Review of:
Scientific Basis to Assess the Effects of Nutrients on San Francisco Bay Beneficial Uses

Prepared for:
BACWA

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LimnoTech
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Cover image: Landsat 8 Operational Land Imager (OLI) satellite image of the San Francisco Bay region acquired April 16, 2013 during initial satellite testing approximately two months after launch.

Credit: created by Jesse Allen and Robert Simmon of NASA Earth Observatory, using data provided by the U.S. Geological Survey and NASA.

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Table of Contents

1
Executive Summary

This review of the draft *Scientific Basis to Assess the Effects of Nutrients on San Francisco Bay Beneficial Uses*, referred to hereafter as the *Scientific Basis (SB)*, is intended to highlight strengths of the document and provide comments on potential areas for improvement. The reviewers recognize the substantial expertise and effort represented by the authors of the document, and its value as a contribution to the larger San Francisco Bay Nutrient Management Strategy.

Particular strengths of the *SB* include the overall goals of the effort, the conceptual approach to realizing those goals, and the clear consideration of practicality in determining the implementation of the recommended characterization. In addition, the effort represents a valuable synthesis of the current scientific understanding of nutrient-driven processes in San Francisco Bay in the context of related processes operating in other estuaries. It is an important step in advancing the Nutrient Management Strategy.

Areas for improvement of the document, many of which are acknowledged as remaining areas for refinement by the *SB*'s authors, include: water and nutrient budgets; the role of numerical modeling; data analysis and the statistical basis for indicator thresholds; spatial and temporal resolution; linkage to beneficial uses; and consideration of other analogous estuaries and coastal systems.

Some of these suggestions will likely be addressed through companion efforts in nutrient monitoring, modeling, research, and management programs, but there is value in stating them at this early stage in the development and implementation of the planned "test drive" of the *SB* so that they may have a greater likelihood of contributing to its eventual success.

2
Introduction

The *SB* provides the scientific background for a program of ecological characterization of the health of San Francisco Bay's subembayments using a small set of indicators, with a special emphasis on the concentration of the phytoplankton pigment chlorophyll-*a* as a proxy for a larger set of conditions. The authors of the *SB* propose that it be used in a "test drive" fashion to determine whether it can serve as a useful approach for determining the actual or potential impact of nutrients on beneficial uses in the bay. In this report we present an assessment of important strengths and areas for improvement in the proposed approach.

2.1 Existing planning documents for Nutrient Management Strategy development

The *SB* was developed within the context of the larger Nutrient Management Strategy (NMS) for San Francisco Bay (Figure 1), which includes research, monitoring, modeling, and management components. Important recent documents that describe essential parts of the NMS include the following:

- Numeric Nutrient Endpoint Development for San Francisco Bay Estuary: Literature Review and Data Gaps Analysis (June 2011)
- San Francisco Bay Nutrient Management Strategy (November 2012)
- External Nutrient Loads to San Francisco Bay: Assessing the Flux of Nutrients from Ocean to Bay (December 2013 draft)
- External Nutrient Loads to San Francisco Bay (January 2014)
- Model Development Plan to Support Nutrient Management Decisions in San Francisco Bay (January 2014)
- Development Plan for the San Francisco Bay Nutrient Monitoring Program (August 2014)
- Scientific Foundation for the San Francisco Bay Nutrient Management Strategy (October 2014)
- San Francisco Bay Nutrient Management Strategy Detailed Modeling Workplan for FY15-FY21 (December 2014)
- Regional Monitoring Program for Water Quality in San Francisco Bay, Multi-Year Plan, Annual Update (January 2016)
- San Francisco Bay Nutrient Management Strategy Science Plan, and Peer Review Report (both March 2016)

Many of these documents were written by authors from the San Francisco Estuary Institute (SFEI), sometimes on behalf of larger groups of advisors and contributors, including regional and national representatives from the academic and agency research communities, as well as by consultants and technical representatives of groups such as BACWA, the Southern California Coastal Water Research Project (SCCWRP), and the San Francisco Bay Regional Water Quality Control Board (SFRWQCB).

