San Francisco Bay Regional Water Quality Control Board

TO: FILE

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DATE: April 2, 2024

SUBJECT: NUMERIC TRANSLATION OF NARRATIVE OBJECTIVE

This memo describes a basis for translating the Basin Plan's narrative biostimulatory substances water quality objective[1] in terms of nitrogen discharges. Nitrogen has been identified as the limiting nutrient for phytoplankton growth in San Francisco Bay[2] and is a biostimulatory substance that can be restricted to control the proliferation of algal blooms. The memo explains the scientific basis for why reducing nitrogen discharges baywide by 40 percent relative to 2022 levels is expected to protect beneficial uses and meet the narrative biostimulatory substances water quality objective. The analysis presented in this memo demonstrates that nitrogen discharge reductions of this magnitude would be sufficient to significantly reduce risks associated with excessive algal blooms and ensure that, under a limited-duration, worst-case scenario, dissolved oxygen concentrations would remain above an acute exposure threshold of 4 mg/L throughout most of San Francisco Bay to protect aquatic life.

Nitrogen discharged from municipal wastewater facilities fueled the significant algae bloom that took place in 2022. The algal bloom resulted in significant fish kills. Therefore, the wastewater facilities' nitrogen discharges have a reasonable potential to cause or contribute to exceedances of the biostimulatory substances objective. The reasonable potential finding requires the Water Board to impose numeric water quality-based effluent limitations (WQBELs) in NPDES wastewater permits sufficient to achieve and maintain the biostimulatory substances objective. There are no *numeric* water quality objectives for nitrogen applicable to San Francisco Bay. To calculate numeric WQBELs, therefore, we must first express the *narrative* objective numerically (i.e.,

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[1] Waters shall not contain bios mulatory substances in concentra ons that promote aqua c growths to the extent that such growths ***cause nuisance or adversely affect beneficial uses***. Changes in chlorophyll a and associated phytoplankton communi es follow complex dynamics that are some mes associated with a discharge of bios mulatory substances. Irregular and extreme levels of chlorophyll a or phytoplankton blooms may indicate exceedance of this objec ve and require inves ga on.

[2] For this memo, when we use the term "San Francisco Bay", we mean this to include the following water bodies: Sacramento/San Joaquin River Delta (within San Francisco Bay region), Suisun Bay, Carquinez Strait, San Pablo Bay, Richardson Bay, Central San Francisco Bay, Lower San Francisco Bay, and South San Francisco Bay

translate the narrative objective).[3] In the following, we describe how dissolved oxygen concentrations can be used to express the narrative objective in terms of nitrogen loads. Nitrogen loads that maintain dissolved oxygen concentrations above 4 mg/L throughout most of San Francisco Bay would protect aquatic life for acute exposures that could occur in response to an algae bloom.

Dissolved oxygen is a reliable indicator for interpreting the narrative objective

Algae (phytoplankton) are microscopic plants that grow by using the sun's energy to convert carbon dioxide into new algal biomass (photosynthesis). In general, the Bay's turbid waters and strong tides limit phytoplankton's access to light, resulting in low to moderate rates of biomass production that support Bay food webs but rarely grow to problematic levels. Phytoplankton growth also requires other chemical building-blocks like nitrogen (and other nutrients). When conditions occur that allow for high phytoplankton production rates, that additional production can lead to adverse impacts to Bay beneficial uses in two ways.

First, excessive blooms that produce high levels of biomass can indirectly impact aquatic life by causing low dissolved oxygen. Second, blooms of specific algae species (HABs) produce chemicals that are directly toxic to aquatic organisms or have other direct impacts (e.g., clog fish gills). The August 2022 bloom was a very rare event because it involved a HAB species that was also an *excessive bloom* that indirectly impacted biota by causing low dissolved oxygen.

In developing the 2024 permit's nitrogen WQBELs, we focused on the August 2022 bloom's excessive-bloom/low-dissolved oxygen pathway because our current understanding of that pathway allowed the WQBELs to be quantitatively determined with greater confidence. The calculation methodology presented in this memo rests on well-understood biogeochemical processes. Growing phytoplankton take up nitrogen from the water in San Francisco Bay. After the phytoplankton die, bacteria in the sediment and water consume available oxygen as they digest the dead phytoplankton. Our understanding of these processes enables us to establish a straightforward quantitative relationship between nitrogen loads, potential dissolved oxygen demand, and dissolved oxygen concentrations in the Bay.

Reducing nitrogen loading to ameliorate dissolved oxygen impacts in the Bay will also mitigate the threat to beneficial uses resulting from HABs, but we are unable to quantify *a priori* the magnitude of this reduced risk for several reasons. First, the complex physical, chemical, and biological processes leading to the growth of HABs are not as well understood as those related to dissolved oxygen. Second, reliable estimates are not available to link nitrogen load reductions to a protective level of HAB biomass. The potential to use HAB biomass thresholds to determine nitrogen load reductions will be reevaluated during future permit cycles. A substantial portion of Nutrient Management Strategy (NMS) monitoring, special scientific investigation, and modeling efforts will

[3] According to 40 C.F.R. sec on 122.44(d)(1)(vi), where reasonable poten al has been established for a pollutant, but there is no numeric water quality criterion for that specific pollutant, water quality-based effluent limita ons (WQBELs) must be established using (1) U.S. EPA criteria guidance under CWA sec on 304(a), supplemented where necessary by other relevant informa on; (2) an indicator parameter for the pollutant of concern; or (3) a calculated numeric water quality criterion, such as a proposed state criterion or policy interpre ng a narra ve criterion, supplemented with relevant informa on.

continue to be devoted to advancing our understanding of algae blooms in general and harmful algae blooms in particular.

