

California Regional Water Quality Control Board

San Francisco Bay Region

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis



Final Staff Report

October 2025

**CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
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1. Executive Summary

The Lake Merritt Low Dissolved Oxygen Advance Restoration Plan was initiated to address recurring low dissolved oxygen (DO) conditions that threaten aquatic life in the lake. As a first step, the Water Board evaluated DO conditions in Lake Merritt to determine whether the lake is meeting the Basin Plan water quality objective (WQO) of 5.0 milligrams per liter (mg/L), which is intended to protect estuarine fish habitat. The assessment focused on exceedance¹ rates of both the 5.0 mg/L WQO and a lower, non-regulatory threshold of 3.0 mg/L, which indicates severely low DO levels likely to cause ecological impacts. The analysis also examined spatial and temporal trends in DO concentrations using monitoring data collected from January 2023 through March 2025.

Key Findings

- Average DO concentrations measured by surface and bottom sondes at all monitoring stations were higher than the 5.0 mg/L WQO. Average surface concentrations were higher than average bottom concentrations at each station, and these differences ranged from 0.5 mg/L to 2.2 mg/L (see Figure 2).
- Combining data from all stations 5.6% of DO measurements fell below the 5.0 mg/L WQO. Bottom DO concentrations fell below the WQO more frequently than surface DO concentrations (9.8% versus 2.3%, see Figure 3c).
- Surface DO concentrations fell below the WQO in the lake center (Station 1) less frequently than in the Glen Echo and Trestle Glen arms (Stations 2 and 3, see Figure 3a).
- In the center of the lake (Station 1), surface DO concentrations remained above the objective nearly all the time (see Figure 6), but bottom DO concentrations fell below the WQO more than 20% of the time in late summer and winter (see Figure 7).
- Among the five monitoring stations, between June and October 2024, the highest average DO concentrations and the lowest rates of exceedance of the WQO occurred at Water Board Station A (see Figure 4, Figure 5, and Figure 6).
- During the period March through July, monthly average surface and bottom DO concentrations were well above the 5.0 mg/L WQO (see Figure 4 and Figure 5), and there were also low exceedance rates of the WQO (see Figure 6 and Figure 7).
- Low DO events in the Glen Echo and Trestle Glen arms occurred most frequently in late summer 2024 and winter 2025. In these two arms, frequent exceedances occurred throughout the water column in August and September (see Figure 6 and Figure 7). In contrast, winter low DO events (December-February) occurred primarily near the bottom (see Figure 7).

¹ Exceedance is a regulatory term of art that describes a circumstance in which a water quality measurement does not meet a water quality objective. Normally, this occurs when the measurement is above the objective. However, in the case of dissolved oxygen, failure to meet the objective occurs when the measurement is below the objective. When used in this report for dissolved oxygen, the term "exceedance" means the concentration falls below the water quality objective.

- Long-term, continuous monitoring of the lake is essential for capturing a more complete picture of lake conditions, identifying meaningful spatial and temporal patterns.

The report provides an overview of available data, a description of analysis methods, and a summary of results. It also includes recommendations for future analyses to inform management strategies aimed at understanding and improving DO conditions in Lake Merritt.

2. Monitoring and Data Availability

General water quality has been continuously monitored at three stations operated by the City of Oakland and the Lake Merritt Institute (Stations 1, 2, 3) since January 2023, with start dates varying by location. In response to the August 2022 fish kill and the expectation of low DO conditions during the summer, the Water Board funded the deployment of sondes at two additional sites: Water Board Station A (WBA) and Water Board Station B (WBB). These two stations were monitored from June through October 2024. Figure 1 shows the locations of all five monitoring stations, and Table 1 provides details on these stations, including data availability at each station.



Figure 1. Map showing the locations of continuous water quality monitoring stations in Lake Merritt

Table 1. Continuous monitoring station details and analytical data inputs

Station Name (CEDEN Station Code)	Location	Sonde Ownership	Coordinates	Depth ^a and Parameters Monitored	Data Used in Analysis – Date Range ^b and Sampling Frequency
Station 1 (204LME450)	Lake Center closest to channel entrance	City of Oakland	(37.800, -122.259)	Both surface and bottom: DO, DO saturation, temperature, salinity Surface only: chlorophyll-a, turbidity Bottom only: depth	January 17, 2023 – March 27, 2025 (every half hour until July 24, 2023, then hourly)
Station 2 (204LME600)	Glen Echo arm	City of Oakland	(37.806, -122.261)	Same as Station 1 except no depth	March 14, 2024 – March 27, 2025 (hourly)
Station 3 (204LME575)	Trestle Glen arm	City of Oakland/Lake Merritt Institute	(37.806, -122.253)	Same as Station 1 except no depth	March 14, 2024 – March 27, 2025 (hourly)
WB Station A or WBA (204LME500)	Lake Center near the boat dock (on Glen Echo arm side)	Water Board	(37.803, -122.258)	Both depths: DO, DO saturation, temperature, pH, salinity Surface only: chlorophyll-a	Surface only: June 5 – October 13, 2024 Bottom: June 5 – October 23, 2024 (every 15 minutes)
WB Station B or WBB (204LME550)	Lake Center on Trestle Glen arm side (surface only)	Water Board	(37.804, -122.255)	Bottom only: same as WBA	June 5 – October 23, 2024 (every 15 minutes)

Notes:

a. Except at Water Board Station B (which only has sondes deployed near the surface), DO are monitored at both near the surface (approximately 1 meter below the surface) and near the bottom (approximately 1 meter from the lakebed).

b. March 27, 2025 was the cutoff date for the data used in this analysis.

Station 2 (in the Glen Echo arm) and Station 3 (in the Trestle Glen arm) were relocated to their current positions on March 14, 2024. Data collected prior to this date were excluded from the analysis, as the previous locations were heavily influenced by freshwater creek inflows and were not spatially representative of overall lake conditions. Additionally, data from Stations 2 and 3 prior to relocation showed data quality issues, including numerous zero or extremely low values, as well as persistently high readings. These anomalies may have been caused by repeated biofouling of the sensors during the early phase of monitoring.

Lake Tech, Inc. is contracted by the City of Oakland to maintain the monitoring equipment and manage data collection at the three city-owned stations (one of which was previously owned by the Lake Merritt Institute until early 2024). Real-time DO conditions are available through the [Lake Tech Data Dashboard](#).

3. Data Analysis Methods and Results

This report evaluated DO conditions in Lake Merritt using two key thresholds: the Basin Plan water quality objective (WQO) of 5.0 mg/L, established to protect estuarine fish habitat, and a non-regulatory 3.0 mg/L threshold, which indicates severely low DO levels likely to cause environmental impacts. For each monitoring station and the lake as a whole (using pooled data from all stations), basic statistics—such as average DO concentrations and the percentage of samples falling below these thresholds—were calculated and plotted. Results are grouped by surface, bottom, and combined depths over the full monitoring period to evaluate spatial variability and overall DO conditions throughout the lake.

The same metrics were also calculated by month to reveal seasonal patterns, identify periods of elevated risk for fish kills, and highlight months with relatively stable DO conditions. This temporal breakdown supports a better understanding of when and where DO-related impacts are most likely to occur.

Finally, the analysis compared the number of DO measurements falling below the 5.0 mg/L WQO—by depth and combined—to the minimum sample counts required to list a water body as impaired under Section 303(d) of the Clean Water Act. This comparison followed the binomial test method outlined in the [State Water Board’s 303\(d\) listing policy](#).

3.1 Dissolved Oxygen Summary Statistics and Exceedance Rates by Station and Across the Lake

Average DO concentrations at each station—calculated for both individual depths (when data are available) and combined depths—are summarized in Figure 2 below. Across all five monitoring stations, average DO concentrations were above the Basin Plan WQO of 5.0 mg/L at the surface, bottom, and combined depths. Average DO concentration measured at the surface, bottom, and combined depths (9.6, 8.5, and 9.1 mg/L, respectively) were highest at Station 1, which represents conditions where the lake first receives tidal inflows from San Francisco Bay. In contrast, average bottom DO (7.1 mg/L) and combined DO (8.2 mg/L) concentrations were lowest at Station 2, located near the lake center inside the Glen Echo arm. Average DO concentrations measured at Station 3 (7.7 mg/L at the bottom and 8.3 mg/L combined), located near the lake center inside the Trestle Glen arm, were slightly higher than those measured at Station 2.

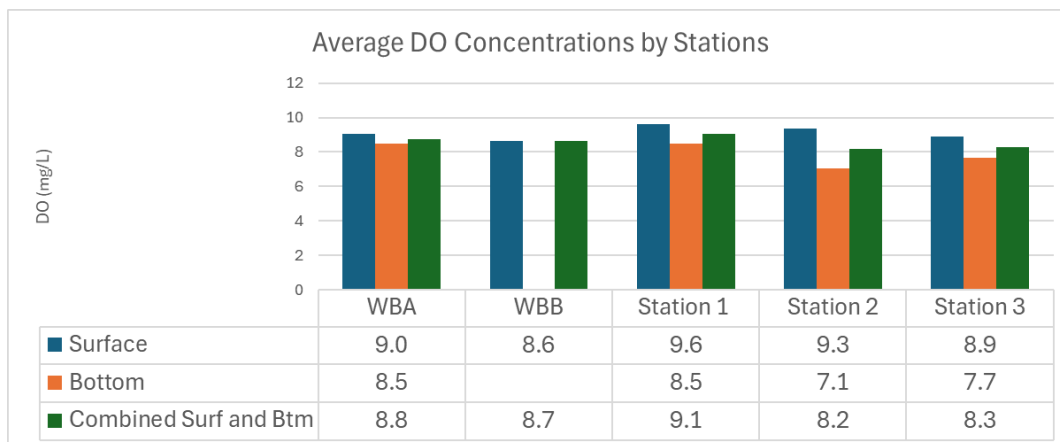


Figure 2. Average dissolved oxygen concentrations by monitoring station and depth

At all stations with both surface and bottom measurements (excluding WBB, which only had surface data), average surface DO concentrations were slightly higher (about 1-2 mg/L) than average bottom DO concentrations. The largest surface-to-bottom DO difference was calculated at Station 2 (2.2 mg/L), suggesting stronger vertical water quality differences and limited mixing in the Glen Echo arm. In contrast, the smallest surface-to-bottom DO difference was calculated at Station 1 (1.1 mg/L), suggesting stronger vertical mixing in this area where tidal flows from San Francisco Bay first enter the lake.