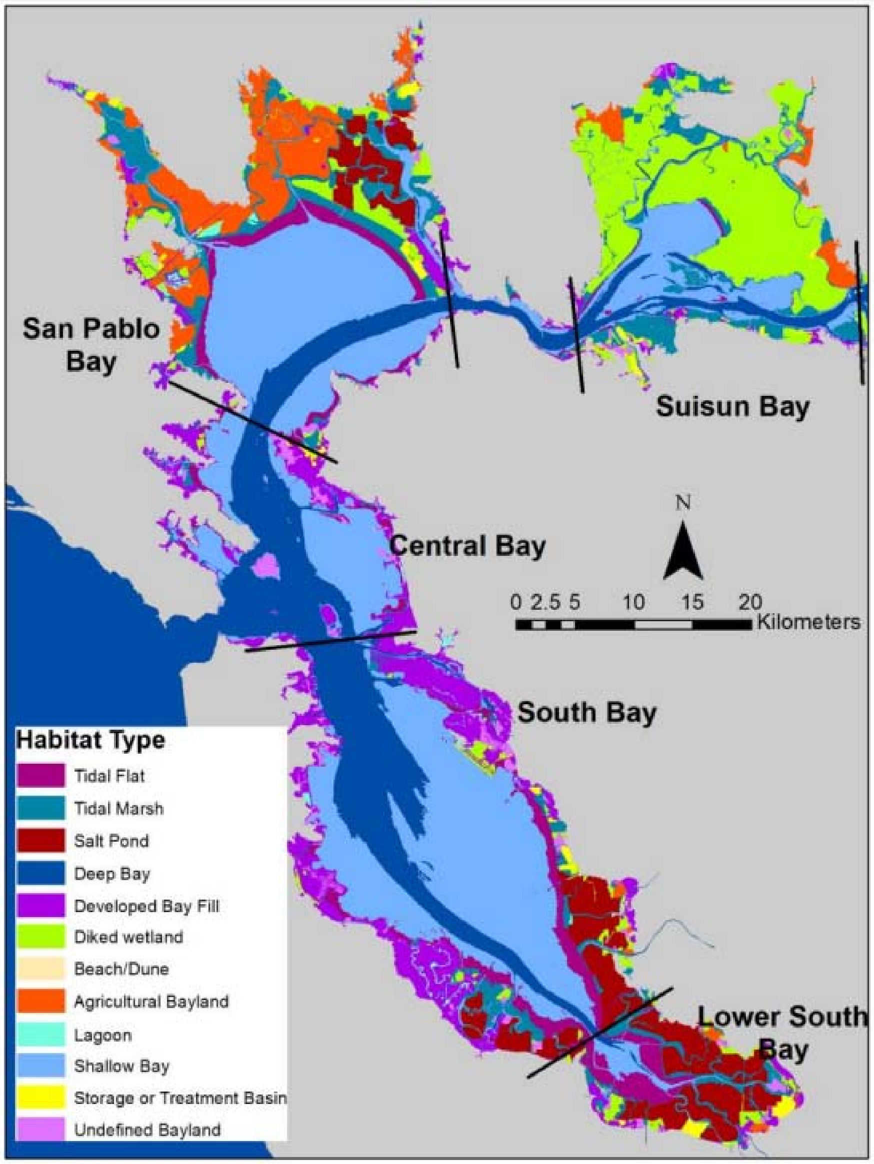


Figure 1. From: SFEI (2014). Development Plan for the San Francisco Bay Nutrient Monitoring Program. Contribution No. 724, San Francisco Estuary Institute, Richmond, CA (Fig. 5.1).

2.2 Peer-reviewed research

The *SB* includes a comprehensive set of 73 references, approximately half of which describe research results from the primary literature of peer-reviewed journal articles. The remainder include technical reports, regional and topical reviews, agency publications, books or book chapters, methods papers, and non-journal publications of professional societies. The references are generally current, appropriate, and comprehensive, and reflect the disciplinary expertise of the *SB* authors, including many of their own publications. Several of the most important references, as well as several other papers that were not cited in the *SB*, are described briefly here as preparation for the discussion that follows.

2.2.1 Currently cited in *SB* as scientific foundation

The authors refer to several documents that describe related assessment efforts in other similar systems, many of which are highly relevant to the development of an effective approach for San Francisco Bay. Complete citations to those references appear in Section 5, "Literature Cited", of the *SB* document. Bricker et al. (2003) described a method for assessing the trophic status of estuaries, based on work done to compile the National Estuarine Eutrophication Assessment (1999) and subsequent international efforts. Sutula (2011) reviewed related efforts to use indicators to develop nutrient numeric endpoints, with intended application to California estuaries, and Harding et al. (2013 online, 2014 in print) described a similar effort that was specific to the use of chlorophyll as an indicator in Chesapeake Bay.

Publications by Cloern et al. (1996, 2005[a], 2007, 2012, 2014[a]; Cole and Cloern, 1984; Cloern and Dufford, 2005; and in Conomos [ed.], 1979) highlight aspects of the USGS monitoring effort in San Francisco Bay that has been in place since 1969. This program documented major red tide events in 2004 and 2010, a food web shift triggered by invasive clams in the late 1980s, and a 15-year change in bay conditions resulting from a persistent ocean climate, and upwelling shift from 1999 through 2014 that followed the strong 1998 El Niño (see also Kimmerer and Thompson, 2014).

Cited papers on harmful algal blooms and their toxins included work by Lehman et al. (four total: 2003, 2005, 2008, 2013; *Microcystis* focus), and Kudela (four total: 2011; with Anderson et al., 2008 and 2009; with Lane et al., 2010; toxin occurrence and detection methods focus, especially SPATT), as well as a global review by Glibert et al. (2005).