To establish the nitrogen WQBELs based on dissolved oxygen, we considered a specific extreme event, the August 2022 *Heterosigma akashiwo* bloom, and evaluated how reduced municipal wastewater treatment plant nitrogen loading levels would have improved Bay water quality with respect to dissolved oxygen. So much phytoplankton was produced during the 2022 bloom that, when the phytoplankton died and were digested by bacteria, a substantial portion of dissolved oxygen was consumed over a large portion of south San Francisco Bay, and there were also documented fish kills in several other locations. Accordingly, the large 2022 algae bloom provides an appropriate framework to assess how nitrogen loading impacts beneficial uses vis-?-vis the narrative biostimulatory substances objective. While we cannot prevent the occurrence of algae blooms because uncontrollable non-anthropogenic factors contribute to bloom initiation and spread, reducing nitrogen loads sufficiently to mitigate the impact of an excessive bloom like the one in 2022 would protect beneficial uses during and immediately after the bloom, when the impacts are most severe.

Focusing on the 2022 bloom reflects a critical condition where load reductions would be necessary to protect beneficial uses and would improve the condition of the Bay with respect to dissolved oxygen. During the 2022 bloom, dissolved oxygen in San Francisco Bay was substantially depressed for a short period of time (a few days) when a large fraction of the dead algae were digested, but oxygen concentrations recovered as oxygen was resupplied from the atmosphere and through tidal mixing. This is consistent with the long-term observations in San Francisco Bay, which shows that sustained long-term (for example, monthly to seasonal time scale) low oxygen concentrations do not occur over large spatial scales because tidal circulation and the shallow nature of much of the Bay ensures replenishment of dissolved oxygen relatively quickly. Therefore, it is appropriate to consider the threat to aquatic life during the critical condition as an acute, rather than chronic, exposure. It is unnecessary to evaluate how nitrogen loads affect dissolved oxygen under typical ambient conditions because high turbidity limits algae growth, and beneficial uses are fully supported under these conditions. Over the last several decades, dissolved oxygen concentrations in the subtidal portions of San Francisco Bay are almost always higher than 5 mg/L under typical (light-limiting non-bloom conditions).[4]

Dissolved oxygen concentrations of 4 mg/L protect aquatic life during acute exposures

The Basin Plan's narrative biostimulatory objective states, "waters shall not contain **biostimulatory substances** in concentrations that promote aquatic growths to the extent that such growths cause nuisance or **adversely affect beneficial uses**." In the context of establishing municipal wastewater loading limits, nitrogen is the biostimulatory substance of concern, and a protective dissolved oxygen concentration is used to interpret the narrative objective to assess the impact on beneficial uses. As

[4] The sub dal por on of San Francisco Bay includes the deepwater por on of the Bay as well as shallower areas that remain submerged except during extremely low des. Dissolved oxygen concentra ons in shallow margin areas like sloughs, dal ponds, and marsh areas can naturally fluctuate drama cally throughout the day, and these areas are not covered by the analysis presented in this memo.

explained in the previous section, we chose the 2022 algae bloom as the critical condition for which we evaluated wastewater nitrogen load reductions. We used a model to identify the magnitude of nitrogen load reductions required to moderate the dissolved oxygen depression during an algae bloom such that beneficial uses would be protected. To use the model results, we identified a dissolved oxygen concentration protective of beneficial uses under the acute conditions of a significant bloom.

The Virginian Province Approach (VPA) is a methodology the U.S. Environmental Protection Agency (U.S. EPA) developed for computing acute and chronic dissolved oxygen criteria to protect juvenile and adult aquatic organisms.[5] Acute criteria are computed from dissolved oxygen toxicity endpoints analogous to those used to set criteria for toxic pollutants. These acute endpoints describing lethality to 50% of test organisms (LC50) for species relevant to the aquatic system are gathered from available sources of laboratory data. Toxicity data are ranked according to genus mean acute values (GMAV), i.e., from most to least sensitive to low dissolved oxygen. The four most sensitive GMAVs are used in a series of equations to determine the final acute value (FAV), which is then converted to an acute criterion by multiplying by the average LC5 to LC50 ratio for juveniles. The result is a dissolved oxygen acute endpoint that ensures that the vast majority of species would experience relatively little mortality.

The VPA methodology has recently been used in the San Francisco Bay Region to compute acute endpoints for two projects – the Suisun Marsh TMDL for Mercury and Dissolved Oxygen, and for the NMS's dissolved oxygen efforts for South San Francisco Bay sloughs. In Suisun Marsh, the four most sensitive species used to calculate the FAV were (from most to least tolerant): striped bass, Mississippi silversides, American shad, and sturgeon. The resultant FAV was translated into an acute endpoint of 3.8 mg/L, and this endpoint was adopted by the Water Board as a water quality objective.[6] For south San Francisco Bay sloughs, the four most sensitive species used to calculate the FAV were (from most to least tolerant): sturgeon, killifish/topminnow, molly, and herring. The resultant FAV was translated into an acute endpoint of 3.7 mg/L.[7]

The acute dissolved oxygen objective and endpoint calculated using the VPA methodology for these two projects were very similar, suggesting the resultant acute endpoints would also protect aquatic organisms found in San Francisco Bay. The sensitive species that determined the acute endpoints calculated for Suisun Marsh and South San Francisco Bay sloughs also occur in San Francisco Bay and generally represent sensitive species living in the Bay. For these two VPA analyses, acute dissolved oxygen laboratory test data were unavailable for salmonids. However, the 1986 U.S. EPA freshwater dissolved oxygen criteria document states that "if the period of exposure to low dissolved oxygen concentrations is limited to less than 3.5 days, concentration of dissolved oxygen of 3 mg/L or higher should produce no direct

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[5] USEPA. 2000. Ambient Aqua c Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Ha eras. EPA-822-R-00-012. U.S. Environmental Protec on Agency, Washington, DC.

[6] Tetra Tech. 2017. ***DO Criteria Recommenda ons for Suisun Marsh***. Prepared for the San Francisco Regional Water Quality Board. March 2017.

[7] Tetra Tech. 2023. **Updated Technical Report - Virginian Province Approach to Dissolved Oxygen in Lower South San Francisco Bay Sloughs**. July.

mortality of salmonids."[8] If the VPA methodology were formally applied to San Francisco Bay, the acute endpoint would likely be very close to 3.7 or 3.8 mg/L. To provide for a margin of safety in our dissolved oxygen translation of the narrative biostimulatory objective[9], we use 4 mg/L as the acute, dissolved oxygen endpoint when interpreting the modeling results described in the next section.