Station 1 had the longest sampling record, with data spanning from January 2023 to March 2025. In comparison, Stations 2 and 3 had data from March 2024 to March 2025, while Water Board Stations A and B were only monitored from June through October 2024. A more refined comparison based on matching timeframes (monthly) is provided in a later section. Therefore, it is important to consider that comparisons between stations may be affected by the different sampling periods.

Figure 3 shows the percentage of DO concentrations falling below 5.0 mg/L and 3.0 mg/L at each station, as well as across all stations combined. These calculated exceedances provide insight into potential spatial patterns and areas of concern within the lake.

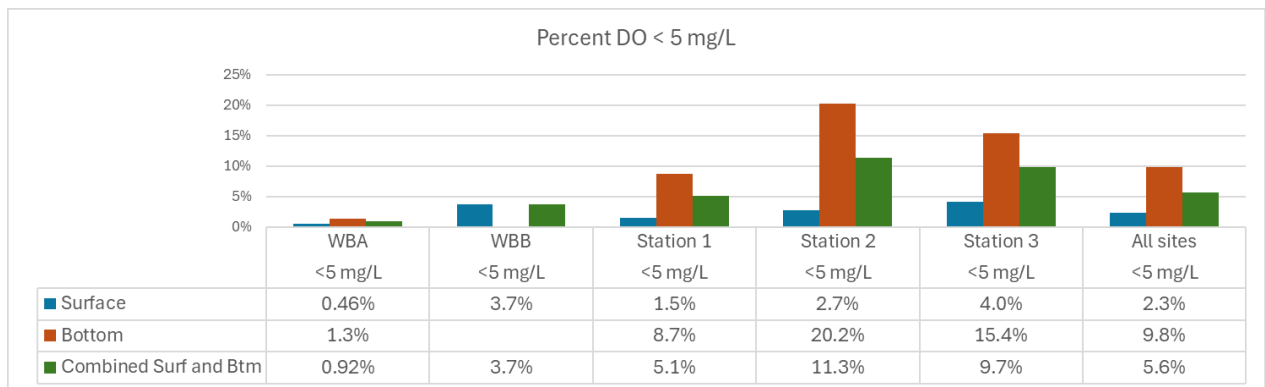


Figure 3a. Percentage of dissolved oxygen concentrations below 5.0 mg/L by station and depth

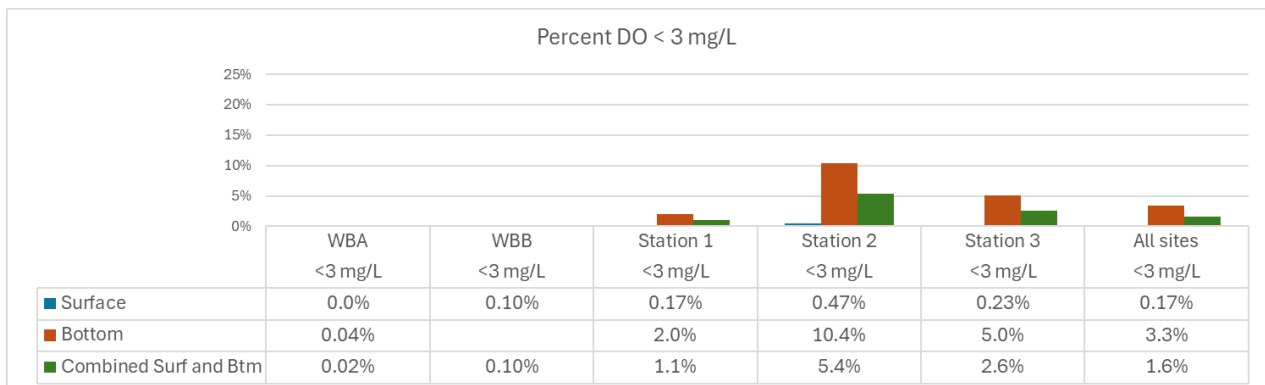


Figure 3b. Percentage of dissolved oxygen concentrations below 3.0 mg/L by station and depth

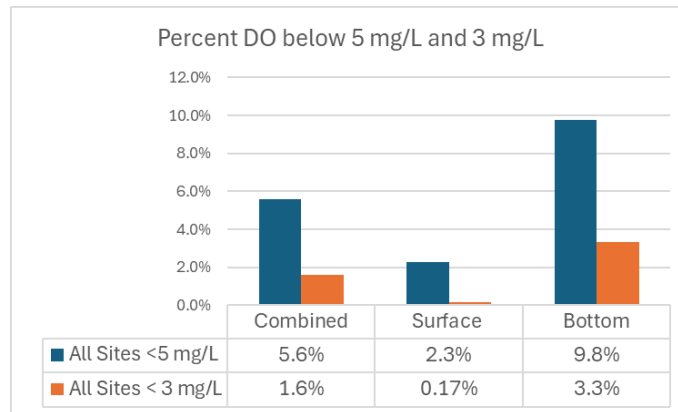


Figure 3c. Percentage of lake-wide dissolved oxygen concentrations below 5.0 mg/L and 3.0 mg/L by depth

Overall, surface DO concentrations in Lake Merritt during the sampling period were consistently above the Basin Plan WQO of 5.0 mg/L. Exceedances below 5.0 mg/L occurred less than 4% of the time at any surface monitoring location, which is far below the 16.6% exceedance threshold (for conventional pollutants) used for impairment decisions under the 303(d) listing policy. Surface Stations 2 and 3, located within the narrower Glen Echo and Trestle Glenn arms, showed slightly higher frequencies of DO concentrations below 5.0 and 3.0 mg/L compared to the lake center stations (Station 1, WBA, and WBB). This suggests that the arms may experience different hydrodynamic or environmental conditions relative to the lake center.

The highest frequency of bottom DO concentrations below the 5.0 mg/L WQO was observed at Station 2, located in the Glen Echo arm, with approximately 20% of measurements falling below the objective. The second highest frequency of bottom DO concentrations falling below 5.0 mg/L was observed at Station 3 (15.4%), located in the Trestle Glen arm. The central portion of the lake, represented by Station 1 (near the channel entrance), WBA (towards the Glen Echo arm side), and WBB (towards the Trestle Glen arm side), generally showed better DO conditions at both the surface and bottom. These results suggest that the two arms of the lake are more susceptible to low DO conditions, likely due to reduced mixing or different hydrodynamic characteristics compared to the central lake area.

Across all stations, surface DO conditions were notably better than bottom conditions (Figure 3c). Exceedances of the 5.0 mg/L WQO occurred in 2.3% of surface samples and 9.8% of bottom samples. When surface and bottom data were combined, 5.6% of measurements fell below 5.0 mg/L, and only 1.6% fell below the more severe 3.0 mg/L threshold. These patterns were consistent with expectations, as surface waters benefit from wind-driven mixing and direct atmospheric oxygen exchange.

3.2 Impairment Analysis using 303(d) Listing Policy

Based on the 303(d) listing policy ([Water Quality Control Policy for Developing California's Clean Water Act Section 303\(d\) List](#)), Lake Merritt is not considered impaired using the available sonde data. The listing policy describes the sample sizes, the minimum number of samples required to place a water body on the 303(d) list. The results are summarized in Table 2 below.

Table 2. Comparison of dissolved oxygen samples below the 5.0 mg/L water quality objective and minimum sample requirements for 303(d) listing

Location	Number of Samples	Combined (Surface and Bottom)	Surface	Bottom
All Sites	Total	117796	65283	52513
	< 5.0 mg/L	6600	1476	5124
	Minimum for 303(d) Listing	19552	10835	8716
WBA	Total	25883	12486	13397
	< 5.0 mg/L	237	58	179
	Minimum for 303(d) Listing	4296	2073	2224
WBB	Total	13394	13394	NA
	< 5.0 mg/L	501	501	NA
	Minimum for 303(d) Listing	2223	2223	NA
Station 1	Total	44431	22279	22152
	< 5.0 mg/L	2273	337	1936
	Minimum for 303(d) Listing	7374	3698	3677
Station 2	Total	16772	8479	8293
	< 5.0 mg/L	1903	230	1673
	Minimum for 303(d) Listing	2784	1408	1377
Station 3	Total	17316	8645	8671
	< 5.0 mg/L	1686	350	1336
	Minimum for 303(d) Listing	2874	1435	1439

Note: Red value indicates an exceedance of listing threshold.

Based on the combined data set for the entire lake, DO concentrations falling below the 5.0 mg/L WQO do not meet the criteria for listing the lake on the 303(d) list. However, decisions for listing water bodies or delisting water bodies in the 303(d) list is performed at the Water Body level or in cases with very large water bodies like San Francisco Bay, by water body segment.

In general, if more than 16.6% of samples of a conventional pollutant fall below the WQOs, it is expected a water body would be put on the 303(d) list. As stated in the previous section, the overall exceedance rate was 5.6% for the entire lake, 9.8% for bottom, and 2.3% for the surface across the lake. They are all well below the 16.6% threshold for listing a water body for impairment.

This analysis does not imply the Water Board is proposing to de-list Lake Merritt at this time. The August 2022 algae bloom resulted in significant harm to aquatic life, underscoring the continued need to address DO conditions in Lake Merritt. Additionally, although not covered in detail in this report, a small-scale fish kill occurred in June 2025 that was associated with low DO levels. Therefore, efforts to improve DO can focus on factors to prevent short-term low DO events, rather than correct an overall lake-wide, chronic DO impairment.

3.3 Temporal Trends in Dissolved Oxygen Concentrations and Exceedances by Station

We performed an analysis to identify potential temporal or seasonal trends at each of the five monitoring stations, as well as spatial variations within shorter time windows (by month). As noted earlier, the time periods of data availability at each station varied. For example, stations WBA and WBB only had data from a five-month period between June and October 2024, while Station 1 had the largest dataset spanning from January 2023 through March 2025. The calculated monthly DO averages at each station are presented in Figures 4 and 5.