Important nitrogen cycling papers included four by Dugdale et al. (2007, 2012; and with Parker et al., 20012a and 2012b; ammonium focus), and one by Glibert (2010; focus on nutrient ratios and food web impacts, including fish). Cloern et al. (2014[b], not cited in the *SB*) discuss the relative merits of different viewpoints about the causes of low biomass in Suisun Bay, which is the focus of Dugdale et al. and Glibert papers.

2.2.2 Additional peer-reviewed literature considered for this review

Although the authors did a thorough job of considering the relevant literature, we identified a few areas where additional references may be useful. These include both publications that (1) expand on topics covered by the *SB*, and (2) were published very recently and not available to the authors.

Cloern (2001) presented a review of coastal eutrophication that emphasized the importance of "system-specific attributes", which is highly relevant to the situation in San Francisco Bay, but was not cited in the *SB*. The paper describes the evolution of thinking about coastal eutrophication from a simpler phase of development dominated by limnologists, to a more complex understanding of how nutrients interact with a variety of other factors in estuaries and coastal waters. More recent work by European researchers (e.g., Duarte et al., 2009; Carstensen et al., 2011) builds on some of these ideas, in a context of how changing nutrient conditions, both increasing and decreasing, yield unpredictable ecosystem responses due to changing baseline conditions and other factors.

Because of the critical role that invasive species play in nutrient cycling, especially benthic grazers such as *Corbula amurensis* (previously known as *Potamocorbula amurensis*), it is important to consider the most current information available. Building upon related explanations by Cloern et al. (2007) and Kimmerer and Thompson (2014) of chlorophyll-*a* changes cited in the *SB*, important subsequent studies include Parchaso et al. (2015), which covered benthic communities in the lower South Bay. Parchaso et al. (2015) documented complex interactions between benthic grazers and deposit feeders (clams and crustaceans), predators, phytoplankton, and water quality in the sloughs of Lower South San Francisco Bay, which may provide insight on more general seasonal and interannual patterns observed in the broader bay. In particular, this study shows how the presence or absence of grazers in sloughs may influence chlorophyll concentrations at nearby sampling stations in the main bay.

Climate variability and cycles that have strongly influenced upwelling and changes in chlorophyll-*a* values over the last two decades in the California Current as well as San Francisco Bay include the North Pacific Gyre Oscillation (DiLorenzo et al., 2008; Chenillat et al., 2012) and the Pacific Decadal Oscillation (Newman et al., 2016). Harding et al. (2016) analyzed long-term data from Chesapeake Bay to separate out the influences of climate from anthropogenic nutrient loading. This approach could also work well for

San Francisco Bay. Moftakhari et al. (2015) hindcast flows and sediment inputs to San Francisco Bay back to 1849, which is important for understanding factors that influence ecosystem variability and trends over time due to watershed hydrology, climate, and land use change.

Very recent and ongoing biogeochemical modeling work by Hollowell and related efforts described in an abstract by Liu (2016) show the potential of incorporating these tools into assessment of dynamic and spatially-variable nutrient processes in San Francisco Bay ecosystems. For example, such models can be used to accurately and mechanistically simulate changes in the bay's primary productivity during wet and dry years at a spatial and temporal resolution that monitoring alone cannot capture, even using satellite data and continuous monitoring instruments. Evans and Scavia (2013) published a very relevant review of factors influencing the sensitivity of various estuaries to nutrient loading. Using a Bayesian-based process model, they concluded that chlorophyll sensitivity to nitrogen loading was closely linked with water residence time, and dissolved oxygen (DO) sensitivity was linked to relative mixing depth.

Additional references related to non-nutrient drivers of HAB occurrence and toxicity include Paerl and Huisman (2008) and Paerl and Otten (2013a and 2013b). These papers describe 26 environmental factors controlling cyanobacterial algal blooms, including climate warming and toxin production as a defense against damage by reactive oxygen species. The first one (*Blooms like it hot*) has been cited over 950 times. A paper by Cloern et al. (2005[b]) in *Geophysical Research Letters* described an unusual bloom of a non-toxic dinoflagellate in San Francisco Bay that was not driven by nutrients, expanding on the group's other article in *Eos* in the same year (2005[a]) that was cited in the *SB*.

3
Strengths of the Scientific Basis

The draft *SB* represents a substantial contribution to the understanding of the science related to achieving the goal of protecting the bay from negative impacts of nutrient loads. Particular aspects that are noteworthy are the clearly stated and specific goals of the effort, the logic of the conceptual approach, and the incorporation of practical considerations in the document, including explicit exclusion of certain indicators and methods that are still in development and not yet ready for operational use. The *SB* strikes a good balance between both very new information (>30 percent of references are from 2012-2015), and classic review papers and reports that assess nutrient impacts on estuaries at national and global scales. The authors have advanced the thinking of the scientific community and have further strengthened the scientific basis for future decisions about nutrient management in San Francisco Bay.

3.1 Goals

One strength of the existing *SB* is the clear objective of understanding trends in bay water quality, and detecting any evidence of possible degradation that may indicate a movement toward future impairment. This is a sensible approach, given that many other estuaries have not received similar attention by research and management communities until they have become quite eutrophic with substantial impairment of beneficial uses. The goal of protecting the bay from potential impacts of nutrient overenrichment is prudent, and the use of the best available science, explicitly recognizing limitations and uncertainty, is appropriate.