Load reductions can be linked to dissolved oxygen concentrations for a Summer 2022-like bloom

Evaluating how reduced municipal wastewater nitrogen loading may have mitigated dissolved oxygen impacts during the 2022 bloom requires a model. The NMS Science Team has developed a numerical model for San Francisco Bay that can predict dissolved inorganic nitrogen (DIN) concentrations, algae growth and decay, and resultant dissolved oxygen concentrations. The model was developed and validated to simulate the typical long-term ambient conditions observed in the Bay, and it performs reasonably well in predicting algae growth and dissolved oxygen levels under those conditions. However, it was not developed to simulate HAB-like events similar to the one observed in 2022 so we did not use the NMS model to predict algae growth and dissolved oxygen for our analysis. Notwithstanding the challenges of predicting phytoplankton during a HAB-like bloom, the current model predicts DIN concentrations well, which is the limiting nutrient that fuels algae growth in the Bay. Accordingly, we rely on the model's capability to simulate nitrogen successfully in our calculation methodology for establishing necessary municipal wastewater nitrogen load reductions.

The NMS model accounts for nitrogen loads that enter the Bay from municipal wastewater treatment plants, inputs through the Golden Gate, and inputs from large and small rivers, and simulates the physical and chemical processes relevant to the transport and transformations of nitrogen throughout the Bay.[10] The output of the model is a set of simulated DIN concentrations at finely resolved grid cell locations all throughout the Bay at any time chosen by the modeling team. Simulations were performed to obtain the DIN concentrations through July just prior to the start of the 2022 bloom. These predicted nitrogen concentrations match the observations leading up to the early summer before the HAB event sufficiently well to use the model to simulate nitrogen within the Bay. This provided a basis for evaluating the changes in DIN for different levels of point source load reductions.

To estimate how much phytoplankton can be produced by the available nitrogen "fuel," we made the "worst case" assumption that all the available nitrogen predicted by the NMS model will be converted to phytoplankton, and then all of the phytoplankton produced will be digested by bacteria, a process that consumes oxygen. This assumption of complete conversion of nitrogen to phytoplankton biomass during the bloom does not account for the complexities of nutrient cycling and phytoplankton

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[8] U.S. EPA (1986) ***Ambient Water Quality Criteria for Dissolved Oxygen***. U.S. EPA 440/5-86-003

[9] The VPA calcula ons to derive the acute water quality objec ve in Suisun Marsh and acute endpoint for Lower South Bay sloughs may not account for all possible habitats and species present in San Francisco Bay. Therefore, the margin of safety was applied to the calcula on results.

[10] SFEI (2024) ***Simula ons of load reduc on scenarios to inform nutrient management planning for San Francisco Bay***. SFEI Contribu on #1175, San Francisco Estuary Ins tute, Richmond, CA

dynamics in the Bay. However, "back-of-the-envelope" calculations based on nitrogen and phytoplankton measurements made during the bloom suggest that, in large portions of Central and South San Francisco Bay, all available nitrogen was, in fact, completely converted into phytoplankton. Therefore, the assumption reasonably represents what occurred in the southern portion of the Bay during the bloom and represents what *potentially* could have happened in the rest of the Bay if complete conversion of available nitrogen had occurred there as well.

Assuming that all DIN is converted to phytoplankton biomass, the known chemical composition of phytoplankton provides a straightforward way to do the necessary calculations. We know that, in phytoplankton, there is a ratio of about 6.6 carbon atoms for every atom of nitrogen. We used this ratio, along with the DIN concentrations from the model, to estimate the amount of phytoplankton biomass that would be produced if all the DIN was converted into phytoplankton. We also know that when organic matter is decomposed, two atoms of oxygen are required for every carbon atom in the decomposed organic matter. Using these relationships, we calculated the amount of dissolved oxygen consumed by the complete degradation of the phytoplankton produced and subtracted this oxygen from the dissolved oxygen concentration in the Bay at the beginning of the bloom. The remaining dissolved oxygen concentration can be compared to the 4 mg/L acute criterion for dissolved oxygen.

We applied this calculation method to the simulated DIN concentrations in each grid cell for a set of simulations representing different municipal wastewater treatment plant load reduction scenarios ranging from about 30% to 60% reduction from 2022 loading levels. To reproduce the observed bloom conditions as closely as possible, we interpolated the observed DIN concentrations from a representative date in July[11] when the highest DIN levels were observed, and adjusted the model predicted DIN throughout the month of July. This provided the initial fuel for the HAB-event over the course of July, from which the worst-case dissolved oxygen levels within the Bay were estimated as described above. The estimated dissolved oxygen remaining after phytoplankton decomposition for each grid cell was summed over all grid cells to calculate the percent area in various geographic regions of the Bay for which the dissolved oxygen concentration was depressed below 4 mg/L. This approach was applied to various nitrogen load reduction scenarios as described below, and the corresponding percent area in different regions of the bay with dissolved oxygen levels below 4 mg/L was calculated to assess the improvements in dissolved oxygen. These modeling results are presented in a section below.

Interpreting modeling results

In the previous section we described the calculation methodology for determining the percent area of the Bay (or portions thereof) in which dissolved oxygen concentration would fall below the acute dissolved oxygen criterion (4 mg/L) for a given load reduction scenario. To interpret these modeling results in the context of determining if water

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[11] Even though the HAB-event occurred in August, the bloom ini ated in parts of South Bay in early August. Therefore, measurements from August were not used for the spa al interpola on. The last USGS Peterson Cruise before the HAB-event occurred on July 20. This was combined with SFEI shoal mooring and DWR data collected closest to July 20 to develop a bay-wide interpola on of reasonable DIN levels prior to the bloom.

quality standards would be achieved, the California's Listing Policy[12] (Listing Policy), which are used to determine if water quality objectives are met based on available water quality monitoring data, provides useful information. The U.S. EPA recognizes that beneficial uses can be supported even if water quality criteria (objectives in California) are not achieved 100% of the time in a water body. In fact, U.S. EPA guidance provides an allowable exceedance threshold of 10% for conventional pollutants (e.g., dissolved oxygen, pH, temperature, and others) and a 5% exceedance frequency threshold, or an exceedance no more than once every three years, for toxic pollutants[13]. Many states, including California, use exceedance frequencies associated with beneficial use protection that reflect this guidance.[14] California's Listing Policy, consistent with U.S. EPA guidance, considers a water quality objective to be achieved if the exceedance frequency is no more than 10% for a conventional pollutant like dissolved oxygen. We used modeling results to calculate the dissolved oxygen concentration in **every** grid cell throughout San Francisco Bay for the critical condition. We then compared these modeling results to the 10% exceedance threshold for conventional pollutants to determine whether the narrative biostimulatory objective is achieved[15]. In other words, the objective would be achieved if no more than 10% of the data (or, in our case, modeling results) in a water body falls below the acute dissolved oxygen criterion of 4 mg/L. We applied this 10% threshold to individual portions of San Francisco Bay and the Bay as a whole. The water quality objective would be achieved if no more than 10% of the area of any individual subembayment and Bay as a whole falls below 4 mg/L.