DO concentrations near both the surface and bottom showed strong seasonal variations at each station but the trends varied between surface and bottom DO measurements as explained below.

Near the surface, across all five stations, higher average DO concentrations occurred in the months of December to July; whereas lower average DO concentrations occurred in August to November (Figure 4).

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis

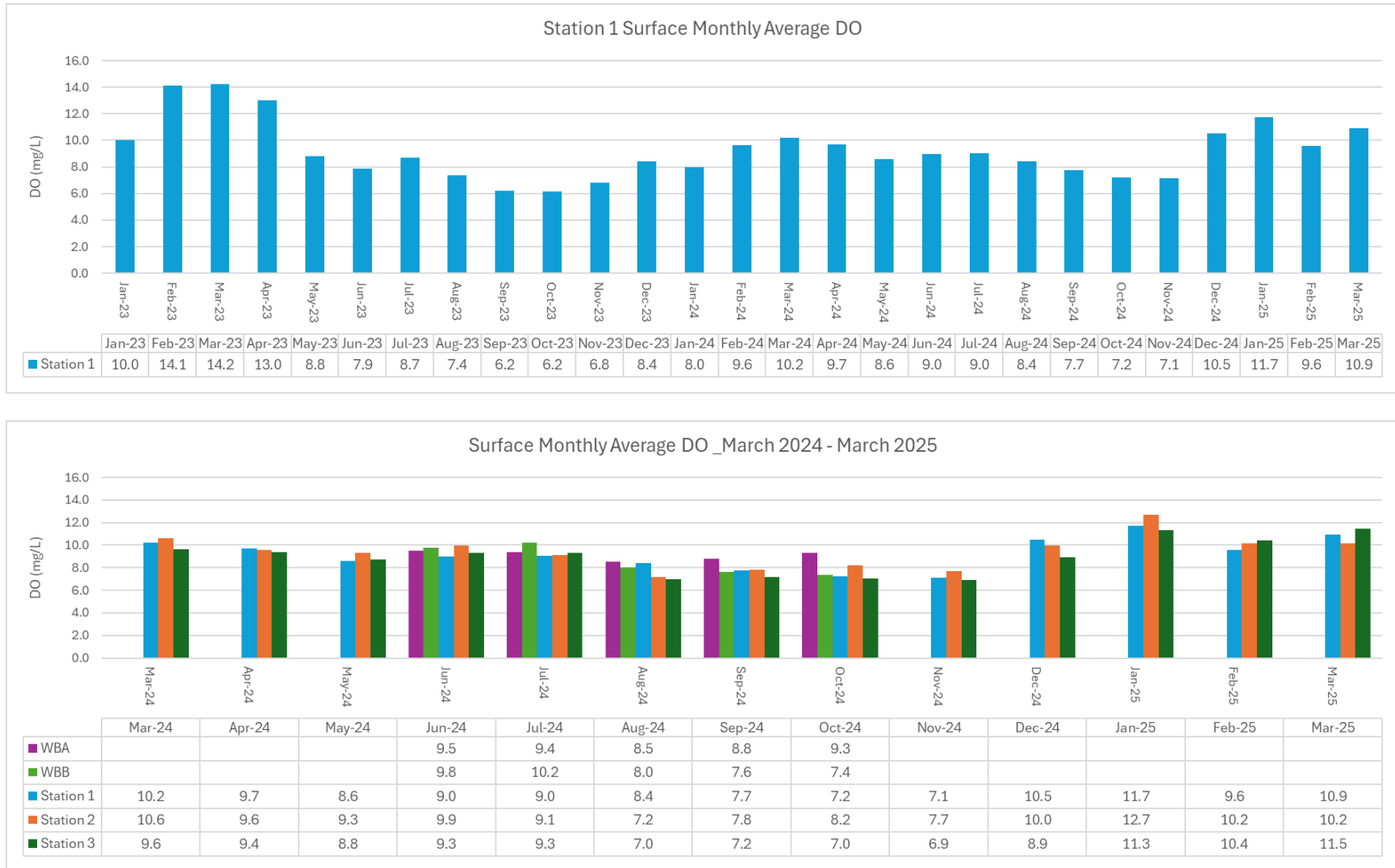


Figure 4. Monthly average surface dissolved oxygen concentrations – Station 1 (January 2023–March 2025, top) and all five stations (March 2024–March 2025, bottom)

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis

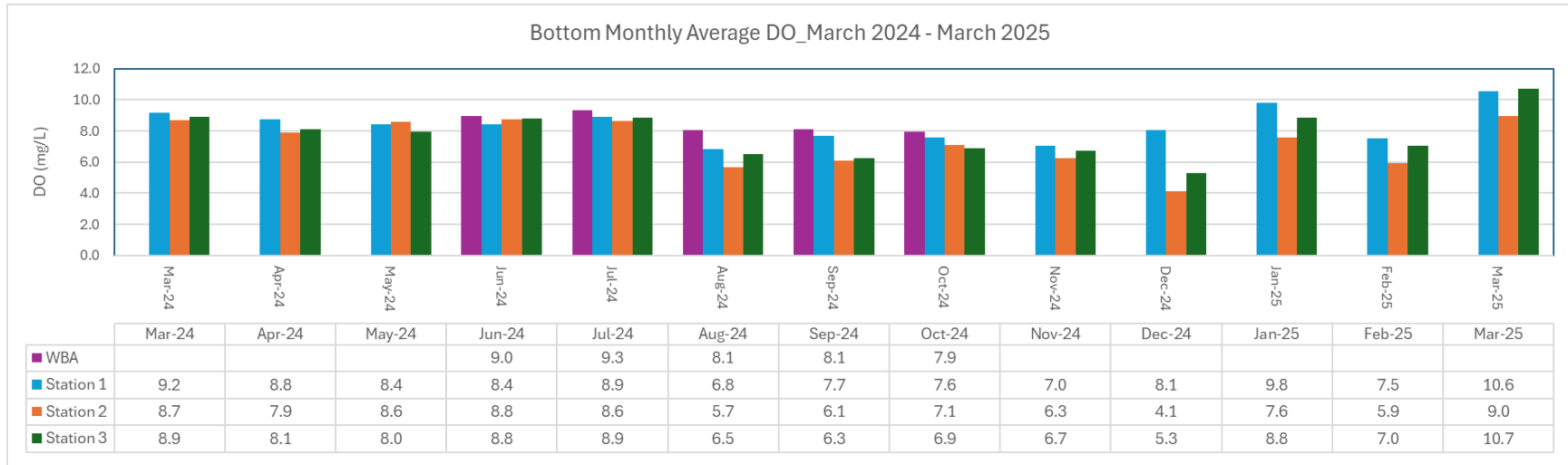
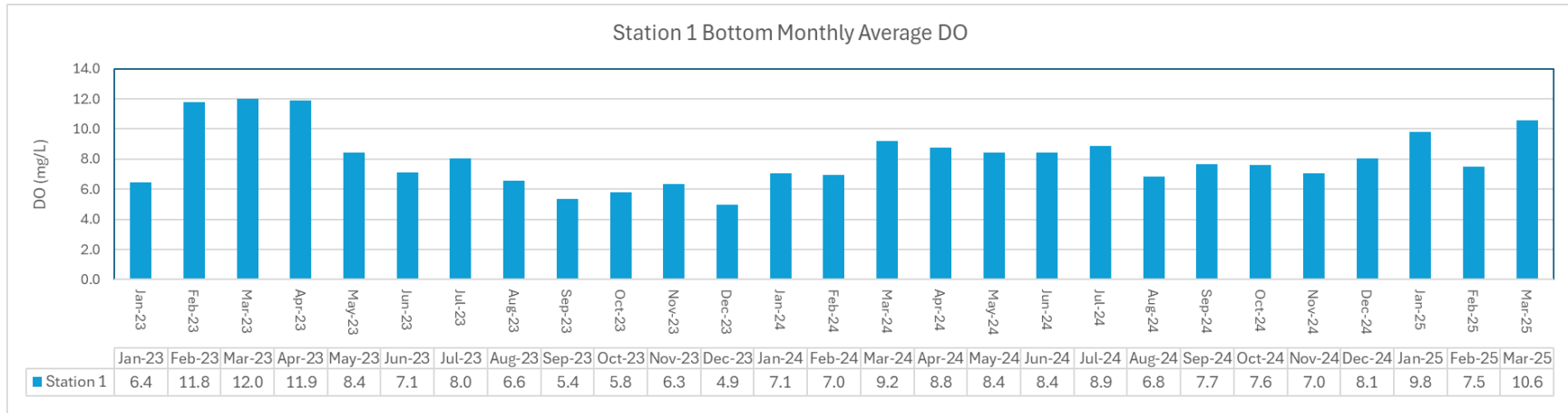


Figure 5. Monthly average bottom dissolved oxygen concentrations – Station 1 (January 2023–March 2025, top) and all five stations (March 2024–March 2025, bottom)

Near the bottom, monthly average DO concentrations were higher in January and March to July; DO concentrations were lower from August to December and in February (Figure 5). The lowest monthly average bottom DO concentrations were observed in December 2024 at Station 2 (Glen Echo arm) and Station 3 (Trestle Glen arm), measuring 4.1 mg/L and 5.3 mg/L, respectively. The lower bottom average DO concentrations in the winter months of November, December, and February, particularly at Stations 2 and 3, were a surprising result, as we were initially focused on low DO conditions in summer when algae blooms are most likely to occur and the 2022 *Heterosigma* bloom occurred.

The lowest monthly average bottom DO concentrations were consistently recorded at Station 2 for most months between March 2024 and March 2025. In contrast, the highest bottom monthly average DO concentrations were recorded at Station WBA from June through October 2024, indicating that bottom DO levels, like surface DO levels, tended to be higher in the central portion of the lake.

Monthly percentages of DO measurements falling below 5.0 mg/L and 3.0 mg/L provide additional insight into specific DO conditions. Figure 6 below illustrates exceedance rates for surface DO measurements by month.

