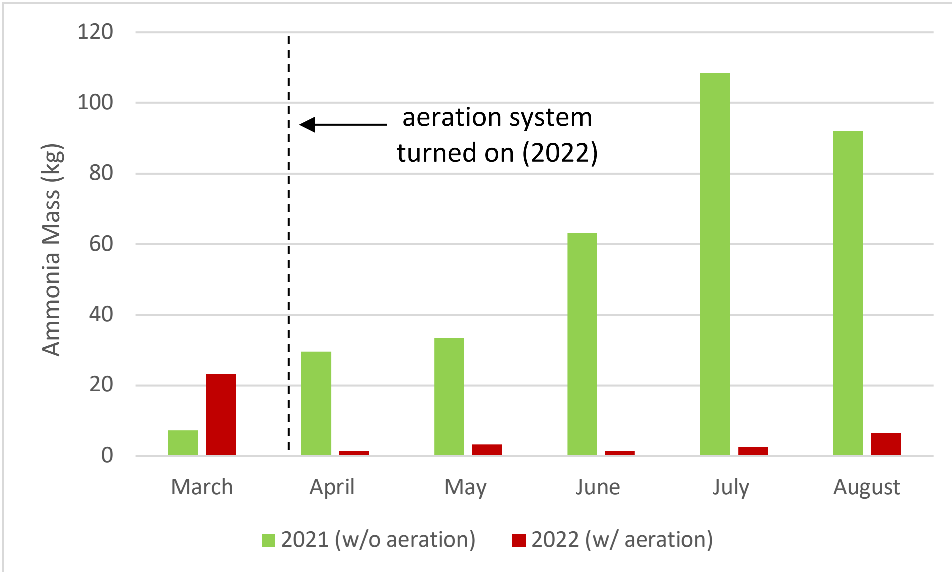

Figure 11. 2021 vs. 2022 Station A Total Ammonia Loads

Nutrient Masses - Phosphorus

Unlike for temperature, dissolved oxygen, and ammonia, phosphorus data from 2021 was confounded by an additional factor: alum was applied to Lake San Marcos in June 2021 in order to inactivate (bind) phosphorus. As a result, comparing 2022 phosphorus masses to 2021 masses is not an apples-to-apples comparison. Our assessment here therefore included data from 2014, a year when no phosphorus inactivation treatment was used, aeration was not deployed, and prior wet-season rainfall was similar.

Total phosphorus loads at Station A are presented in Figure 12. Two patterns are apparent: 1) that both phosphorus inactivation and aeration appear to have similar efficacies for phosphorus reductions in comparison to the 2014 year, and 2) that total phosphorus masses in 2022 at Station A increased over the course of the monitoring period. Similar patterns were observed for dissolved phosphorus (Figure 13).

Due to the complexity of the available data, further assessment over wider spatial scales (comparing deep lake to shallow lake data), at a more detailed level (i.e., considering additional monitoring stations in each area of Lake San Marcos), and over different time horizons (i.e., multiple years) is warranted. Additional considerations will be explored and included in the final pilot study report.

