Morro Bay Estuary Bacteria and Dissolved Oxygen Analysis
Water Year 2023

Date Range: Water Year 2023 (October 1, 2022 to September 30, 2023)
Analytes: Dissolved Oxygen, *Enterococcus spp*.

Background

The Morro Bay National Estuary Program's Monitoring Program conducts monitoring in the Morro Bay estuary and watershed to track ambient water quality trends and to assess the impacts of specific implementation projects.

Monitoring data is collected by Estuary Program staff and volunteers, under the guidance of a Quality Assurance Project Plan (QAPP) which is reviewed and approved annually by the EPA and the State Water Resources Control Board. This quality control document contains the monitoring locations, protocols, equipment specifications, and other details that allow users to assess the quality of the collected data. The full QAPP is available upon request.

Bay Bacteria

The Estuary Program's goal for bay bacteria monitoring is to assess the safety of the bay shoreline waters for recreational contact. Since 2005, program volunteers have sampled monthly at eight bay shoreline sites and analyzed the samples for the indicator bacteria enterococcus. The samples are collected using sterile technique. The Estuary Program formed a partnership with Cuesta College in which student volunteers collect and analyze samples with the IDEXX method in a biology lab on campus. This partnership provides real-world skills for students while helping the Estuary Program continue to collect this long-running data set.

Enterococcus Monitoring Specifications:

Specification	**Value**
Method	IDEXX Enterolert
Detection Range	10 to 24,190 MPN/100 mL
Hold Time	24 hours
Sample storage conditions	4°C in the dark

For results of < 10 MPN/100 mL, which is the detection limit for this method, a random value between 0.1 and 10 was assigned. For reports through WY2021, new random values were generated for all non-detects in the time series during each year's analysis. Starting with WY2022, the randomized non-detect values for previous years have been kept static to reduce the differences between subsequent reports.

This method of handling non-detect data is utilized by the Central Coast Regional Water Quality Control Board (CCRWQCB) in their own analysis.

Monitoring Locations

The eight bay shoreline monitoring sites were selected because they represent the areas with the most frequent recreational contact. The sites are (from north to south) Coleman Beach (site code COL), Tidelands Park (TID), Windy Cove (WIN), State Park Marina (SPM), Pasadena Point (PAS), Baywood Pier (BAY), Cuesta Inlet (CIN), and Sharks Inlet (SIN).

The following map (Figure 1) indicates the monitoring locations.

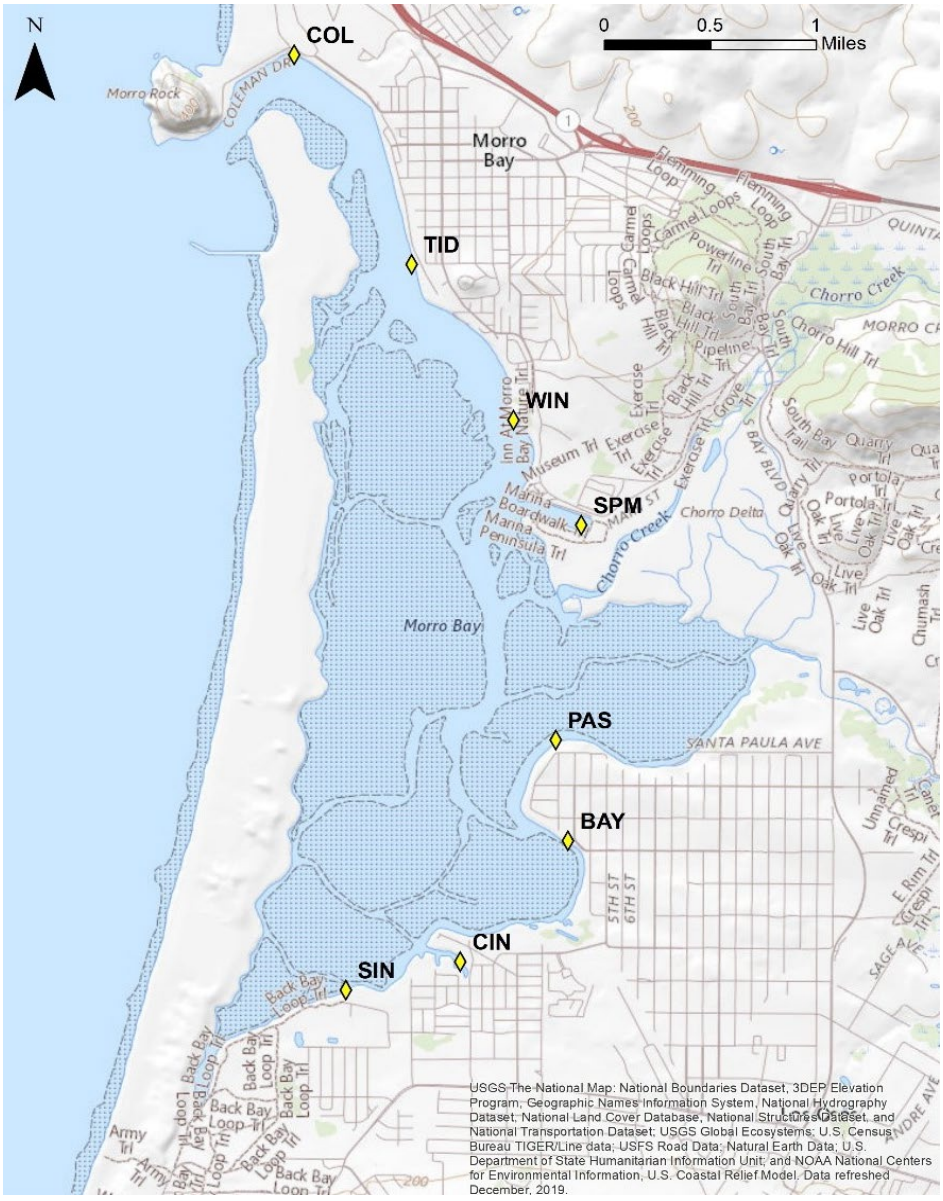

Figure 1. Locations of shoreline bacteria monitoring sites in the Morro Bay estuary.