Modeling results suggest beneficial uses can be protected during a severe bloom event

The NMS modeling team used the procedures described above to investigate the following load reduction scenarios:

- Current (2022) nitrogen loads (no reductions)
- BACWA scenario corresponding to specific foreseeable load reductions of approximately 37% from 2022 loads (load reductions vary by facility)
- 40% nitrogen load reduction from 2022 loads (year-round and seasonal)
- 45% nitrogen load reduction from 2022 loads (year-round and seasonal)
- 50% nitrogen load reduction from 2022 loads (year-round and seasonal)
- 55% nitrogen load reduction from 2022 loads (year-round and seasonal)

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[12] ***Water Quality Control Policy for Developing California's Clean Water Act Sec on 303(d) List***. Adopted September 30, 2004 Amended February 3, 2015.
h ps://www.waterboards.ca.gov/board_decisions/adopted_orders/resolu ons/2015/020315_8_amendment_clean_version.pdf

[13] ***Consolidated assessment and lis ng methodology toward a compendium of best prac ces***. First edi on. Washington, D.C.: Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protec on Agency. 2002

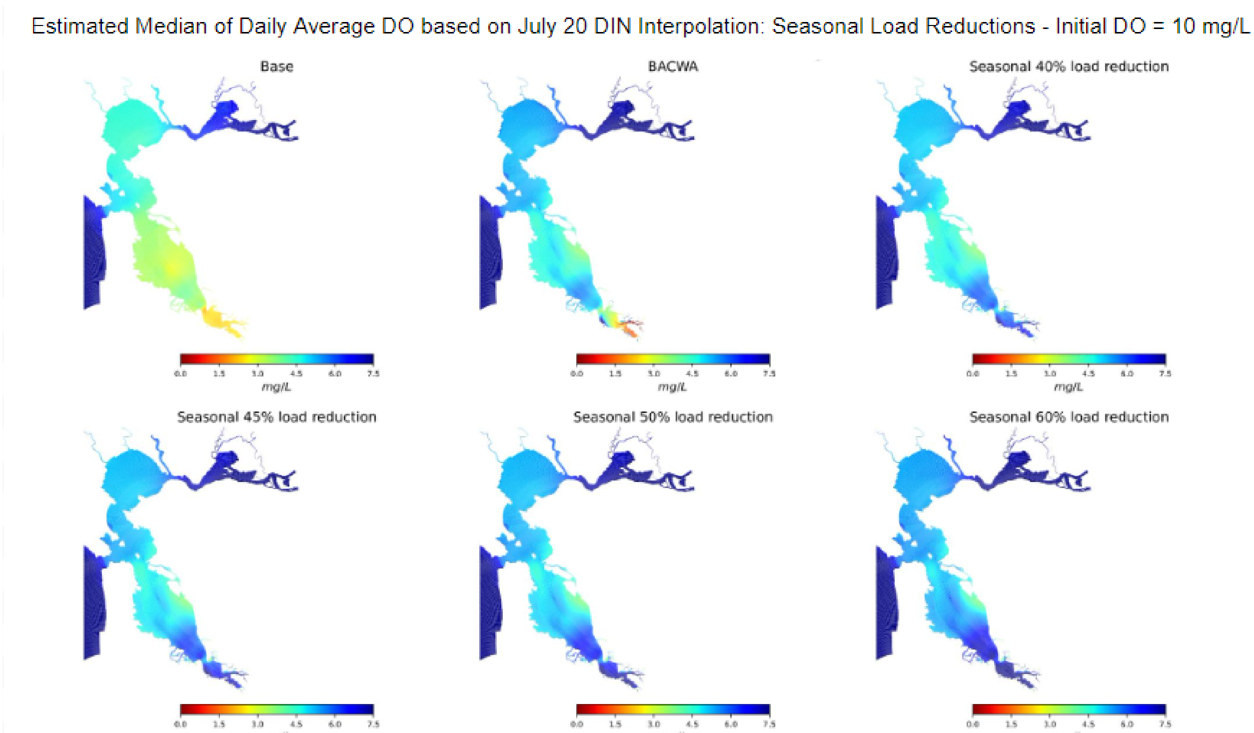
[14] ***Func onal Equivalent Document: Water Quality Control Policy for Developing California's Clean Water Act Sec on 303(d) List***. September 2004.

[15] U.S. EPA guidance (2002) and the Lis ng Policy's Func onal Equivalent Document (2004) allow for an effect size applied to the underlying 10% exceedance frequency to account for sta s cal errors associated with sampling from the unknown true data distribu on. Applica on of this effect size is not necessary in our circumstances because we calculate the dissolved oxygen concentra on throughout the waterbody and do not merely rely on a limited sample of the full distribu on of these concentra ons.

- 60% nitrogen load reduction from 2022 loads (year-round and seasonal)

For the 40-60% load reduction scenarios, the simulations were performed two ways – with the municipal wastewater facility DIN load reductions applied during the entire year and with the reduction applied only for the period from May through September. The modeling results for the May through September reductions are presented below based on a starting dissolved oxygen concentration of 10 mg/L (explained below). More detailed information concerning how the simulations were performed is available in a technical memorandum prepared by the NMS science team.[10]

We present the modeling results in two ways. First, the spatial pattern of estimated dissolved oxygen concentrations with colors ranging from red (low dissolved oxygen) to blue (high dissolved oxygen) are superimposed on a map of San Francisco Bay. As modeled load reductions increase, these maps show that the portion of the Bay colored red or orange (low dissolved oxygen) diminishes. Because the dissolved oxygen levels are directly derived from the estimated DIN levels, these maps also illustrate where the DIN is highest, thus causing the highest biomass production corresponding to the areas exhibiting the lowest dissolved oxygen levels.