3.2 Conceptual approach

The approach taken in the *SB* is to determine key integrative indicators of ecosystem status. This is sound if such indicators can be identified and developed with substantial scientific justification. The approach recognizes distinct differences among bay segments, which is critical to optimizing the associated assessment methodology. The discussion of the current status of the bay and the appropriateness of particular indicators incorporates much of the most current data available for the bay. Finally, the outlined methodology recognizes the benefit of taking a weight-of-evidence approach to determining nutrient-related conditions in the bay, rather than relying on an overly narrow set of parameters or measurements.

3.3 Practical considerations

The authors acknowledge the challenges of monitoring a complex system like San Francisco Bay, including high variability in flows and loading, and a variety of scaling issues. The literature review synthesizes what is known about nutrient-driven processes in San Francisco Bay and recognizes knowledge gaps. The value of modeling in data integration, interpolation, and development of mechanistic linkages to management scenarios is discussed, even though development of these models is not at a stage where they could provide much value to the *SB*.

4

General discussion of uncertainty

We share the authors' concerns about uncertainty and the need to strengthen the *SB* through basic research, monitoring, and modeling, including the areas for refinement described in Section 4.3 of the framework. That said, we also recognize the desire to move forward with development and implementation of an integrated nutrient management strategy for the bay, understanding that some amount of uncertainty will always exist about the bay's complex and dynamic systems and processes. Specific areas of the greatest current uncertainty, as described in the *SB*, include translation of indicator values into meaningful or useful conclusions about the overall status and trends of dissolved oxygen, harmful algal bloom occurrence and toxicity, and their combined impacts on ecosystem health and beneficial uses.

An additional overarching area of uncertainty is the proper approach to delineation of subembayments and associated offshore and nearshore habitats (channels, sloughs, marshes, salt ponds, and tidal flats) so that monitoring and modeling resolution are matched to the appropriate ecosystem management units. As much as possible, such subdivision of the bay should optimize the matching of regions of generally homogeneous habitat conditions and species occurrence with associated sources of nutrient loading. This would make it possible to tie future management decisions about nutrient loading directly to the relevant subembayment where environmental impacts of changes in loading would be expected to be observed most strongly.

SB: We recommend establishing an explicit validation and refinement process for the *SB*, building on the authors' discussion of a "scientific test drive", which will lay out a detailed approach for improving the methodology and reducing uncertainty over time.

Finally, we strongly endorse the use of process-based modeling to help reduce uncertainty in parallel with refinement of the *SB* and ongoing monitoring and research. Mechanistic modeling forces integration of existing data, represents the complexity of process interactions over time and space, and provides for the development and testing of multiple hypotheses and scenarios about how the system is likely to respond to a variety of perturbations. Modeling also makes it possible to perform realistic numerical experiments to test the sensitivity of the bay system to a variety of drivers (e.g., climate, nutrients, and invasive species).

5
Specific areas for improvement

SB: We identified ten areas where the draft *SB* can be improved. Some of these areas were mentioned by the authors of the *SB*, while others were not addressed directly. In many cases, the following suggestions lay out addition information or approaches that could be included or further developed in the *SB*. We believe that incorporating these suggestions will provide a more solid scientific foundation for the *SB*. Some suggestions will also result in an approach that is linked more closely to important complementary elements of the overall nutrient management strategy for San Francisco Bay, including research, monitoring, modeling, and habitat restoration programs.

5.1 Water and nutrient budgets for the entire bay are inadequate

Creation of detailed and balanced water and nutrient budgets is a fundamental first step in developing assessment and management plans for any water body. The 2012 San Francisco Bay Nutrient Management Strategy recognized "[c]haracterization of nutrient loads, sources and major pathways" as a major work element (cited in Line 244 of the *SB*). This characterization is not yet complete, although recent efforts to create nutrient budgets for particular embayments (e.g., Suisun Bay) and for net ocean inputs or exports through the Golden Gate are recognized. The Nutrient Numeric Endpoint review (2011; table on p. viii) recognized numerous data gaps that need to be filled to properly constrain nutrient loads to the bay from seven different categories of sources. NOAA is in the process of developing an operational hydrodynamic model for the bay based on the FVCOM code, which will be an essential tool for improving water budgets. Current budgets, however, are incomplete, outdated, or insufficiently constrained by data or resolved over space and time to serve as the basis for planned assessments (e.g., Smith and Hollibaugh, 2006).

Accurate water budgets are needed to address average flushing times in the bay, and how they vary by subembayment, season, and climate cycle in order to assess ecological risk, system resiliency, and time to recovery after disturbance. Bay-wide water budgets are reasonably well known, but cannot fully resolve complexities of estuarine circulation, thermal and saline stratification, mixing, high-flow processes, and shallow-water processes operating in tributaries, tidal creeks, and salt ponds.