Results

Indicator bacteria data show how frequently the waters in specific locations along the bay shoreline have levels greater than those safe for recreational contact.

The following graph (Figure 2) shows the percentage of samples from Water Year 2023 (WY2023) that exceeded the Statistical Threshold Value (STV) criteria. Ideally, no more than 10% of samples exceed this value of 110 MPN/100 mL for enterococcus in marine waters. This guiding value is from the State Water Resources Control Board's Bacterial Objectives. This state guidance was developed for a situation where multiple samples are collected in a month. As the Estuary Program collects only one sample each month, the comparison of program data to this criterion should be considered an adaptation of these water quality objectives and are not adequate for regulatory decision making.

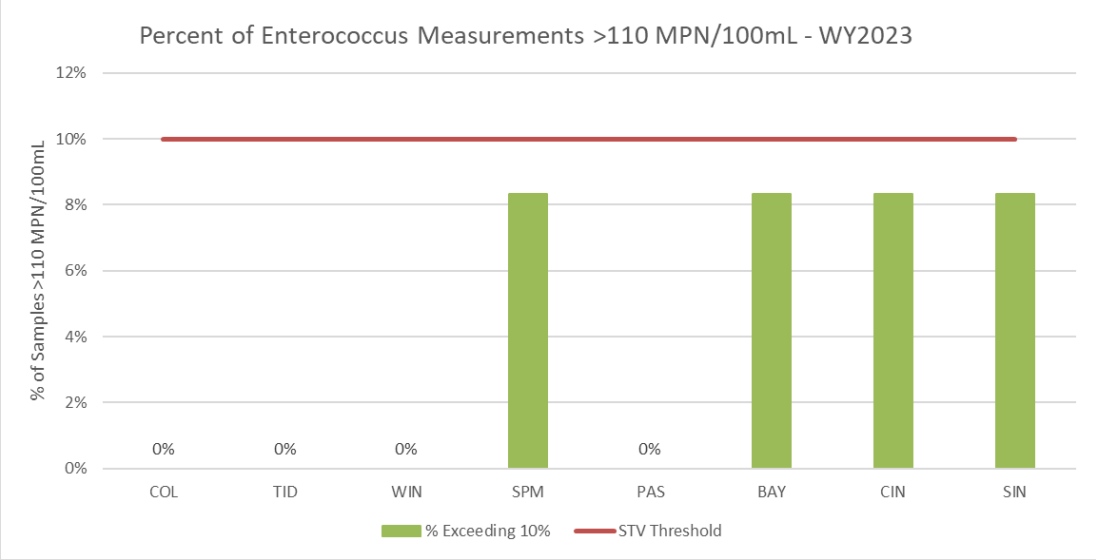

Figure 2. Percent of Enterococcus results greater than 110 MPN/100 mL for WY2023. The red line indicates when 10% of samples exceed the STV threshold. Ideally no more than 10% of samples exceed this threshold, a condition that was met at all eight sites in WY2023.

The following graph (Figure 3) shows the geomean of all WY2023 data for each site. Ideally, the sample geomean remains below the regulatory threshold of 30 MPN/100 mL. This criterion is from the State Water Resources Control Board's Bacterial Objectives. Once again, this state guidance was developed for a situation where multiple samples are collected in a month. As the Estuary Program collects only one sample each month, the comparison of program data to this criterion should be considered an adaptation of these water quality objectives and are not adequate for regulatory decision making.

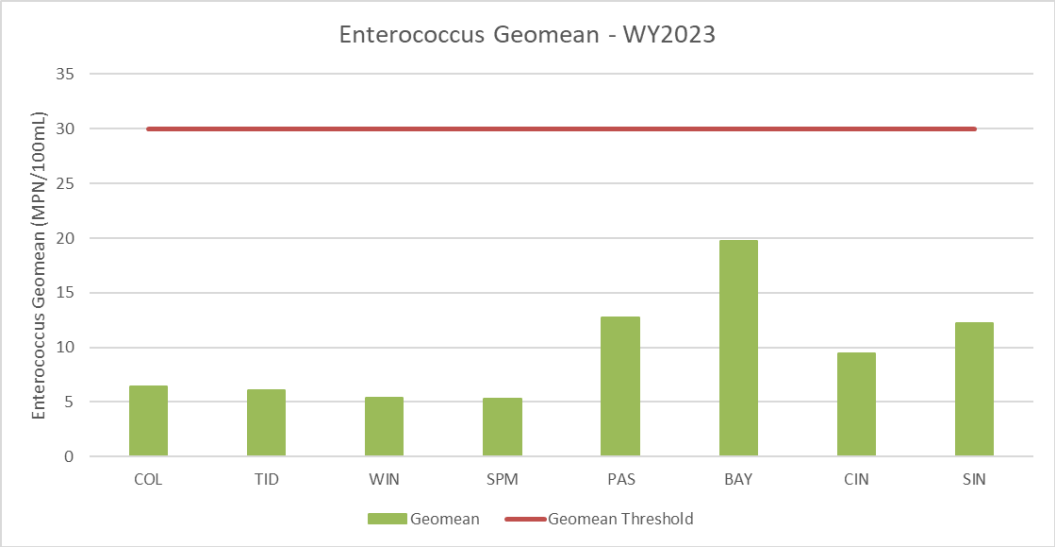

Figure 3. Geomean values from WY2023 collected from Morro Bay estuary shorelines sites. The red line indicates the geomean threshold of 30 MPN/100 mL. Ideally the geomean of data from a site remains below this threshold. All eight sets met the geomean criteria in WY2023.