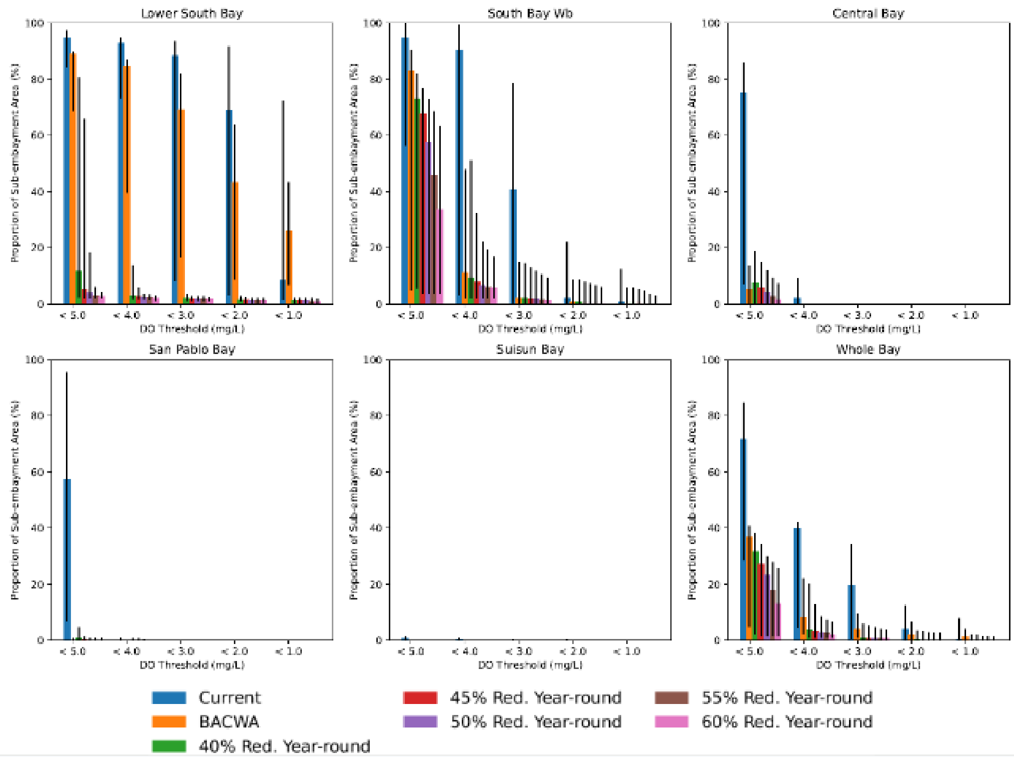


The modeling results can also be represented using bar charts (shown below) to represent the proportion of each subembayment that falls below various dissolved oxygen concentrations. The height of each colored bar represents the percent area for the indicated geographic region falling below the dissolved oxygen threshold indicated on the horizontal axis. These results represent the dissolved oxygen impact corresponding to the median estimated DIN[16] in each grid cell for July 2022. Each bar

[16] Es mated DIN is obtained by taking the model simulated differences in daily average DIN concentra ons between the base case and the load reduc on scenario for the month of July (July 1 to July 31) subtracted from the spa ally interpolated observed

also has “whiskers” representing dissolved oxygen outcomes corresponding to the 10th and 90th percentile DIN for July 2022. These whiskers are included to remind us that there was a range of simulated DIN for July 2022, and we are using the median of the DIN prediction at each grid cell and over the month of July and interpreting the results for our analysis of required load reductions.

July 20 Change in area for DO improvements (May-Sep Load Reductions): Initial DO = 10 mg/L



Notes:
1. Height of bars show the July 2022 median of the area not meeting DO threshold

2. Error bars show the 10th and 90th percentile over July 2022

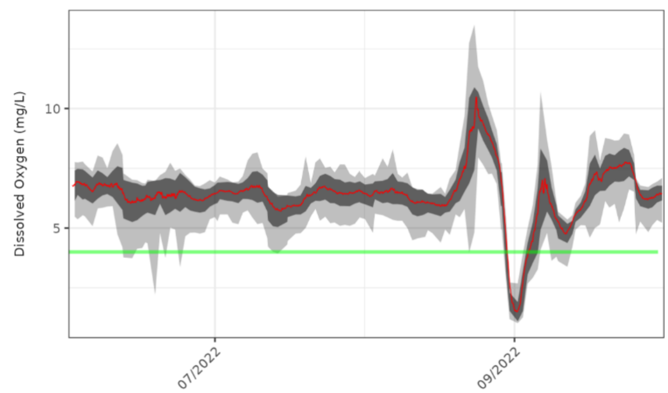
For example, for the South Bay (middle panel of top row), the current DIN loading (blue bar) would result in about 90% of the area of the South Bay having a dissolved oxygen concentrations below 4 mg/L. DIN reductions of 40% (green bar) would result in about 9% of the area of the South Bay having dissolved oxygen concentrations below 4 mg/L. The table below summarizes these percentages for select load reductions for all subembayments and for the Bay as a whole. All scenarios with 40% DIN reduction or greater will result in less than 10% of area of each subembayment (and San Francisco Bay as a whole) having a dissolved oxygen concentration below 4 mg/L.

DIN for July 20. These calcula ons are performed for all grid cells, and the median (and 10th and 90th percen le) es mated DIN for each grid cell for July is selected and used in subsequent calcula ons. The results are then summed for all grid cells by subembayment.