For surface DO, the most exceedances occurred in August and September 2024 at most stations. The Glen Echo arm (Station 2) and Trestle Glen arm (Station 3) experienced the lowest DO conditions in August 2024, with 20% and 16% of surface DO measurements falling below the 5.0 mg/L WQO, respectively. In contrast, there were very few exceedances at Station 1 in August of both 2023 and 2024.

Low DO conditions were also observed in September 2024 across the lake. Most stations recorded more than 6% of surface DO concentrations falling below the 5.0 mg/L WQO. The most DO exceedances were observed at Station 3 with approximately 17% of measurements falling below the 5.0 mg/L WQO. Interestingly, Station 1 experienced similar exceedances in September 2023 with approximately 19% of measurements falling below the 5.0 mg/L WQO. WBB also experienced relatively high exceedance rates in both August and September 2024, whereas WBA consistently showed minimal DO exceedances.

When applying a more stringent DO threshold of 3.0 mg/L, which is used as a threshold when short-term environmental impacts occur, the exceedance rates dropped significantly. The highest exceedances below 3.0 mg/L were recorded at Stations 2 and 3 during August 2024, with approximately 4% and 2% of measurements falling below this threshold, respectively.

From March through July, surface DO concentrations rarely exceeded the 5.0 mg/L WQO. In contrast, the most frequent exceedances occurred in August and September 2024, particularly in the lake arms—Station 2 (20.0%) and Station 3 (16.7%). Among the central lake monitoring stations (Station 1, WBA, and WBB), surface DO measurements exceeded the WQO at the highest rate (19.4%) at Station 1 in September 2023.

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis

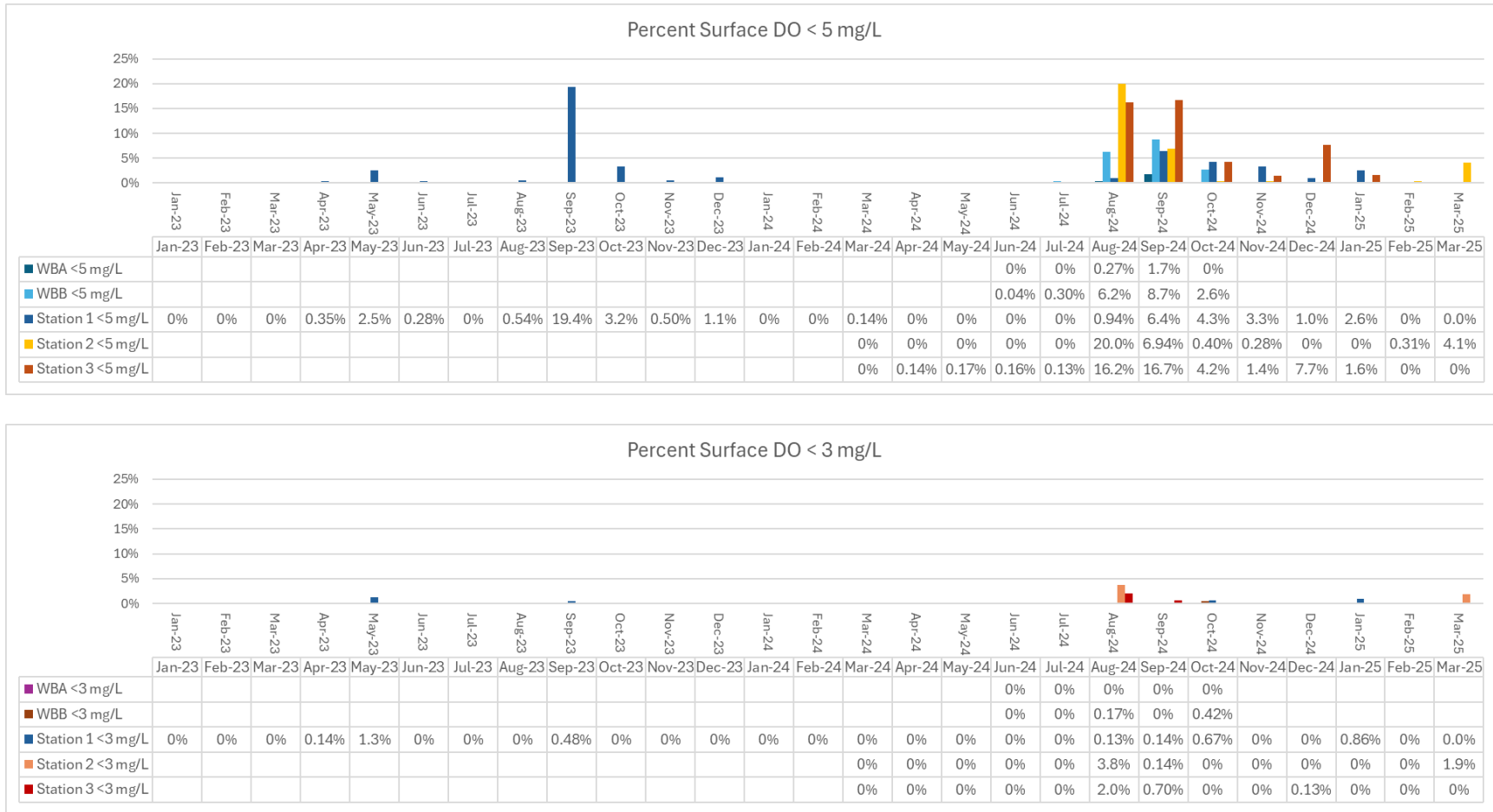


Figure 6. Percentage of surface dissolved oxygen concentrations below 5.0 mg/L (top) and 3.0 mg/L (bottom) by month

Compared to surface waters, bottom waters exhibited more frequent and greater DO exceedances, reflecting limited mixing near the lakebed. As shown in Figure 7, DO measurements near the lake bottom fell below the 5.0 mg/L and 3.0 mg/L thresholds more often than at the surface, which was consistent with expectations.

Higher percentages of low DO measurements were observed at Stations 2 and 3 (located in the Glen Echo and Trestle Glen arms) during August and September, similar to the surface, with Station 2 again showing the highest exceedance in August, where approximately 40% of bottom DO measurements fell below the 5.0 mg/L WQO.

However, there were similarly frequent DO exceedances and extended periods of very low DO observed during the winter months (November through February). Bottom DO exceedances were widespread across all stations in December 2024 and February 2025. For example, in December, 62% of bottom DO concentrations at Station 2 fell below the 5.0 mg/L WQO, while 52% of bottom DO concentrations at Station 3 fell below the WQO. During these months frequent precipitation events and tidal gate closures occurred—conditions that likely limited vertical mixing. This pattern suggests that low DO conditions may not be solely a summertime concern and warrants a closer investigation into the combined effects of hydrology, vertical mixing, and tidal management on winter DO dynamics.

From March through July, bottom DO exceedances were minimal across all stations, with the exception of June 2023 at Station 1, where 8% of measurements fell below 5.0 mg/L. October 2024 showed relatively favorable DO conditions across all five stations.

It is important to note that DO conditions show interannual variability at each station, particularly at Station 1, which had two to three years of data available for each month. For example, DO exceedance rates in January 2023 differed noticeably from those in January 2024. Similarly, in October 2024, only 0.13% of measurements at Station 1 fell below the 5.0 mg/L WQO whereas in October 2023, the exceedance rate was significantly higher at 16%. Long-term, continuous monitoring of the lake is essential for capturing a more complete picture of lake conditions, identifying meaningful spatial and temporal patterns, and understanding interannual variability.

When surface and bottom data were combined at each station, the resulting statistics are shown in Figure 8. Overall, DO conditions were poorest during the late summer months of August and September. While DO levels improved slightly in October, concentrations began to decline in November and continued to decrease through the winter months (December through February) across the lake. In contrast, from March through July, DO levels were consistently high, with very low percentages of DO concentrations falling below the 5.0 mg/L or 3.0 mg/L thresholds.