Discussion

Of the eight sites monitored, historical trends have shown six sites only rarely exceed recreational contact standards. The four sites toward the mouth of the bay (COL, TID, WIN, and SPM) have historically had very few elevated bacteria results. These sites are along the well-mixed main channel and are thought to be primarily influenced by ocean water entering the bay with the incoming tide. While the two sites furthest back in the bay, Cuesta Inlet (CIN) and Sharks Inlet (SIN), may experience some water circulation issues due to the shallow depth and minimal mixing with the incoming tides during certain times of year, they rarely exceed the recreational standards. This may be due at least in part to lower levels of bacterial input from sources such as urban storm runoff.

Two sites, Baywood Pier (BAY) and Pasadena Point (PAS), have had frequent exceedances of recreational standards over 18 years of monthly monitoring. During WY2023, PAS had no exceedances while BAY had one exceedance. Figures 4 and 5 illustrate historic exceedances of regulatory thresholds from WY2009 to WY2023.

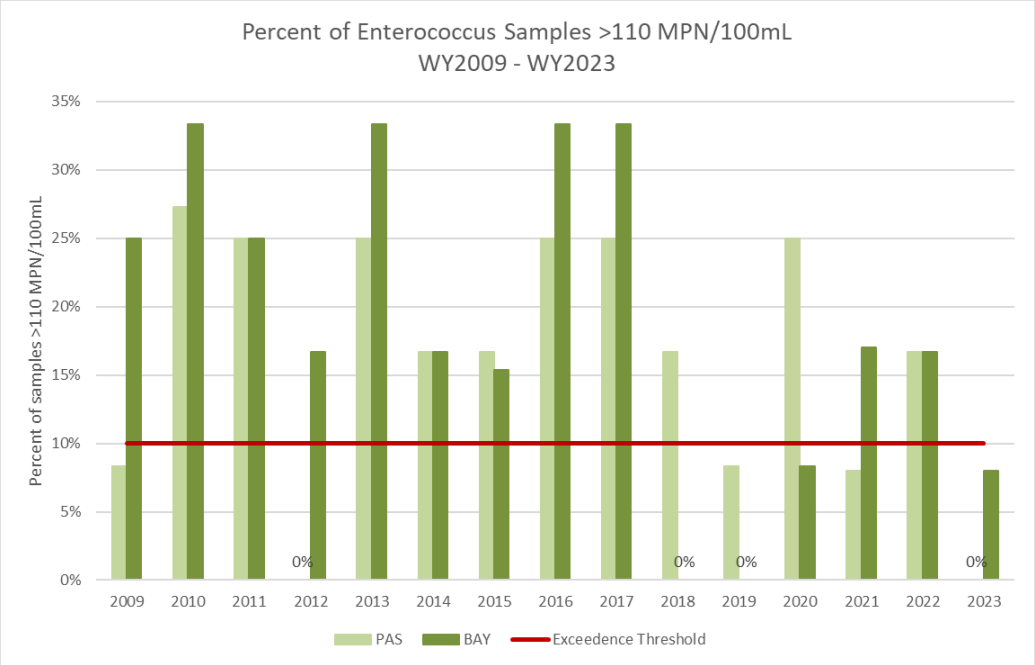

Figure 4. Percent of Enterococcus samples greater than the Statistical Threshold Value (STV) of 110MPN/100 mL over the last 15 years. Note that the absence of a bar indicates that 0% of samples exceeded the threshold for the year. The red line indicates when 10% of the samples exceed the STV, or Exceedance Threshold. Ideally no more than 10% of samples exceed the threshold.

Figure 4 shows the exceedances of the recreational standard for the last fifteen years. BAY had eleven years and PAS had ten years where more than 10% of samples were at levels unsafe for swimming, although these did not always occur during the same year. This is the first year since WY2019 that both sites were below the regulatory threshold. This is an infrequent occurrence, as the last time both sites were below the threshold before that was over a decade prior, in WY2008. When no exceedances were reported throughout the water year, it is represented in the graph with the absence of a line and a label of 0%.

The following graph (Figure 5) shows the geomean of bacteria results for each water year from WY2009 to WY2023. All monthly data for the year is used to calculate a single geomean value representing bacteria concentrations for that year. For PAS, four of fifteen years exceeded the geomean criteria of 30 MPN/100 mL. For BAY, seven of fifteen years exceeded the geomean criteria of 30 MPN/100 mL. In the last six years, neither site exceeded the geomean criteria.