Geographic Region	Percent of geographic region below 4 mg/L dissolved oxygen acute threshold			
	BACWA scenario (orange bars)	40% DIN reduction (green bars)	45% DIN reduction (red bars)	50% DIN reduction (purple bars)
Entire Bay	8%	4%	3%	< 3%
Lower SF Bay	85%	3%	< 3%	< 3%
South SF Bay	11%	9%	< 8%	< 7%
Central Bay	< 1%	< 1%	< 1%	< 1%
San Pablo Bay	< 1%	< 1%	< 1%	< 1%
Suisun Bay	< 1%	< 1%	< 1%	< 1%

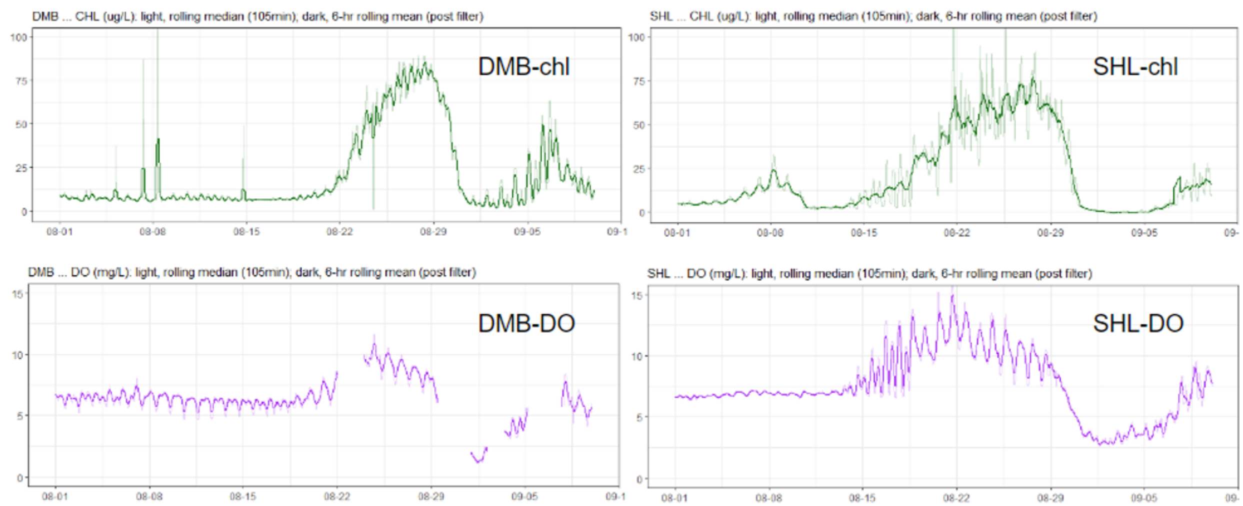
** Note that the color indicated refers to the color of the bar for this load reduction scenario on the bar charts above. These dissolved oxygen results correspond to the median DIN concentration for the period July 1 – July 20, 2022.

Dissolved oxygen concentrations reach 10 mg/L prior to digestion of algae from bloom



The NMS modeling team modeled changes to dissolved oxygen concentrations based on different starting concentrations prior to the depression due to bacterial digestion of dead algae. To translate the narrative biostimulatory substances objective, we used the results of modeling scenarios with a starting dissolved oxygen concentration of 10 mg/L. This starting point dissolved oxygen concentration is higher than typical dissolved oxygen concentrations, but this concentration was observed in parts of the Bay where algae growth was most pronounced. This increase in dissolved oxygen prior to digestion of the dead algae can clearly be seen in the image at right, which is a portion of continuous dissolved oxygen data from the moored sensor data at the Dumbarton Bridge.[17] This temporary increase in dissolved oxygen is caused by photosynthetic activity (which produces oxygen) of the abundant phytoplankton during the latter stage of the bloom.

[17] Figure produced using SFEI Shiny app: h ps://sfeinms.shinyapps.io/LSB_AF/



One would expect to see this brief period of elevated dissolved oxygen during severe blooms. Therefore, using 10 mg/L as a starting point for dissolved oxygen just prior to the rapid decline is reasonable because we are investigating load reduction impacts in the context of a *severe bloom* critical condition. The figure above shows data from two moored sensors, one at Dumbarton Bridge and another (SHL) approximately 11 miles further North in the South Bay. Data at both sensors indicate that dissolved oxygen concentrations began rising and exceeded 10 mg/L when chlorophyll-a (chl-a) concentrations increased, and then decreased rapidly as dead algae are digested. Dissolved oxygen data at both sensors exceeded 10 mg/L as chl-a surpassed approximately 40-50 µg/L. One could expect a similar phenomenon to occur under bloom conditions when abundant phytoplankton produce enough oxygen through photosynthesis during daylight hours to saturate or supersaturate the water with oxygen.

In our modeling scenarios, we assume that all available DIN is converted to algae, which results in widespread areas of high phytoplankton abundance, hence high chl-a concentrations. The figure below shows that the estimated chl-a concentrations[18] for the load reduction scenarios of interest exceed 40 to 50 µg/L in large portions of the Bay (regions shaded yellowish green to red). The dissolved oxygen depression is most pronounced in the areas with higher chl-a concentrations because of the higher calculated dissolved oxygen debt from digestion of the abundant algae. However, the impact on water quality will be somewhat moderated because dissolved oxygen concentrations prior to the drawdown will be higher in these areas due to the photosynthetic oxygen production of the abundant algae, as described previously. Because chl-a concentrations of similar magnitude (40-50 µg/L) were associated with dissolved oxygen concentrations above 10 mg/L in the moored sensor data, our use of 10 mg/L as the starting point dissolved oxygen concentration for our analysis is reasonable.