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis

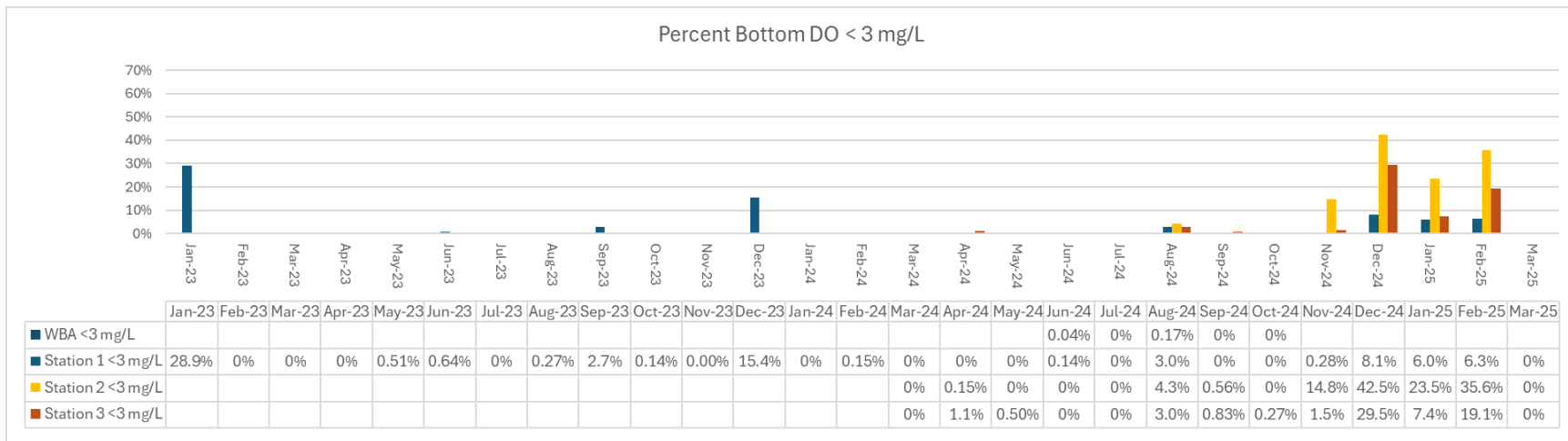
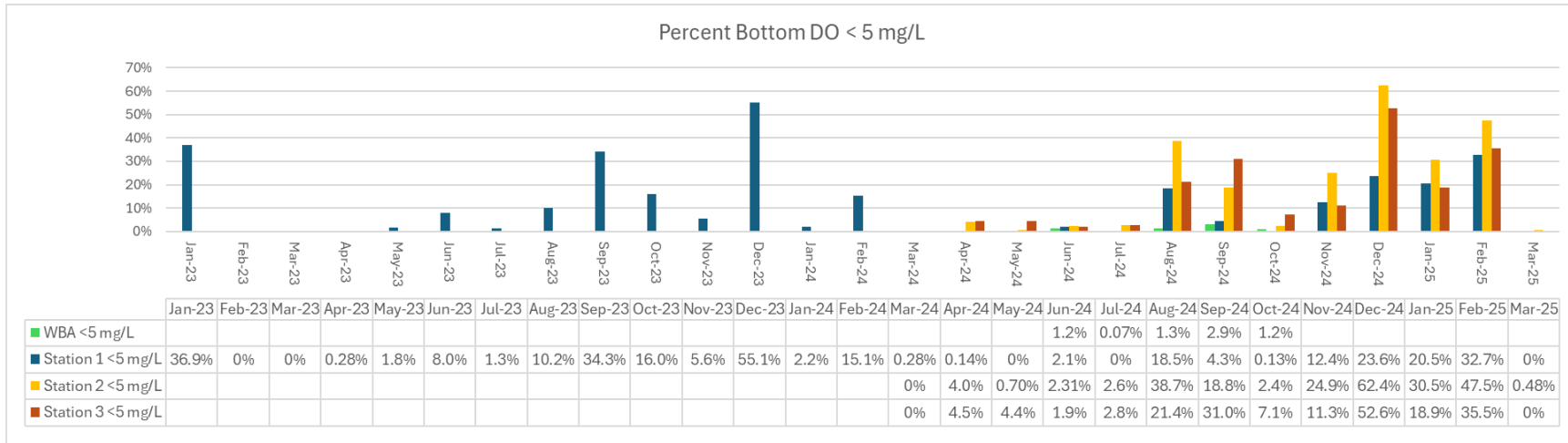


Figure 7. Percentage of bottom dissolved oxygen concentrations below 5.0 mg/L (top) and 3.0 mg/L (bottom) by month

Lake Merritt 2023–2025 Dissolved Oxygen Data Analysis

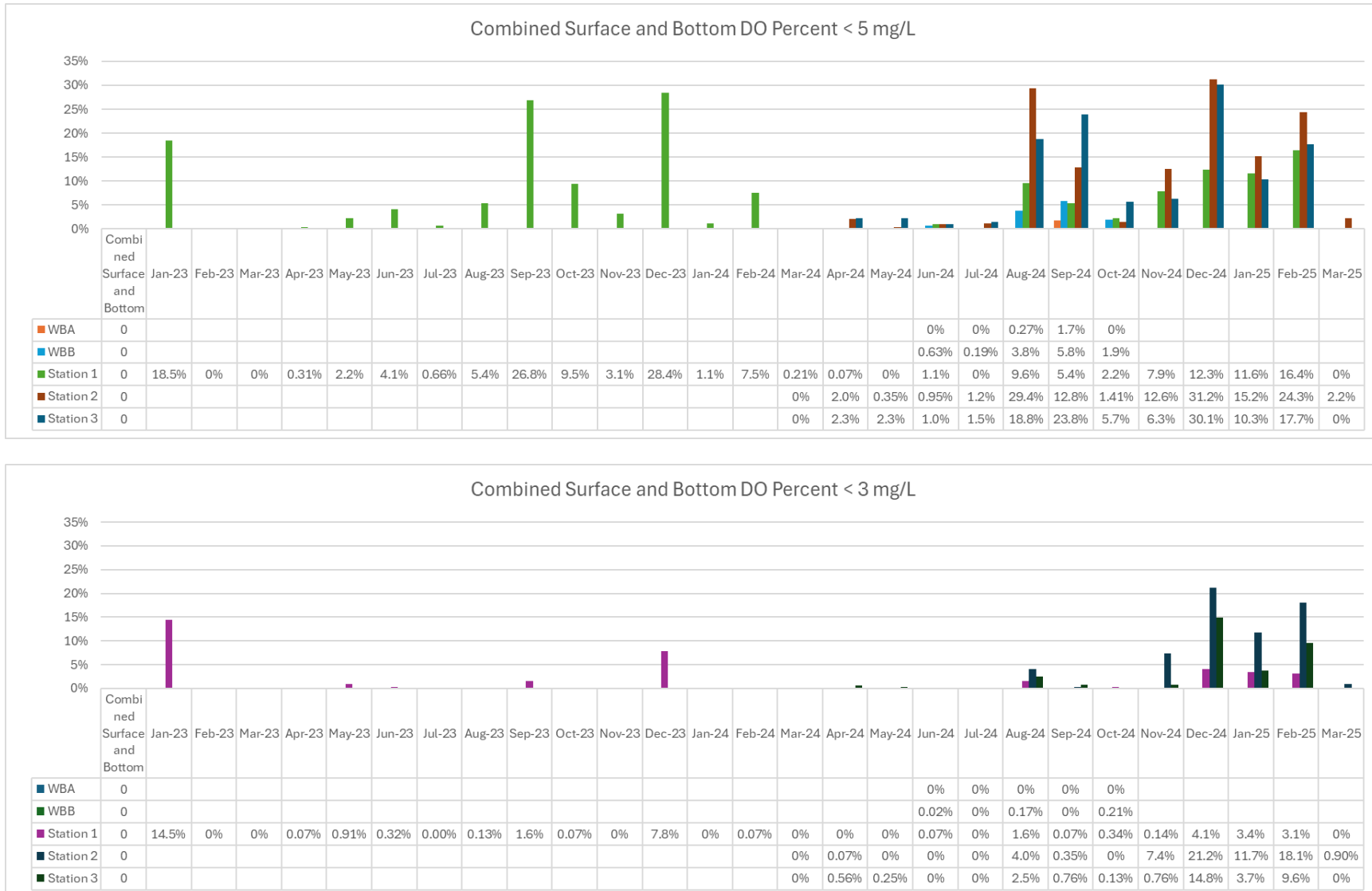


Figure 8. Combined depth (surface and bottom) dissolved oxygen concentrations below 5.0 mg/L (top) and 3.0 mg/L (bottom) by month

In summary, late summer appeared to be the period when the lake experienced the lowest DO levels. Particularly in both arms, where the lowest DO average concentrations and highest exceedance rates of the 5.0 mg/L WQO occurred in August and September in both the surface and bottom waters. This timing was expected, since late summer is when air temperatures are warmest, solar radiation is high, and algae blooms that cause lower DO conditions at nighttime when photosynthesis stops or when the blooms die off are expected. Additionally, this time frame aligns with the *Heterosigma* algae bloom that caused a widespread fish kill in Lake Merritt in August 2022 (Water Board, 2023).

As a next step, we recommend further analysis of potential contributing factors such as air temperature, water temperature, chlorophyll-a levels from the sondes, and tide gate operations. The unexpected wintertime (November through February) low DO conditions near the bottom also warrants a closer look at the possible causes, such as precipitation in combination with extended tidal gate closures, to better understand the drivers of these low DO conditions.

3.4 Time Series Plots of Dissolved Oxygen Concentrations

Time series plots of DO at each station (both surface and bottom) along with precipitation data, are shown in Figures 9a through 9d. These plots are taken directly from the Lake Tech data dashboard. DO time series plots are valuable for identifying short-term temporal patterns, assessing correlations with other water quality parameters, and documenting unusual or extreme DO events.

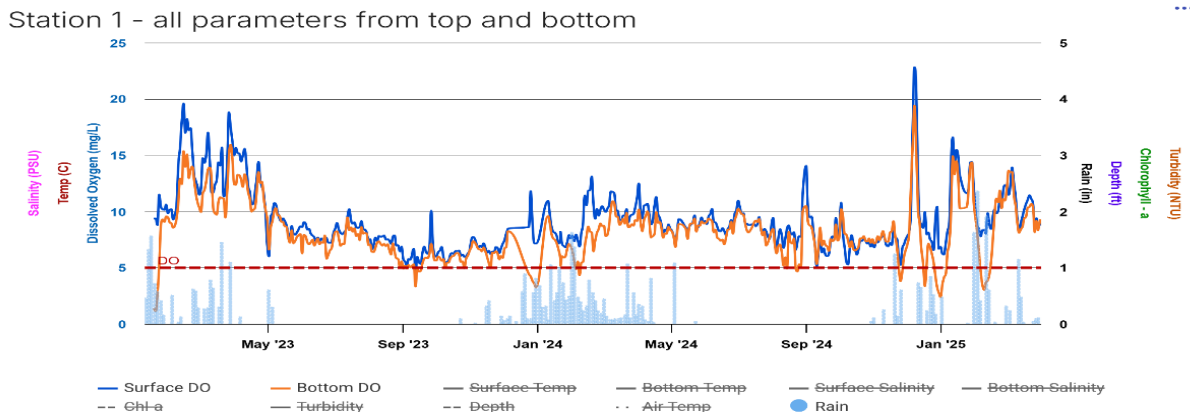


Figure 9a. Time series of dissolved oxygen at Station 1 (surface and bottom) from January 2023–March 2025