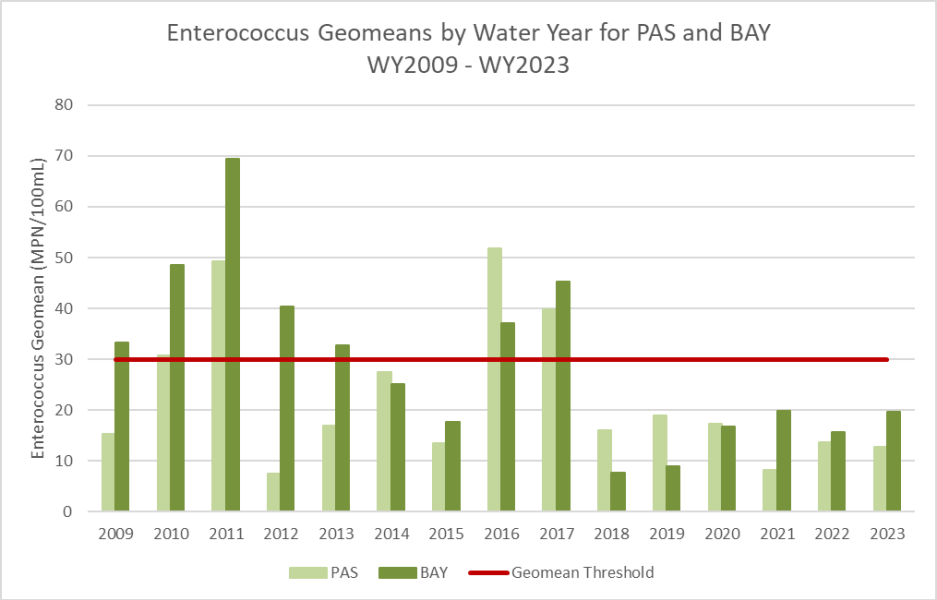

Figure 5. Enterococcus geomean by year for PAS and BAY. The red line indicates the geomean threshold of 30 MPN/100 mL. Ideally, geomean values remain below this threshold.

Pathogens are often flushed downstream into the bay by rainfall events, influencing the seasonality of enterococcus exceedances. Research into the flushing time of the Morro Bay estuary has quantified the amount of time it takes for estuarine water to exchange and mix with oceanic water, which can play a role in the amount of time bacteria introduced by runoff is retained within the bay. Flushing time along the Front Bay sites (COL, TID, WIN, SPM) is typically less than five days, while the Back Bay sites (BAY, PAS, CIN, SIN) experience flushing times of up to two weeks at certain times of year during neap tide cycles (Taherkhani et al. 2023).

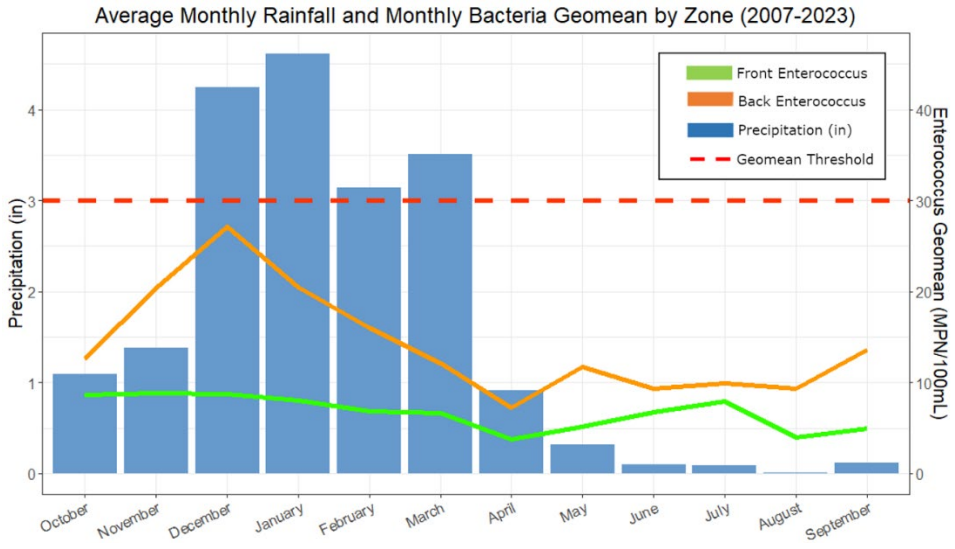

Figure 6. Average monthly precipitation (inches) and Enterococcus geomean by month for all Front Bay sites combined and all Back Bay sites combined from 2007 to 2023. Rainfall is depicted by the blue bars, Front Bay bacteria is indicated by the green line, and Back Bay bacteria is indicated by the orange line. The red dashed line indicates the 30 MPN/100 mL geomean threshold for reference, however these results are meant to visualize trends and have not been analyzed according to established Water Board methods. Total precipitation values were from CIMIS station 52, located in San Luis Obispo.

The figure above demonstrates how bacteria concentrations in the Back Bay are correlated with rainfall and experience higher peaks in concentration during the wetter months. Linear regressions comparing the monthly-averaged datasets found the Back Bay enterococcus geomean to be significantly correlated with total precipitation ($p = 0.007$) while the Front Bay did not exhibit a significant correlation ($p = 0.115$). The regulatory threshold exceedances at BAY and PAS illustrated in the previous figures typically occur during the rainy season (November – January).

The exceptionally heavy rainfall during the winter of WY2023 resulted in notable deviations from the correlations described above. While the Back Bay sites reached their highest bacteria concentrations at the onset of the rainy season in November, these sites showed a significant drop in enterococci during peak rainfall (December – March). It is possible that the sustained rainfall throughout the winter months diluted enterococci concentrations, as has been recorded in other coastal systems (Laureano-Rosario et al 2017).