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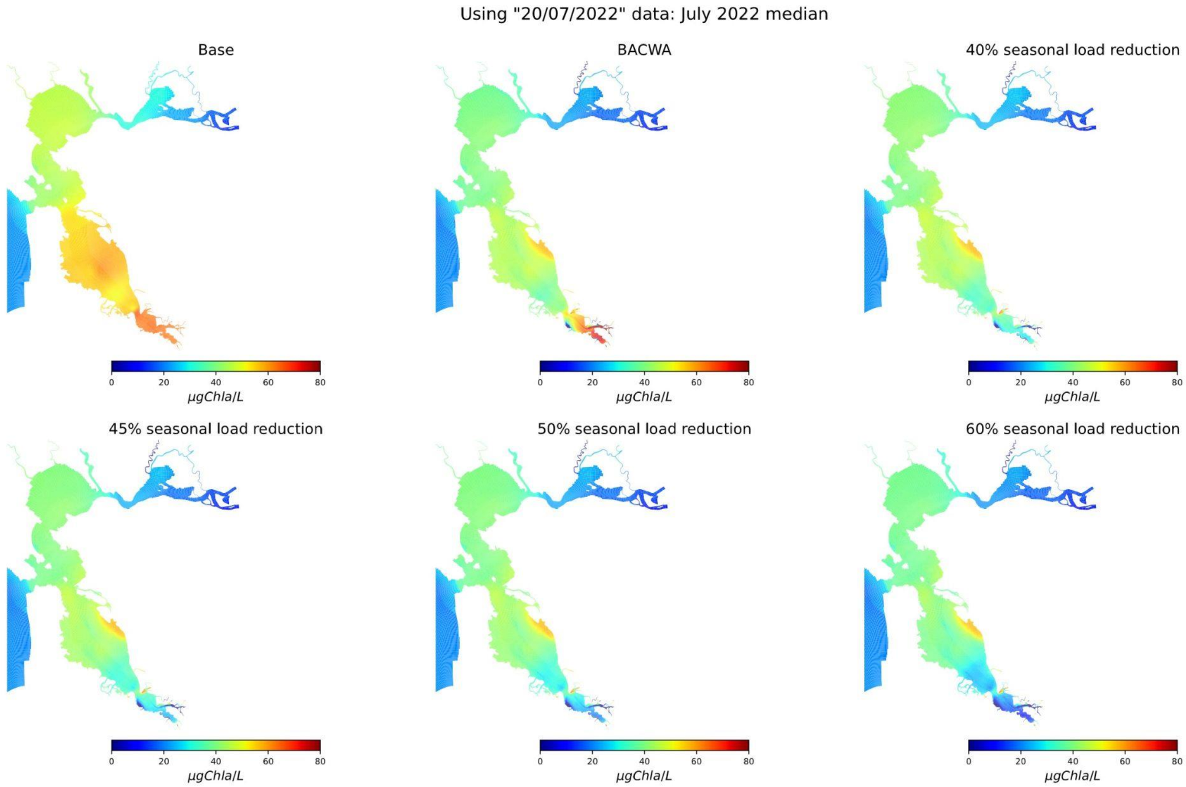
[18] Chl-a concentra ons were obtained by first conver ng DIN to phytoplankton biomass using a typical ra o of carbon to nitrogen in phytoplankton of about 6.6:1. Then the chl-a concentra on can be subsequently calculated using a carbon to chl-a ra o of 45:1.



The chl-a series above shows many areas of the Bay with phytoplankton abundance high enough to elevate dissolved oxygen prior to the steep depression of dissolved oxygen occurring when the algae died and were consumed. The regions of high phytoplankton concentration are the same as the regions where dissolved oxygen is most depressed when the algae are digested by bacteria. In other regions of the modeling domain with lower chl-a, dissolved oxygen may not be elevated as much, but it will also not be depressed as much at the end of a bloom because there will be less organic matter produced to consume the oxygen. As a result, those other regions would likely remain above 4 mg/L, even with a lower dissolved oxygen starting concentration.

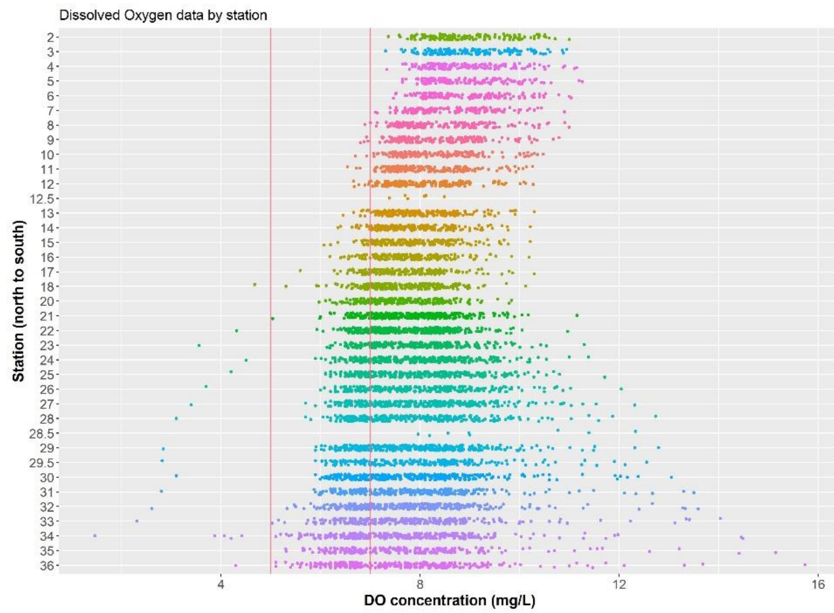
Dissolved oxygen is sufficient to support beneficial uses under typical, non-bloom conditions

We are using a large algae bloom as the critical condition under which to derive the load reductions required protect beneficial uses. Fortunately, dissolved oxygen concentrations in San Francisco Bay are almost always adequate to support beneficial uses because blooms like the one in summer 2022 are rare. We do not know how often severe algae blooms occur, but we know that there has not been a bloom as severe as the 2022 bloom for at least thirty years. We also know that dissolved oxygen levels in the Bay are almost always sufficient to protect beneficial uses based on data collected over many years.