Lake Merritt 2023-2025 Dissolved Oxygen Data Analysis

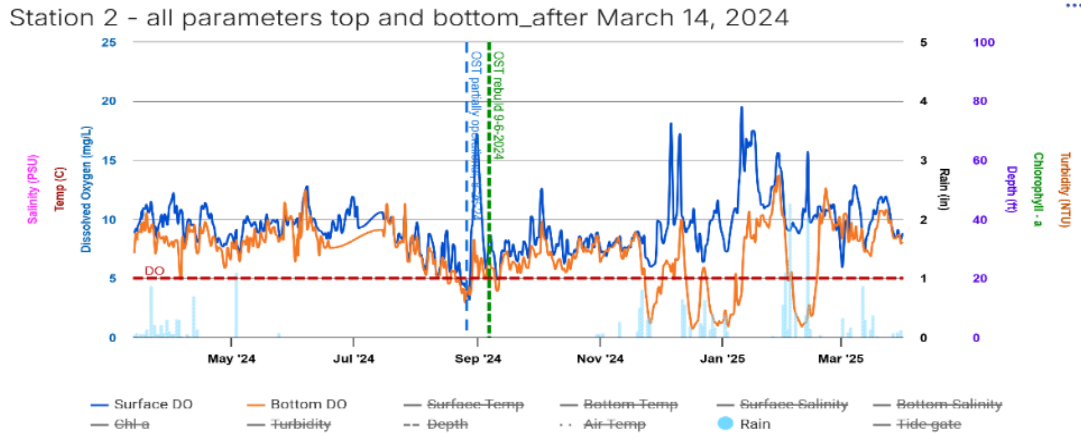


Figure 9b. Time series of dissolved oxygen at Station 2 (surface and bottom) from March 2024–March 2025

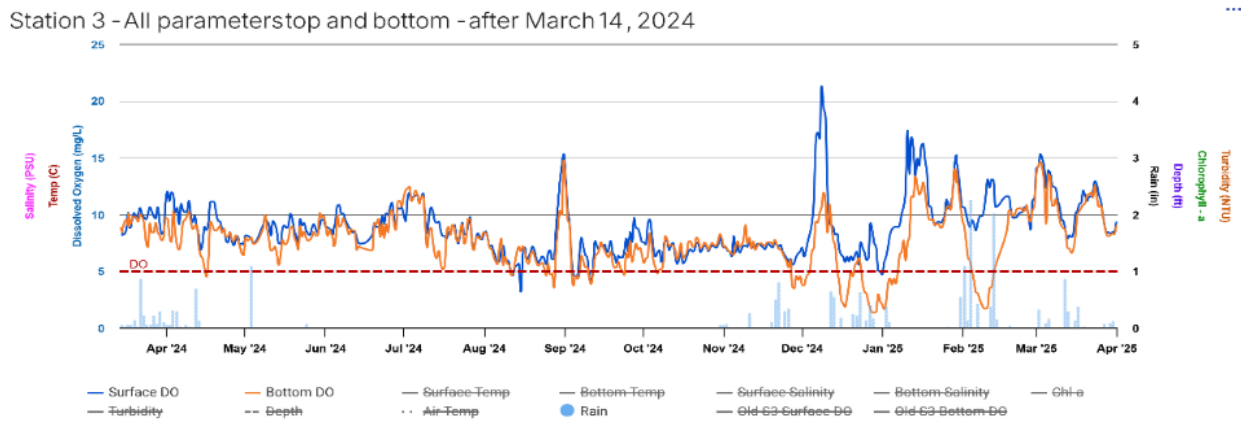


Figure 9c. Time series of dissolved oxygen at Station 3 (surface and bottom) from March 2024–March 2025

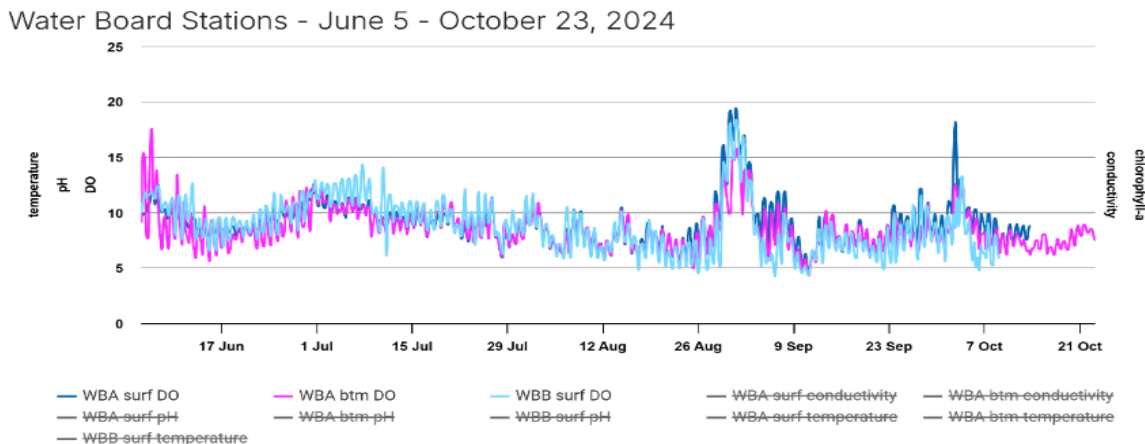


Figure 9d. Time series of dissolved oxygen at Water Board Stations A (surface and bottom) and B (surface only) from June 2024–October 2024

Time series plots are useful for showing the full range of DO concentrations—including both low and high levels—which can help identify periods when the lake can be eutrophic. For instance, DO concentrations above 13.0 mg/L during daylight hours are considered an indicator of an overly productive or eutrophic system (Worster et al., 2010). The DO time series plots revealed a significant spike in DO levels across all monitoring stations in late August to early September 2024.

Another period of major DO fluctuation began in late November and continued through March 2025, with drastic changes in DO concentrations at both surface and bottom depths. This period included several episodes of DO spikes as well as extended periods of very low bottom DO concentrations at all three stations, which resulted in a high percentage of bottom DO concentrations falling below the 5.0 mg/L WQO (see Section 3.3). These wintertime dips in DO concentrations coincided with rain events (visible in the time series plots) and extended tide gate closures (not shown) to prevent flooding. The patterns warrant a closer examination to help identify the potential causes of these fluctuations.

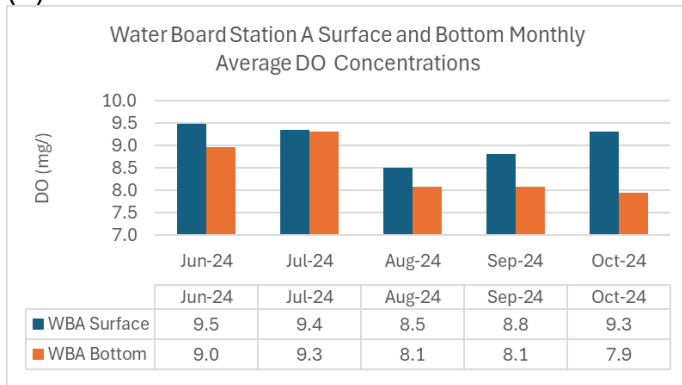
3.5 Surface and Bottom Monthly Average DO Difference

In general, bottom DO conditions were lower near the bottom, which was expected due to greater natural aeration at the surface wind-driven mixing. The following analysis examined, on a monthly basis at each station, which months had lower average bottom DO concentrations compared to the surface (more common), which months had higher bottom DO concentrations (less common), and the magnitude of the difference between surface and bottom average DO concentrations.

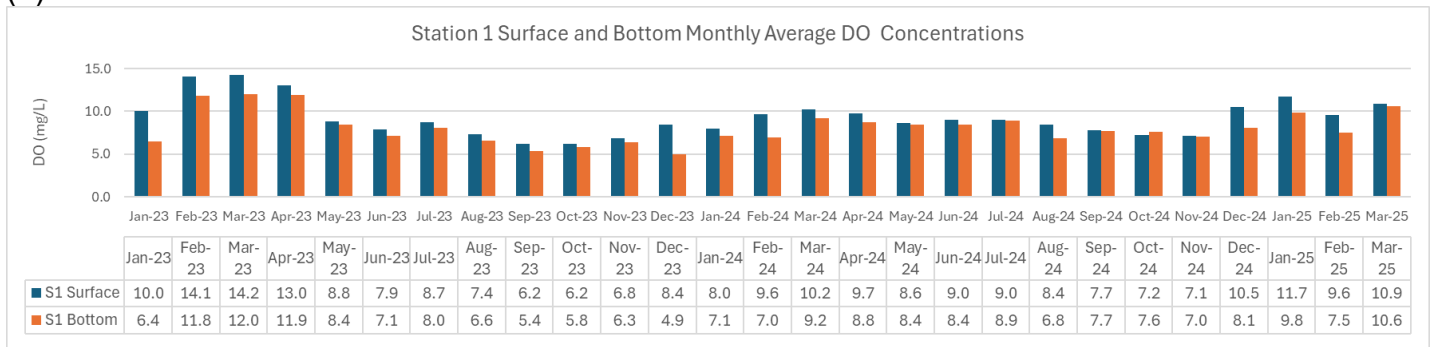
The plots in Figure 10 show the average monthly DO concentrations at both the surface and bottom for each sampling station, allowing for easy comparison of monthly patterns within individual stations. Figure 11 displays the differences between surface and bottom monthly average DO concentrations across four stations, providing a useful view of whether similar trends occurred throughout the lake.