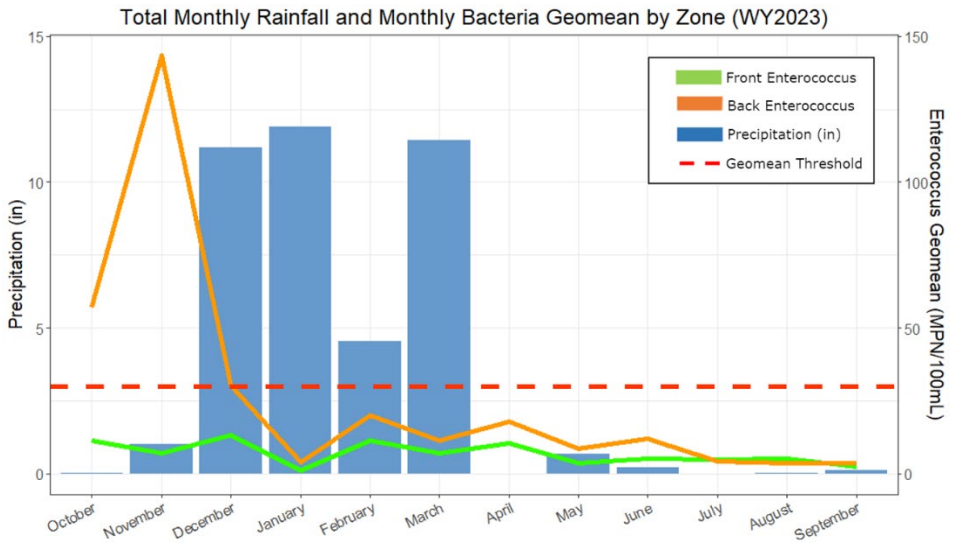

Figure 7. For WY2023, total precipitation by month (inches) and Enterococcus geomean by month for all Front Bay sites combined and all Back Bay sites combined. Rainfall is depicted by the blue bars, Front Bay bacteria is indicated by the green line, and Back Bay bacteria is indicated by the orange line. The red dashed line indicates the 30 MPN/100 mL geomean threshold for reference, however these results are meant to visualize trends and have not been processed according to established Water Board methods. Total precipitation values were taken from CIMIS station 52, located in San Luis Obispo.

Potential sources of bay bacteria could include runoff from land, leaks from boat-waste holding tanks, contaminated groundwater, and wildlife. The California Department of Public Health (CDPH) monitors bacteria levels in the freshwater seeps, which are areas where shallow groundwater is pushing up to the surface and draining into the bay. The data indicates elevated levels of the fecal coliform indicator bacteria.

Bay Dissolved Oxygen

Since 2002, Estuary Program volunteers have collected surface measurements for dissolved oxygen (DO) concentration, temperature, and salinity at seven sites in the bay on a monthly basis. The monitoring occurs within two hours of sunrise to capture the lowest DO levels of the diurnal cycle. Monitoring the lowest DO levels of the day allows the Estuary Program to assess the extent to which various regions of the bay support aquatic species that require adequate oxygen levels to thrive.

Equipment Specification

The Estuary Program uses a YSI Pro 2030 meter, which measures DO concentration (mg/L), DO % saturation, temperature (°C), specific conductance (µS/cm), and salinity (ppt).

The equipment specifications for DO are as follows:

Specification	Value
Sensor Type	Polarographic
Measurement Range	0 to 50 mg/L
Calibrated Range	0 to 20 mg/L; 0 to 35°C
Accuracy	±2% of reading for 0 to 20 mg/L; ±6% of reading for 20 to 50 mg/L
Resolution	0.01 mg/L

To ensure data quality, the Estuary Program calibrates the meters weekly for DO using an internal calibration and tests against a Winkler titration twice a month. For specific conductance and salinity, the meters are calibrated using known standards on a weekly basis.

Monitoring Locations

Seven bay monitoring sites were selected to represent different regions of the bay. The sites are (from north to south) Tidelands (site code ATP), State Park Marina (SPO), Los Osos Channel (LO2), Pasadena Point (PSP), Cuesta Channel (CHI), Cuesta Inlet (CSI), and Sharks Inlet (SHI).

The following map (Figure 8) shows the seven monitoring locations. Sites are grouped into two sets: Front Bay and Back Bay. Sites within each group are sampled on the same day, but the two groups are generally not sampled on the same day.