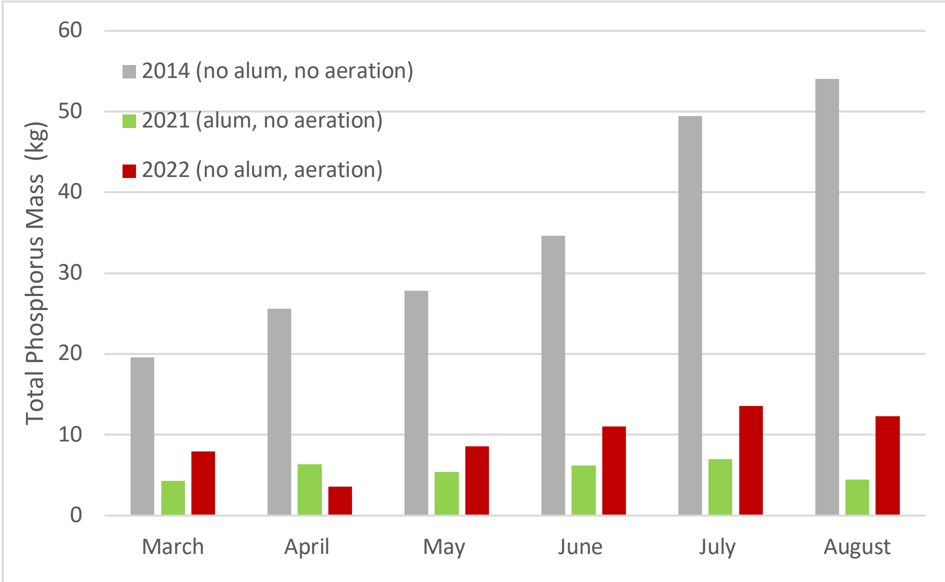

Figure 12. 2014, 2021, and 2022 Station A Total Phosphorus Masses

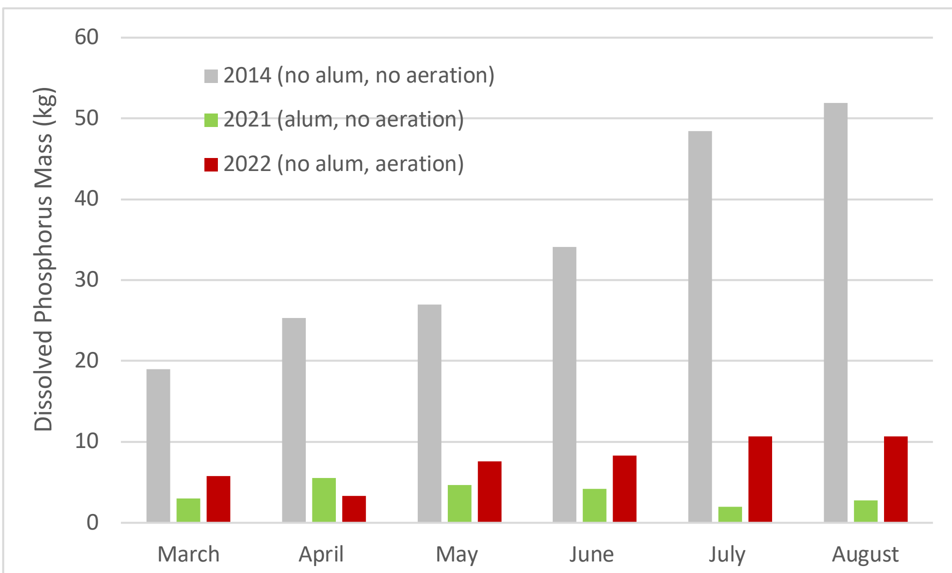

Figure 13. 2014, 2021, and 2022 Station A Dissolved Phosphorus Masses

DISCUSSION

This letter provides a limited summary of on-going aeration pilot study based on a partial analysis of an incomplete data record. A more detailed analysis of the aeration pilot study data is due in December of 2022. Conclusions of this interim assessment are:

- The aeration system suffered from mechanical issues for the first several months of the study, which were resolved, but appeared to affect the initial efficacy of the system;

- Despite partial operation during the first several months of the study, the system was effective in mixing the lake (thermally);
- Dissolved oxygen was successfully managed by the system in later months when the system was fully operational;
- Ammonia masses were successfully reduced in comparison to 2021 data;
- Phosphorus masses were reduced in comparison to the 2014 data; and
- Chlorophyll-*a* data indicated that algae biomass throughout the pilot study period was more uniform and early season algal blooms were not observed.

The final pilot study monitoring event was conducted this month, though data are not yet available. The complete set of physical, chemical, and biological data are expected later this fall. The above conclusions will be vetted and verified upon review of all available pilot study data later this year; final conclusions and recommendations will be included in the final report.

On behalf of the Lake San Marcos Technical Group and with best regards,

Nick Buhbe, M.S.
Senior Managing Scientist
Great Ecology

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Mr. Tim Simpson, GSI Environmental (via email)
Mr. Tim Gallagher, Mediator, the Gallagher Group (via email)