Lake Merritt 2023-2025 Dissolved Oxygen Data Analysis

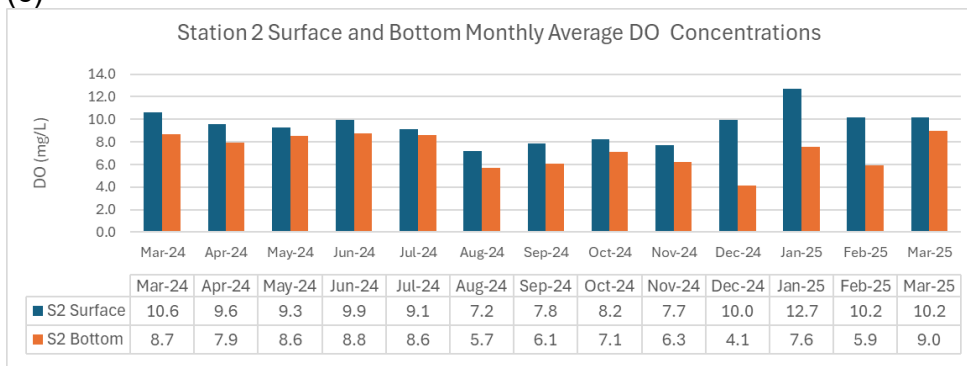
(a)



(b)



(c)



(d)

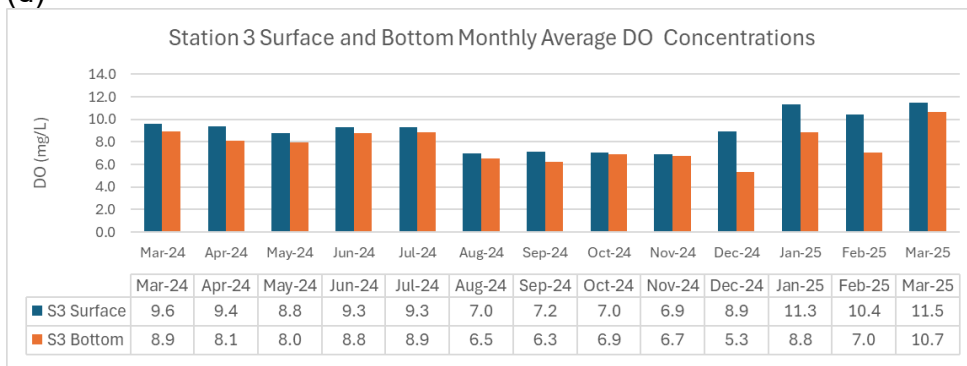


Figure 10. Surface and bottom average dissolved oxygen concentration comparisons at (a) Water Board Station A, (b) Station 1, (c) Station 2, and (d) Station 3

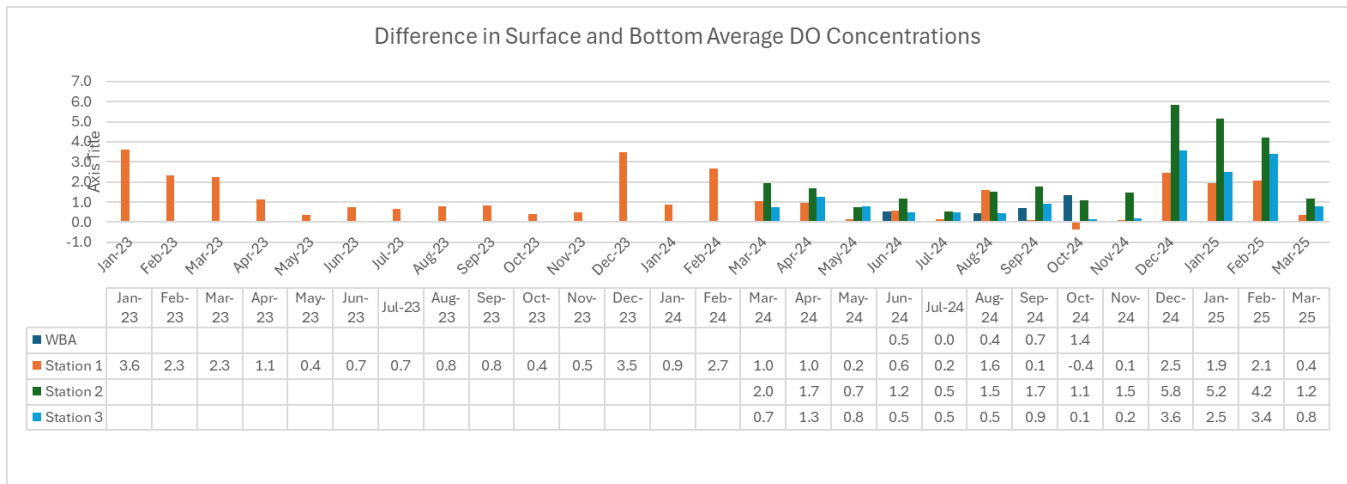


Figure 11. Difference between surface and bottom monthly average dissolved oxygen concentrations all stations

The plots in Figure 10 show that at all four stations—except for October 2024 at Station 1—surface monthly average DO concentrations were always higher than bottom average DO concentrations at the same station. The differences also exhibited some temporal variation.

December 2024, and January and February 2025, showed the largest differences between surface and bottom average DO concentrations across Stations 1-3 (Figure 11). A similar trend was observed at Station 1 for the same months in 2023 and 2024, with the exception of January 2024. These large differences were primarily driven by significantly higher surface DO averages and, in some cases, lower bottom DO values during these months.

Station 2 consistently exhibited the greatest surface-to-bottom DO differences, both in these winter months and throughout much of the year (Figure 10c). In December 2024, the difference between the surface average DO concentration and the bottom average DO concentration at Station 2 was 5.8 mg/L. The differences remained substantial in January and February 2025, at 5.2 mg/L and 4.2 mg/L, respectively. In contrast, Station 1 showed the smallest differences between average surface and bottom DO concentrations, for most of the months when data from all three stations were available.

Understanding patterns in surface and bottom DO levels can provide valuable insight into the overall condition of the lake. While it is common to observe higher DO concentrations near the surface, due to atmospheric exchange and photosynthesis of algae in the surface water column, there are periods when DO levels become more uniform throughout the water column, or, less commonly, when DO is higher at the bottom than the surface. It is important to examine the factors that contribute to these patterns, such as tidal mixing, wind, temperature, stratification, and biological activity. Equally important is understanding how these conditions impact aquatic life, particularly in relation to habitat quality and the availability of oxygen for fish and invertebrates.

For example, Station 1, located near the mouth of the Lake Merritt Channel, always showed the smallest differences between average surface and bottom DO concentrations, indicating stronger and more consistent vertical water column mixing likely driven by its proximity to tidal inflow. In contrast, Station 2 frequently exhibited larger surface-to-bottom DO differences,

suggesting weaker vertical mixing. This may have been due to its distance from the tide gate channel, its narrow and elongated basin shape, lack of wind mixing due to the narrow shape, or other factors. Due to the differences in water quality conditions in the top and bottom of the lake, continued monitoring of both surface and bottom conditions is essential. Declines in bottom DO concentrations can create stressful or even harmful conditions for benthic invertebrates and bottom-dwelling fish species, which may have limited ability to relocate to areas with more favorable oxygen levels.

4. Summary of Findings

DO levels in Lake Merritt showed strong seasonal, spatial, and vertical (depth-related) variation.

- Overall Lake Conditions
 - Across the entire lake (all stations combined), average DO concentrations at both the surface and bottom were well above the 5.0 mg/L WQO, with combined averages exceeding 8.2 mg/L at all stations.
 - Approximately 5.6% of all DO measurements fell below the 5.0 mg/L WQO, and only 1.6% fell below the more acute 3.0 mg/L threshold. Based on these exceedance rates, DO measurements in the dataset did not meet the criteria for impairment under the 303(d) listing policy for conventional pollutants, which uses a threshold of approximately 16.6% exceedance to determine impairment.
- Spatial Patterns
 - Station 2, located in the Glen Echo arm, generally had the lowest DO conditions, followed by Station 3 in the Trestle Glen arm.
 - Water Board Station A (WBA), located near the center of the lake, consistently recorded the highest DO concentrations during June through October 2024—the only period with available data for that station. For the remaining months in 2024 and first quarter of 2025, Station 1 generally showed better DO conditions compared to the other stations. Additionally, Station 1 exhibited the smallest differences between monthly average surface and bottom DO concentrations, suggesting stronger vertical mixing, likely driven by its proximity to tidal inflows from San Francisco Bay.
- Seasonal and Monthly Patterns
 - Spring and early summer (March through July): The lake generally had high average DO concentrations with minimal exceedances of the 5.0 mg/L WQO at both the surface and bottom.
 - Late Summer (August and September): DO levels declined, particularly near the bottom at Stations 2 and 3. The Glen Echo and Trestle Glen arms experienced the poorest conditions during this period.
 - Winter (December through February): Bottom DO concentrations frequently fell below both the 5.0 mg/L WQO and the 3.0 mg/L threshold, particularly in December and February. During these months, average surface DO concentrations were among the highest of the year, while average bottom DO concentrations were among the lowest,

especially at Stations 2 and 3, resulting in the largest differences between average surface and bottom DO concentrations.

- Surface versus Bottom Comparisons
 - Surface DO conditions were generally better than those near the bottom. Across all stations, only about 2.3% of surface DO measurements fell below the 5.0 mg/L WQO, compared to 9.8% of bottom measurements.
 - When combining all surface and bottom data at each station, average surface DO concentrations are between 0.5 mg/L (at WBA) and 2.2 mg/L (at Station 2) higher than their corresponding bottom averages.
 - On a monthly basis, the difference between surface and bottom DO averages at each station ranged from 0.1 to 5.8 mg/L, with the largest difference observed in December 2024 at Station 2.

5. Conclusions

- Across Lake Merritt, average DO concentrations at both the surface and bottom layers were all above the WQO of 5.0 mg/L. Surface DO conditions were generally better than those near the bottom.
- From March through July, DO conditions are favorable across both surface and bottom layers, with the surface and bottom monthly average DO concentrations well above the WQO, and very low exceedance rates of the WQO.
- Low DO conditions are most common during late summer months (August and September) throughout the water column and during winter months (December to February) near the bottom.
- The center of the lake exhibited better DO conditions, with Water Board Station A consistently showing the highest DO levels during the summer months of 2024. In contrast, the Glen Echo and Trestle Glen arms remained as the primary areas of concern for low DO, particularly near the bottom.
- DO conditions showed interannual and intraannual variability at each station. Therefore, long-term, continuous monitoring of the lake is essential for capturing a more complete picture of lake conditions, identifying meaningful spatial and temporal patterns.

It is important to consider differences in data availability (time periods) and sampling frequency across stations, as these factors may influence the results. For example, although WBA only collected data over a five-month period, its 15-minute sampling interval resulted in a high number of data points, contributing more than 30% of the total dataset. In contrast, Stations 1, 2, and 3 collected data at hourly intervals. For future analyses, we plan to only use hourly readings for WBA and WBB to prevent these stations from being overly represented in the analysis. Additionally, Station 1 had over two years of data, making it more heavily weighted in the analysis compared to Stations 2 and 3, which had only one year of data available.