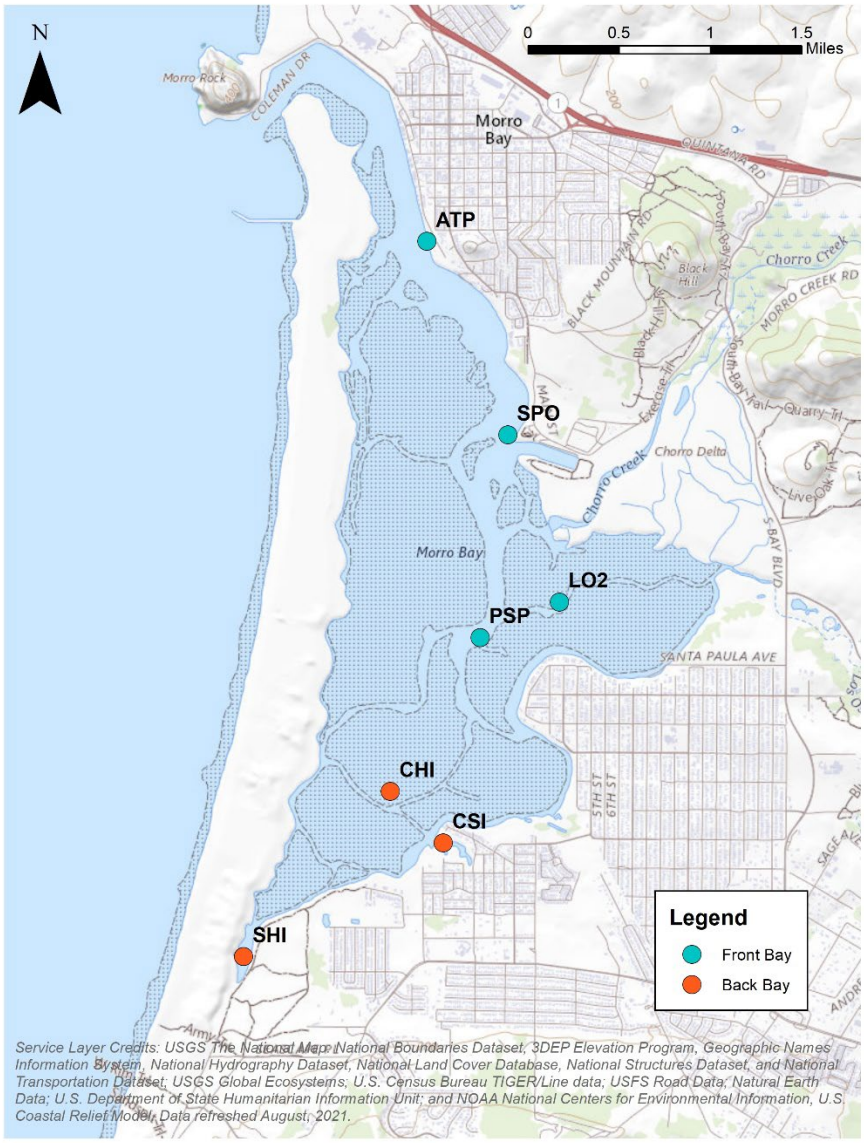

Figure 8. Map of bay dissolved oxygen monitoring locations.

Results

Analysis compares measured DO levels to standards protective of aquatic life. The CCRWQCB has designated the Morro Bay estuary as Marine Habitat and lists an objective that DO concentrations must remain at 7 mg/L or higher to be protective of aquatic life.

Data collected at the ATP site in the Front Bay during October 2022 was excluded due to equipment errors that resulted in inaccurate readings. Thus, a full year of readings are not available for that site for WY2023.

The following graphs show the DO concentration data for WY2023 at each of the seven sites. Figure 9 shows the distribution of measurements for each site over WY2023 using a box-and-whisker plot.

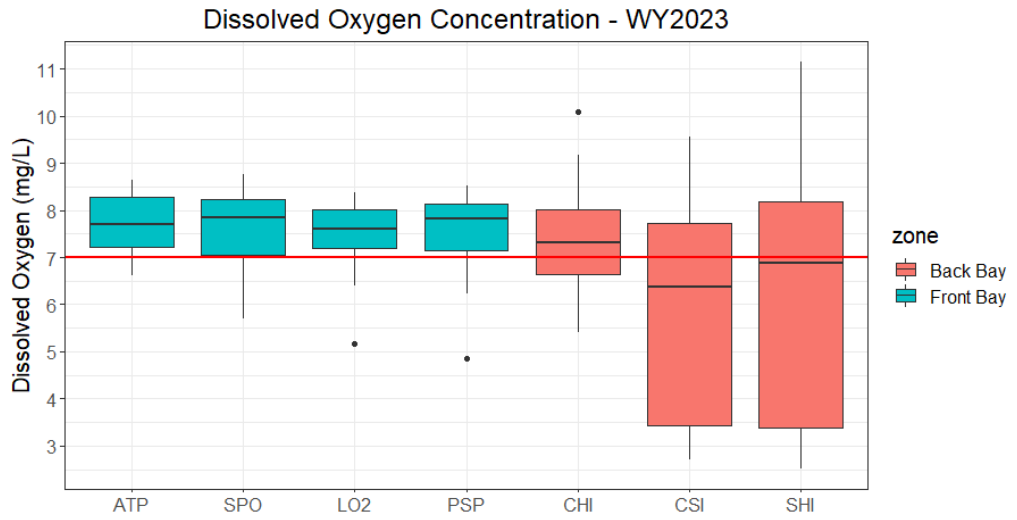

Figure 9. Dissolved oxygen concentration distribution at seven representative sites during WY2023. The horizontal red line depicts the 7 mg/L protective limit. Ideally DO concentrations remain at or above 7 mg/L at all times. The October result from ATP was excluded due to an inaccurate sensor reading.

Figure 10 shows the percentage of DO concentration readings in WY2023 that were less than 7 mg/L, meaning that the recorded DO measurements failed the numeric objective set by the CCRWQCB to be protective of marine waters. Ideally, no more than 10% of results would fall below the standard.