Validated budgets of dissolved and particulate nitrogen and phosphorus species are needed to rank nutrient sources by type, location, and subwatershed land use. Terms to better quantify and balance on a bay-wide basis and as they vary seasonally include: inputs from and losses to the Pacific Ocean, inputs from the Delta and tributaries, coastal wetland uptake, stormwater discharges and direct runoff, sediment diffusive fluxes and resuspension, sediment burial, direct atmospheric deposition and air-water nitrogen exchange, direct groundwater inputs, and wastewater discharge from municipal and industrial sources.

Knowing the magnitude and variability of water and nutrient inputs, outputs, and within-bay changes is essential for understanding the role of nutrients in trends, cycles, and seasonal variability of chlorophyll-*a* and dissolved oxygen, as well as their importance as drivers of harmful algal blooms and changes in other proposed indicators. Quantitatively constraining the water and nutrient balances and fluxes is an essential element of a comprehensive scientific understanding of cause and effect in the bay.

5.2 Process-based modeling is underemphasized

In its current form, the *SB* focuses on ecological health classification, and not sufficiently on development of a better understanding of the cause-and-effect relationships needed to support management of ecological health and beneficial uses. Valid indicators can track progress toward desired endpoints and trigger action when thresholds are approached or exceeded; however, models are the tools of choice to develop science-based management plans, to set initial endpoints, and to guide nutrient management in complex systems. Indicators and models are collaboratively used to develop effective nutrient management plans in other large ecosystems (e.g., Great Lakes, Chesapeake Bay, Gulf of Mexico, Tampa Bay, Everglades, Neuse River Estuary). Models have become critical tools in the nutrient management process, essentially becoming part of the standards of practice (Shoemaker et al., 2005).

Models can help determine the relative contributions of each driver and governing process to observed indicator and ecosystem trends. Models should be used in the bay and its subembayments to develop load-response relationships linking nutrient loads to eutrophication response indicators. Mechanistic models can parameterize major nutrient ratios, nutrient bioavailability, light/extinction, temperature/stratification, salinity, hydrology/residence time, hydrodynamics, sediment oxygen demand, and biomass of major algal functional groups. We recognize that San Francisco Bay model development is ongoing, but its role is not yet sufficiently integrated or articulated into the *SB* or the overall strategy to support effective nutrient management and provide the full potential return that could be realized from this investment.

5.3 Data analysis is insufficient to demonstrate nutrient impacts

Despite 40 years of data and the stated objective of a risk-based conceptual design (*Framework* Section 2.3), there is still excessive reliance on look-up thresholds (such as a Scottish "early-warning" alert level for *Alexandrium*) in the proposed classification scheme. Prior episodes of undesirable conditions (e.g., 2004 red tide event in Table 3.2, S4) are mentioned, but are not directly linked to indicators or used to develop indicator thresholds. The implication is that isolated incidents of algal blooms or low dissolved oxygen may be evidence of the more general approach of the system or embayment to a nutrient-driven tipping point, but this concept is not clearly stated, justified, or quantitatively developed. There is a general statement in Section 2.2 that "conditions may be trending toward adverse impacts due to elevated nutrient loads", but this is insufficient to scientifically support a plan.

In general, there is an incomplete assessment of actual beneficial use states or criteria to indicate that the bay or its embayments are either impaired or approaching impairment. Evidence of this would include not just changes in species present, but actual changes in beneficial uses and ecosystem health (e.g., fish, benthos, phytoplankton, or zooplankton abundance and diversity). An integrated ecological classification should tie more directly to something like an Index of Biological Integrity or be referenced to desired system states or endpoints. Although more comprehensive ecological assessments have been carried out for the bay (e.g., 33 indicators used in the *State of the Estuary Report*, 2015), the approach proposed in the *SB* is not strongly justified by the data analysis used to support it.

One particular area of concern is that the "harmfulness" of HAB species occurrence is not sufficiently demonstrated or linked to nutrients, and the methodology of selection of appropriate risk-based alert thresholds (Framework Table 3.7) is not convincingly or consistently supported (e.g., through correlations of HAB species abundance with toxicity).