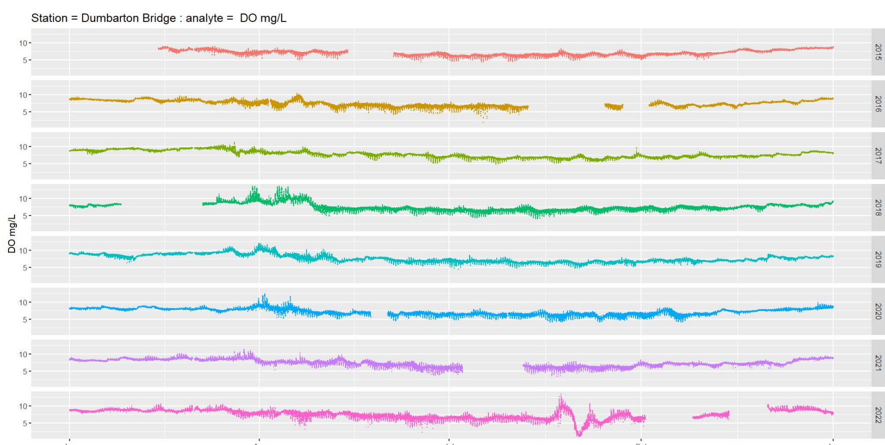
For the past five decades, the United States Geological Survey (USGS) has made ship-based measurements of water quality along a 145-kilometer-deep water transect that spans the length of the entire estuary system from ocean to inland delta.[19] The figure on the left shows the numbered station locations where the data are collected during every cruise. Since 1993, the USGS has conducted monthly cruises along the entire Bay-Delta system as part of the Regional Monitoring Program for Water Quality in San Francisco Bay. Additional cruises in the South and Central Bay are conducted during spring and when rapid water quality changes associated with phytoplankton blooms are predicted.

[19] h ps://www.usgs.gov/centers/california-water-science-center/science/sampling-loca ons-water-quality-san-francisco-bay

The figure on the right is a plot of over 9,100 depth-averaged daily dissolved oxygen concentrations at the station number on the vertical axis (these are shown on the figure above). The stations at the top of the plot are in the northern portion of the estuary, and the stations at the bottom of the plot are in the south. The vertical red lines indicate the Basin Plan’s 7 mg/L dissolved oxygen objective (applies to stations 2-10) and 5 mg/L objective (applies to stations numbered 11 and higher).

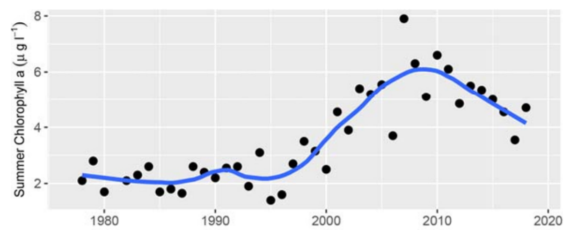


The plot illustrates that dissolved oxygen is almost always sufficient to protect beneficial uses in the Bay because nearly all measurements are higher than 5 mg/L. In fact, only 12 of the measurements are below 4 mg/L, and 11 of the 12 were collected on August 31, 2022, during the severe algae bloom. Only 20 of the concentrations on the plot are below 5 mg/L, and 15 of the 20 were collected during the bloom in August 2022. These data illustrate that low dissolved oxygen concentrations have occurred very rarely in San Francisco Bay, and, in fact, the low dissolved oxygen concentrations measured during the 2022 algae bloom account for the vast majority of such low concentrations measured over the last three decades by the USGS monthly cruises.



The NMS has been collecting continuous (every 15 minutes) water quality data for nearly a decade using moored sensors in South Bay sloughs and at the Dumbarton Bridge. The data from the Dumbarton Bridge sensor represents water quality in the southern portion of the San Francisco Bay modeling domain used to assess load reductions, and the figure on the left shows the dissolved oxygen data from the Dumbarton Bridge sensor from 2015 through 2022. Just as for the USGS boat-based data, dissolved oxygen concentrations rarely fall below 5 mg/L, but low dissolved oxygen concentrations occurred in late August 2022 in the aftermath of the bloom. For the 2,922 days depicted in this plot, the daily average dissolved oxygen concentration was less than 5 mg/L on seven days and below 4 mg/L on five days. These occurrences were in late August or early September during the late stage of the 2022 algae bloom.

We do not know if future dissolved oxygen data in San Francisco Bay will continue to be similar to the USGS cruise and moored sensor data. However, severe blooms have been rare, and the Bay has been resilient against excessive algae growth. There is some evidence that this resilience is diminishing because chl-a data measured during USGS cruises since about 2000 are higher than in the past, as seen in the image on the right[20]. However, even during the last two decades of higher chl-a concentrations, blooms have been rare and dissolved oxygen levels have been maintained well above the 4 mg/L acute criterion, except during the recent bloom.



Improved understanding of the Bay will inform our adaptive permitting strategy

The modeling, surveillance and scientific studies supported through the NMS science program continue to advance our understanding of phytoplankton dynamics in the Bay. The load reductions called for in the permit will not only protect beneficial uses but will also provide an opportunity to evaluate how the system responds to the load reductions. Observing this response, combined with improved understanding through the NMS science program, will inform the Water Board's future determination as to whether additional load reductions will be necessary to protect beneficial uses.

A critical focus of the NMS science program is to achieve improved modeling capabilities. Currently, we can confidently simulate the fate and transport of nitrogen in the Bay. Consequently, we used simulated changes in nitrogen values to estimate the dissolved oxygen improvements associated with load reduction scenarios. The NMS is supporting improvements in our modeling capabilities that, in the future, may be adapted to simulate HAB-like events and a direct simulation of the dissolved oxygen impact from the decay of phytoplankton produced during such events. Once such a model is available and its performance validated, our analytical approach to estimating required load reductions would be substantially improved. Such a model would allow us to explore modeling scenarios for different load reductions and different sets of physical and biological conditions[21] relevant to phytoplankton bloom initiation and growth leading to HAB-like events. An improved model will thereby enhance our confidence that modeled load reductions not only account for the influence of municipal wastewater loads and other loads, but also for other factors that determine phytoplankton growth and decay.

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[20] Cloern, J.E., Schraga, T.S., Nejad, E. et al. Nutrient Status of San Francisco Bay and Its Management Implica ons. Estuaries and Coasts 43, 1299–1317 (2020). h ps://doi.org/10.1007/s12237-020-00737-w

[21] There are so called "non-anthropogenic factors'' that impact the modeling outcome but that do not involve nutrient loads. These factors include meteorological condi ons like sunlight, wind and cloud cover, ocean boundary condi ons including des and salinity, freshwater inflows from the tributaries, and light ex nc on derived from observed suspended sediment concentra ons, and zooplankton growth and grazing intensity.