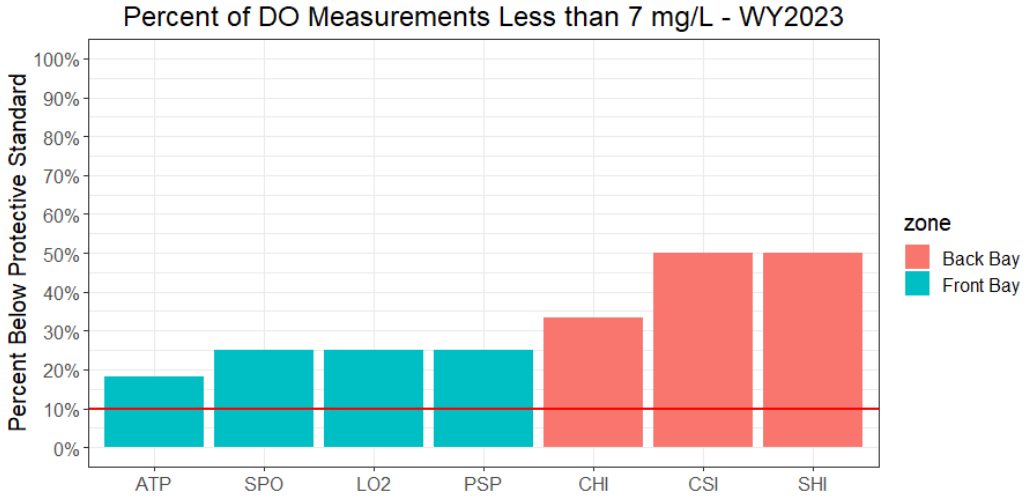

Figure 10. Percent of DO measurements less than 7 mg/L during WY2023. All sites had more than 10% of samples fall below the protective standard. The horizontal red line depicts the 10% threshold. The October result from ATP was excluded due to an inaccurate sensor reading.

Figure 11 shows the average DO values for WY2023 data. Ideally, all readings are greater than 7 mg/L to ensure adequate oxygen to be protective of aquatic life and to comply with CCRWQCB standards.

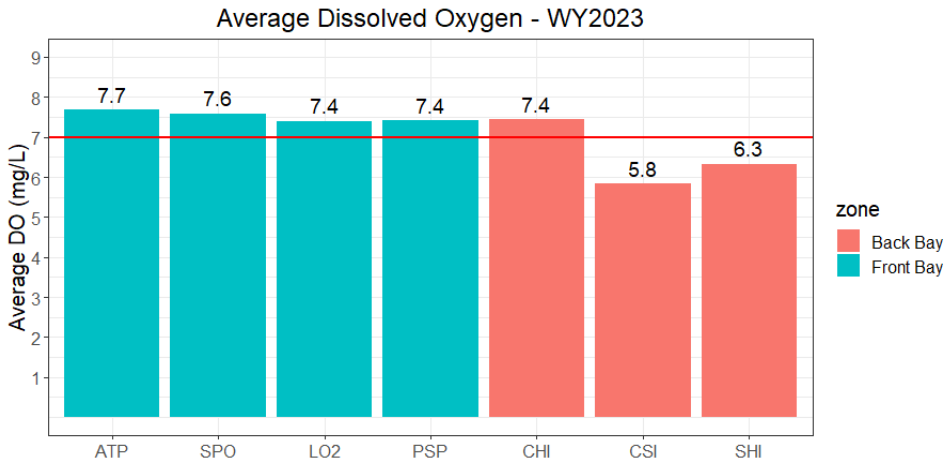

Figure 11. Average of dissolved oxygen levels measured during WY2023. The horizontal red line depicts the 7 mg/L protective limit. Ideally, DO concentrations stay above that limit at all times. The October result from ATP was excluded due to an inaccurate sensor reading.

For the following figure, data from all Front Bay sites were combined (ATP, SPO, LO2, PSP) and data from all Back Bay sites were combined (CHI, CSI, SHI) to show how dissolved oxygen levels varied throughout WY2023 in the Back Bay versus the Front Bay. The Front Bay remained above the level of concern from December to May. It then fell below the threshold in June and July before reaching healthy levels again for the rest of WY2023. The Back Bay was below the threshold in October, was above the threshold from November to April, and fell back below for the remainder of the water year (Figure 12). Dissolved oxygen readings at all three Back Bay sites were atypically high in February 2023, however they were not excluded from the dataset since data collected by a Central & Northern California Ocean Observing System (CeNCOOS) sensor array maintained by Cal Poly deployed in the Back Bay corroborated these high values.

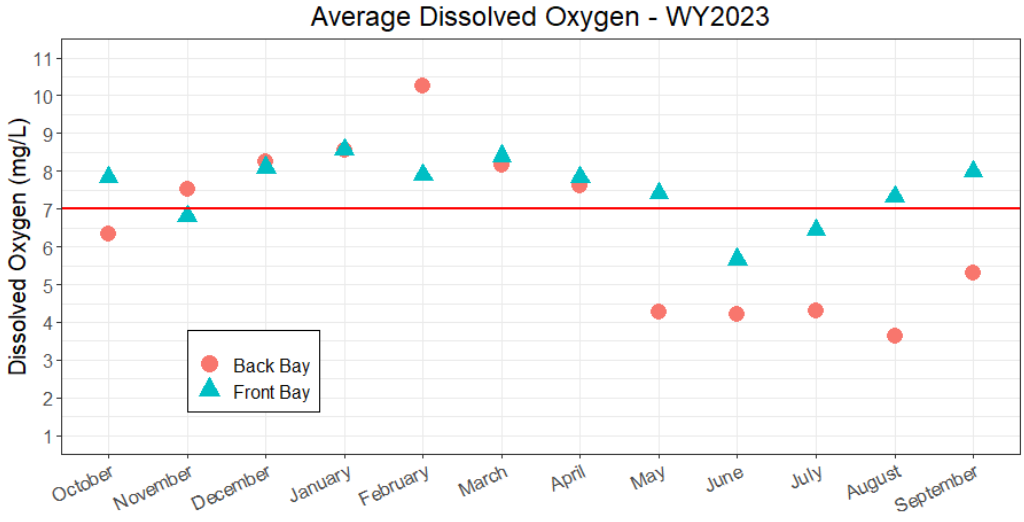

Figure 12. For each month, average dissolved oxygen levels for all Front Bay sites combined and for all Back Bay sites combined, for WY2023. The horizontal red line depicts the 7 mg/L protective limit, and ideally DO concentrations stay above that limit at all times.