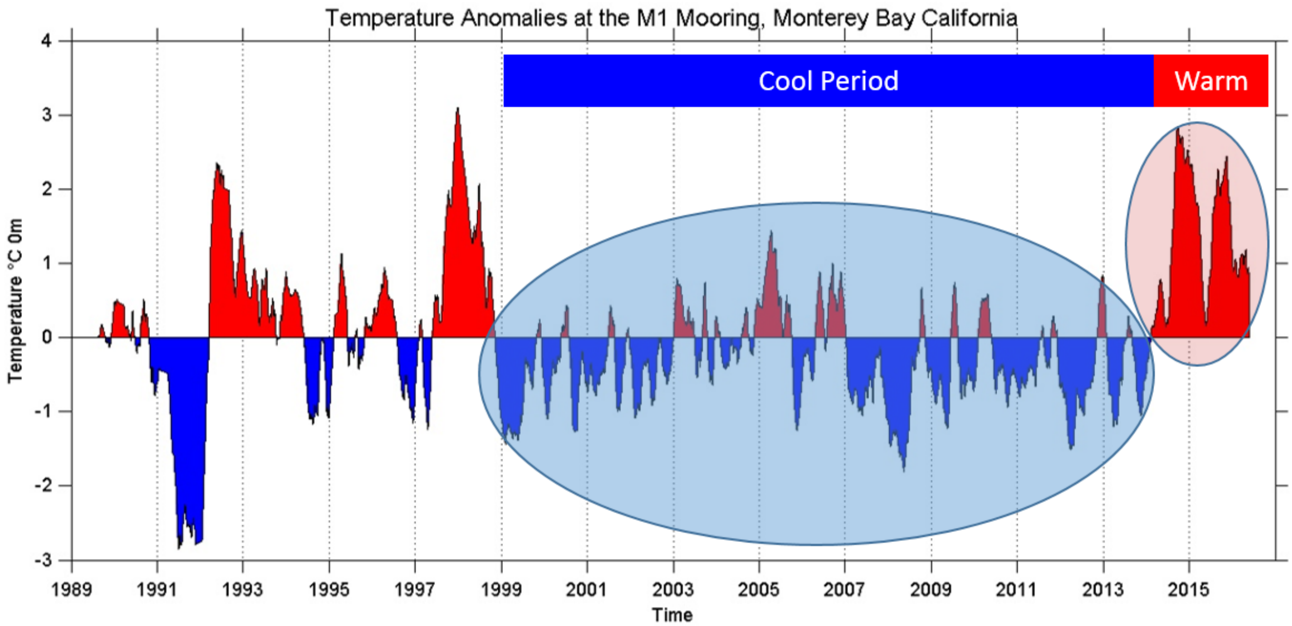
5.4 Statistical justification of chlorophyll-*a* thresholds is too simple

The basis for determining chlorophyll-*a* thresholds neglects known cofactors, and falls short of demonstrating quantitative causal relationships (i.e., from nutrients to chlorophyll-*a* to indicators); correlation does not imply causation. Unless stronger and more robust links between chlorophyll-*a* and ecological health can be established, direct measurements of dissolved oxygen and algal toxins would seem to be more reliable indicators than chlorophyll-*a*.

Quantile regression, one of the statistical techniques upon which the development of the *SB* relies, is widely used by ecologists in situations where many of the factors thought to affect ecological processes have not been measured (Cade and Noon, 2003). In the case of San Francisco Bay, data have been collected not only for chlorophyll-*a*, but for many other variables that are understood to play important roles in affecting algal growth and related ecological health. Some of the cofactors that were either not considered or not eliminated by quantitative methods as significant drivers of chlorophyll-*a*/DO/HABs relationships were light limitation by suspended solids, ocean upwelling, ammonia, and invasive species. These cofactors are part of the conceptual model, but the statistical work neglects their causative role in the *SB*.

Trends attributed to nutrient control on chlorophyll-*a* could be due in part to changes in other factors (e.g., temporary decline in benthic grazers; see Cloern et al., 2007; *SB* Appendix C, Figure 4). For example, there was a documented cold period from 1999 to 2014, which might be a factor in chlorophyll-*a* increases, and in the recent stabilization and reduction in chlorophyll-*a* after the cold climate phase weakened and ended. The data are consistent with this hypothesis, but this apparent effect of temperature is not recognized as a potential factor in the *SB* (see figures below; note that the "Cool Period" box was added to the second figure to facilitate intercomparison). The rise in chlorophyll-*a* from 1999 to 2005 is not correlated with a corresponding increase in nutrient loading from watershed or point sources to the bay. Cloern et al. (2007) proposed that the increase in chlorophyll-*a* over the cool period could be attributed to a documented increase in flat fish and crab predators of benthic grazers. If this proposed mechanism is correct, it reinforces the need to better understand direct biological drivers of changing chlorophyll-*a* concentrations in the bay, and indirect influence of ocean climate cycles on bay food webs.

Two-dimensional parameter statistics omit the recognized cofactors listed above and risk spuriously attributing effects to chlorophyll-*a* as the included independent variable; multivariate methods could account for cofactors, using available data, and could also help quantify their relative effects on dissolved oxygen and HABs. A range of methods is available, from close inspection of the data represented in scatter diagrams (e.g., in Appendix C Figure 5, what cofactors cause data points to cluster around the low-DO lines [tau = 0.1] rather than the median-DO lines [tau = 0.5]?), to more complex multivariate regression tools. A concerted effort to identify the relative contributions of various cause-effect relationships to changes in ecosystem health should be a key element of the ongoing research program.



Note: 60 point moving average applied to daily averaged values.