6. Suggestions for Additional Analyses

This analysis highlighted several time periods with unusual DO patterns. For example, a noticeable spike in DO concentrations occurred across the lake in late August and early September 2024, which coincided with the same period during which the August 2022 fish kill took place, when DO levels dropped to nearly 0 mg/L for approximately one week. Similar fluctuations, including both spikes and drops in DO, occurred between November 2024 and February 2025. Smaller, short-term variations were identifiable by examining time series plots over shorter time periods.

Future analyses should explore potential correlations between DO and key environmental factors, including:

- Chlorophyll-a, to assess the influence of algal growth and decay on oxygen levels;
- Precipitation, which can produce a freshwater layer on top of saltier lake water;
- Tide gate operations, since closures reduce tidal flushing and overall lake water circulation;
- Air and water temperature, which can affect algal productivity; and
- Effectiveness of the hypolimnetic oxygenation system (HOS) located in the Glen Echo arm and the aeration system in the Trestle Glen arm.

Investigating these factors would help explain short-term DO fluctuations and better inform future management strategies aimed at improving oxygen conditions in the lake.

7. References

1. San Francisco Bay Regional Water Quality Control Board (Water Board), 2023. [Lake Merritt Fall 2022 Water Quality and Fish Kill Observations](#).
2. Worcester, et al., 2010. California Central Coast Water Board, [Narrative Objectives for Biostimulatory Substances for California Central Coast Waters](#).

Appendix – Boxplots of pooled surface and bottom DO concentrations and monthly DO trends at each station

Boxplots can be used to better visualize the distribution and variability of DO levels at each station (both surface and bottom), either for the full dataset across the entire monitoring period or broken down by smaller time intervals, such as monthly.

In the boxplots below, the range between the upper and lower edges of each box represents the middle 50% of observed DO concentrations, which are those from the first quartile (Q1) to the third quartile (Q3), also known as the interquartile range (IQR). The median is shown as a horizontal line within each box, while the mean is marked with an "x." Differences between the median and mean can indicate skewness in the DO distribution. Outliers, which are unusually high or low values, appear as small circles beyond the whiskers. In these Excel generated boxplots, outliers are those values below $Q1 - 1.5 \times IQR$ or above $Q3 + 1.5 \times IQR$.

The below plots illustrate not only the average conditions but also the variability and extremes in DO concentrations across stations and time periods.

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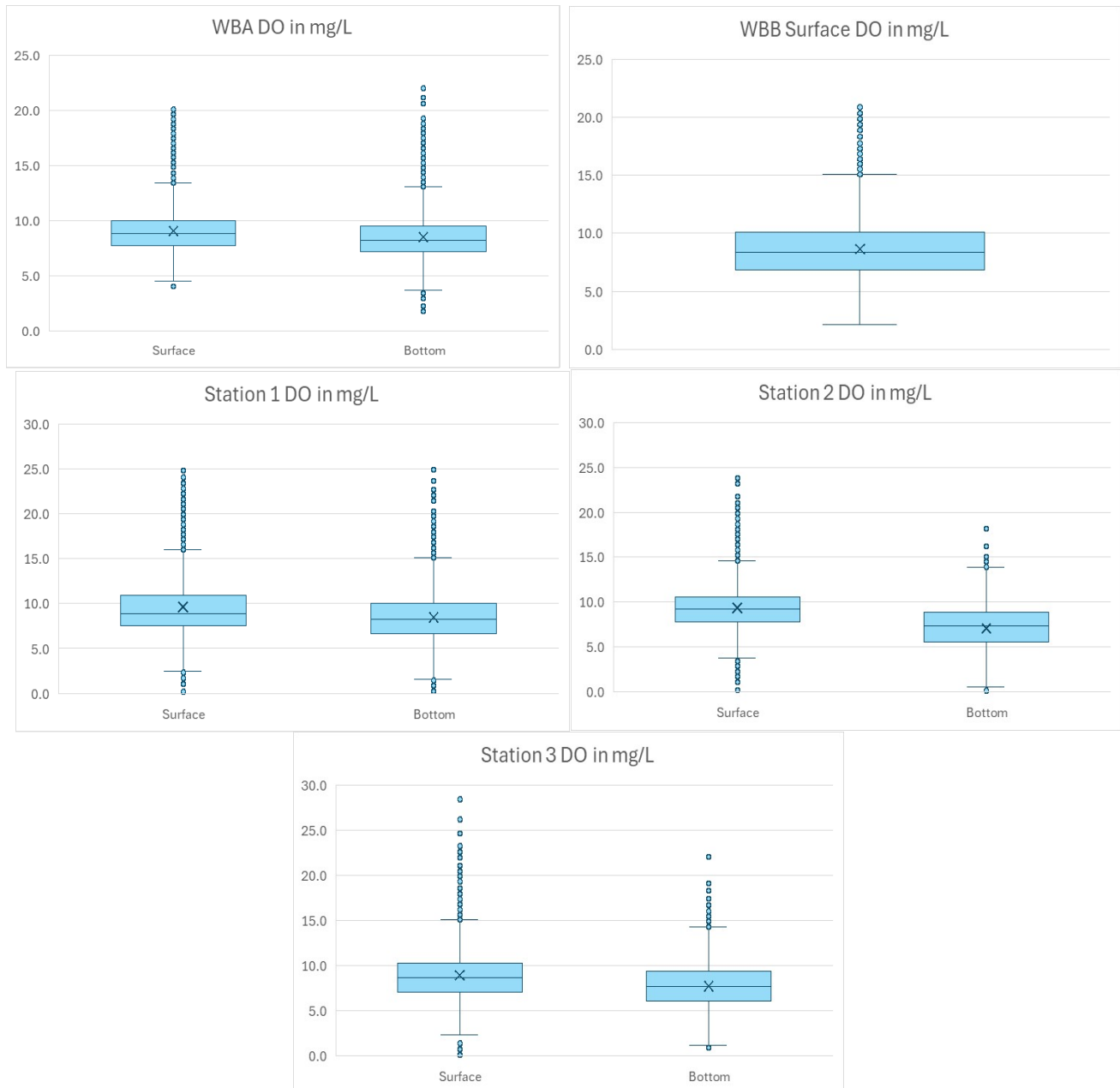


Figure A-1. Boxplots of dissolved oxygen concentrations by depth at each sampling station

Lake Merritt 2023-2025 Dissolved Oxygen Data Analysis



Figure A-2. Boxplots of monthly dissolved oxygen concentrations at each sampling station

Lake Merritt 2023-2025 Dissolved Oxygen Data Analysis

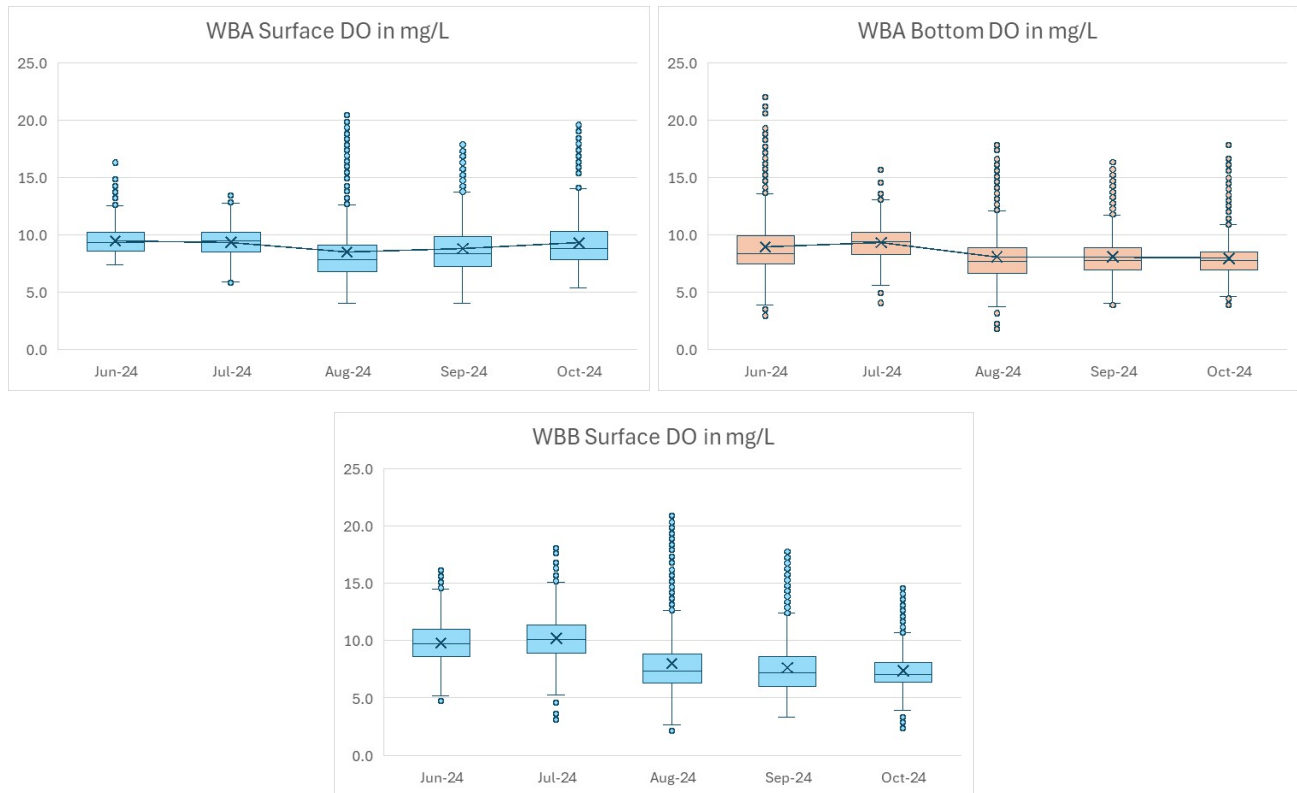


Figure A-2 (continued). Boxplots of monthly dissolved oxygen concentrations at each sampling station