In Figure 12, dissolved oxygen in the Front Bay and Back Bay appears to follow a trend throughout the water year, which can also be seen in the five-year averages for Front and Back Bay sites. Dissolved oxygen stays above the protective limit during cooler months and drops below the limit during warmer months, with the Back Bay sites experiencing the largest decrease in concentration. Five-year averages for the Front and Back Bay sites can be seen in more detail in Figure 13.

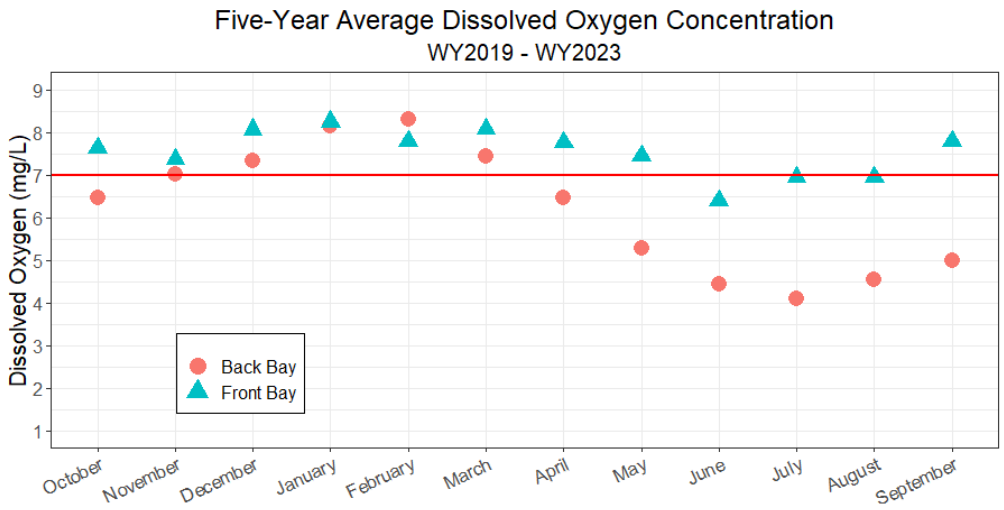

Figure 13. Five-years of DO concentration data averaged by month for all Front Bay sites and for all back Back Bay sites, from WY2019 to WY2023. Monthly averages are presented to depict seasonal trends, with the 7 mg/L level of concern in red. Ideally DO concentrations stay above that limit at all times.

Discussion

The estuary waters frequently have DO levels below the 7 mg/L water quality objective protective of the beneficial uses of the estuary, as outlined by the Water Quality Control Plan for the Central Coastal Basin. These trends also apply to data prior to WY2023. Sites located closer to well-mixed channels (ATP, SPO, LO2, and PSP) had fewer readings that fell below 7 mg/L, although all sites violated the Basin Plan standard during WY2023 in more than 10% of the readings.

The depressed DO levels in summer and fall may be due in part to bay circulation. Waters in the Back Bay are shallower, meaning they heat up faster in the sun. Warmer water cannot hold as much DO as cooler water. These shallow waters evaporate, leading to water that is more saline than the front bay at certain times of year. Salty water cannot retain as much oxygen as fresh water. Sites toward the back of the bay seem to have lower DO concentrations on average than those located in the channel and towards the front of the bay. Moreover, nutrient availability likely plays a fundamental role in the observed DO levels of aquatic environments. When excess nutrients enter the bay, the overall biomass of photosynthetic organisms like algae can increase. While this may lead to elevated peak DO levels, the microbial organisms that eventually break down this plant material absorb oxygen and cause very low minimum DO values. In addition to nutrients, many other factors such as temperature, light availability, and tidal currents also contribute to the distribution of algae in the bay and its effect on localized DO concentrations.

Exceptionally high DO values observed in the Back Bay during February were likely due to a combination of both physical and biological processes. High rainfall in January and March 2023 resulted in high turbidity recorded at the Back Bay CeNCOOS sensor station, but turbidity was relatively low in February. Lower turbidity means the water is clearer, which can promote higher levels of photosynthesis by microalgae that pump oxygen into the water. Large swings in DO recorded at the Back Bay station corroborate an increase in biological activity. DO readings at creek sites throughout the watershed in February 2023 were also atypically high, with higher-than-normal flows due to the wet winter. As these creeks drain into Morro Bay near the Back Bay, this higher-than-normal influx of oxygenated water may have contributed to elevated DO levels in the Back Bay. The combination of these factors likely contributed to DO that was highly variable, yet still sustained above typical conditions.

Data Availability

The data is available from the California Environmental Data Exchange Network (CEDEN), a State Water Resources Control Board data portal. To retrieve data,

- Visit www.CEDEN.org.
- Click on Find Data.
- For Program, choose Morro Bay National Estuary Program.
- Bay Bacteria: For Stations, choose Morro Bay sites Coleman Beach shoreline, Tidelands Park shoreline, Windy Cove, State Park Marina shoreline, Pasadena Point shoreline, Baywood Pier shoreline, Cuesta Inlet shoreline, and Sharks Inlet shoreline.
- Bay DO: For Stations, choose Tidelands Park, State Park Marina bay, Sharks Inlet bay, Pasadena Point Bay, Near Cuesta Inlet, North of Cuesta Inlet Mouth, and Los Osos Creek Channel.
- Click on Retrieve Data.

For additional details, contact the Estuary Program at 805-772-3834 or staff@mbnep.org

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreements CE-98T25101 and 4T98T47301 to the Bay Foundation of Morro Bay. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.