Monterey Bay Aquarium Research Institute *Updated:23-May-2016*

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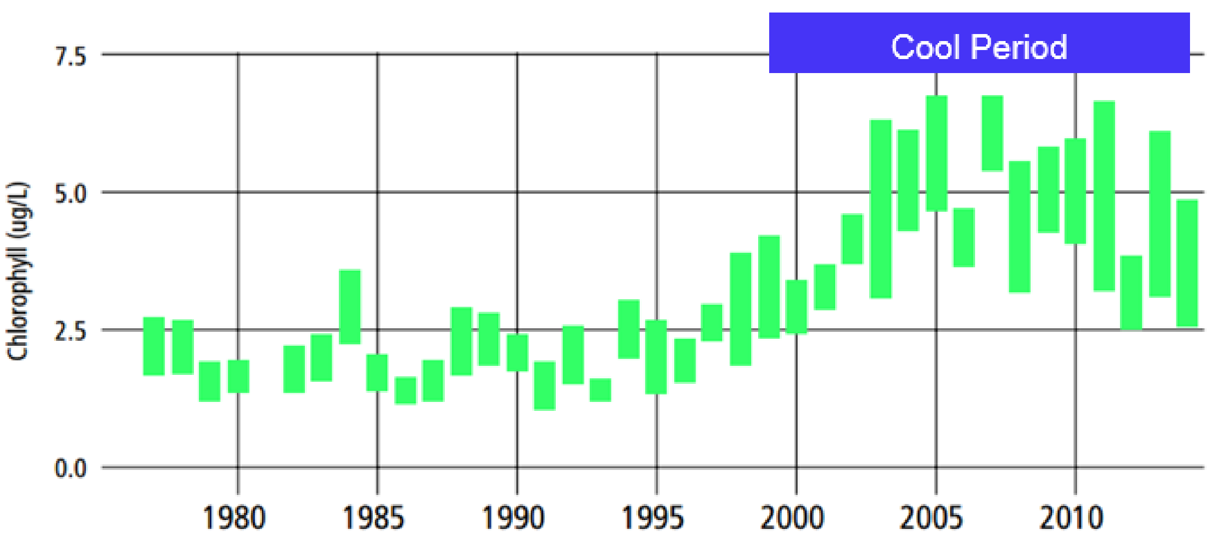
LATE SUMMER CHLOROPHYLL IN THE SOUTH BAY



The middle range (between the 25th and 75th percentiles) of annual chlorophyll concentrations in the South Bay in late summer. Historically, the South Bay had low chlorophyll production compared to other estuaries with comparable nutrient inputs. Data from USGS. Additional details on page 61.

SFEI, 2015, The Pulse of the Bay: The State of Bay Water Quality, 2015 and 2065. SFEI Contribution #759, San Francisco Estuary Institute, Richmond, CA.

5.5 Statistical basis of chlorophyll-*a* thresholds is not robust

Determination of thresholds for chlorophyll-*a* based on dissolved oxygen correlations depends on small numbers of data points and extrapolation beyond the dataset for some subembayments (e.g., see Appendix C, Figure 5, which indicates that data for most subembayments aren't rich enough in the high-chlorophyll-*a*-/low-DO range of concern to estimate reliable statistical relationships). Trial efforts to develop reliable quantile regression estimates settled on February-through-September chlorophyll-*a* as a predictor for May-through-July dissolved oxygen, although other combinations of averaging periods for chlorophyll-*a* and dissolved oxygen produced stronger correlations for some subembayments. Appendix C proposes a literature-based hypothesis related to detritus build-up and decomposition for the averaging periods chosen and used in developing chlorophyll-*a* thresholds; however, the results shown in Appendix C, Table 1 are not yet definitive and reflect an element of data exploration.

HABs-based chlorophyll-*a* correlations are not clearly risk-based and rely on inappropriate use of thresholds (including the UK "early-warning" *Alexandrium* threshold noted in Section 5.3). Analysis of San Francisco Bay data, either including or excluding *Alexandrium*, does not yield a useful threshold because the risk-to-concentration relationship is quite flat up to relatively high chlorophyll-*a* concentrations, and the best estimates are shown within very wide error bounds. The identification of a 13 mg/m^3 chlorophyll-*a* threshold for HABs is not well supported by Appendix C Figure 6, which shows a higher threshold (25 mg/m^3) for all HABs and no apparent threshold when *Alexandrium* data are excluded, nor by Appendix C Figure 8, where the indication of a threshold is based on only three data points. Similar chlorophyll thresholds for use as HABs proxies have not been developed for other estuaries (e.g., Chesapeake Bay), due to scientific uncertainty.

Monitoring locations, timing, and methods of sampling on which HAB and DO-based chlorophyll criteria are developed were not optimized for this application, or with beneficial use and eutrophication assessment in mind; this may bias data that were used in framework development. As stated in the 2015 *Pulse of the Bay* report, "Although these [2012 mussel] data suggest that toxins are ubiquitous, the concentrations were low relative to existing standards". This monitoring program was more closely linked to a beneficial use (i.e., shellfish harvest and consumption), but still did not show consistent "harmfulness" of HABs species, nor did it demonstrate a causal linkage to nutrients.

5.6 Appropriate spatial resolution for assessment is not yet resolved

Classification of ecosystem status is critically dependent on the scale of assessment, as identified in the framework. It is important for delineation of distinct ecological communities and determination of their ecological condition based on appropriate comparative standards of diversity, biomass, and function. The current segmentation of the bay was inherited from programs that were not primarily ecological in their design. Questions remain about how to properly subdivide the bay into assessment bins, including the following: (1) What methods or criteria will be used to determine how many bay segments are needed for characterization?, and (2) Can Delta influences on the North Bay be distinguished more clearly from distinct Central Bay (Golden Gate) and South Bay drivers? Distinctions between open water processes and those operating in sloughs, marshes, and salt ponds are not sufficiently made, especially in areas of active restoration and related research. Finally, the importance of stratification in development of low DO is recognized (e.g., Appendix D) but is not incorporated sufficiently into the *SB* methodology.

5.7 Temporal resolution and variability could influence annual classifications in unintended ways

In addition to proper spatial binning (ecological zones, depths), implementation of the *SB* would require explicit specification of temporal sampling plans for indicator analytes. For example, data on algal blooms should reflect some seasonal averaging across individual subembayments, in addition to measurements of peak concentrations. Diurnal, tidal, and seasonal variation can bias grab sample monitoring, so a plan to integrate sampling and continuous monitoring of indicator parameters may be helpful. An approach to dealing with interannual variability in assessment also needs to be articulated and incorporated. Decadal-scale variations, such as recent drought and ocean temperature shifts, and resulting salinity changes and trophic cascades (Cloern et al., 2007) have not been adequately incorporated into the existing framework.

5.8 Linkages to beneficial use impairments are not yet strongly established

Ecological conditions and human beneficial uses should be individually and specifically related to proposed indicators in more detail than what is presented in Framework Table 3.2. In the case of recreation and fishing, potential nutrient impacts are unlikely to be tightly correlated with assessment of ecological condition. In the case of ecological uses, it is unclear why the use of Index of Biological Integrity or other established integrative approaches were not proposed. The impact of many invasive species on the system, along with the role of toxins (e.g., PCBs, mercury, pesticides), are important cofactors that need explicit treatment. The current status, trends, and risk associated with each beneficial use that may be expected to show impacts of eutrophication should be tabulated in the framework for the sake of clarity.

5.9 Integration of lessons from a broader set of water bodies could be useful

As stated previously, building approaches to nutrient management based on the experience gained from other estuaries and coastal systems is a sensible way to move forward. The primary analogous system referenced in the *SB* is Chesapeake Bay, and several of the authors have substantial professional experience with this system. Chesapeake Bay and its watershed are well studied, and this is an obvious system to compare with San Francisco Bay given its size, state of agricultural and urban development, and decades of refinement of its nutrient management policies. It is quite different from San Francisco Bay in many important aspects, however, including its bathymetry, hydrodynamics, climate, watershed land use and hydrology, nutrient loading, development history, trophic state, and ecosystem details.

The nutrient management framework is more mature in the Chesapeake Bay region. In spite of this, however, the draft San Francisco Bay *SB* moves beyond Chesapeake approaches in its use of chlorophyll-*a* as an indicator of broader ecological condition. San Francisco Bay does not have the consistent seasonal hypoxia problems found in the axial basin and the tributary basins of Chesapeake Bay. This is because San Francisco Bay does not have the extensive bay-mouth and tributary-mouth shoals that inhibit flushing and favor summer stratification and oxygen depletion that exist in Chesapeake Bay.

Chesapeake Bay has operational monitoring, modeling, and water quality criteria for its segments, which San Francisco Bay does not, but this is due to the fact that Chesapeake Bay is considered to be impaired by nutrient impacts and is a system in recovery, unlike San Francisco Bay, where the focus is on prevention of impairment. Chesapeake Bay HABs criteria do not yet exist due to recognition of incomplete understanding of HABs occurrence there. Given these differences, it is appropriate to consider estuaries and water bodies other than Chesapeake Bay in developing nutrient management and assessment approaches for San Francisco Bay (see also the Evans and Scavia [2013] review concerning the roles of residence time and mixing). A few examples follow, none of which are perfect matches to San Francisco Bay, but which illustrate that there are research and management programs in other systems that can be reviewed and profitably applied to the bay.

Massachusetts Bay experiences harmful algal blooms of *Alexandrium spp.*, but these are primarily driven by cyst density in sediments and ocean temperature, rather than nutrients (Anderson et al., 2014). These factors have not been considered for San Francisco Bay in the *SB*. Other HAB species are similarly complex and should be treated individually. For example, *Microcystis* appears to originate in the Delta and tributary mouths, while *Pseudo-nitschia* in the bay comes from the Pacific Ocean.

Narragansett Bay in Rhode Island and Massachusetts is deep and generally well flushed like San Francisco Bay, but it experiences intermittent summer hypoxia in segments with depths of 3 to 11 meters that receive high nutrient loads and have less flushing under certain conditions, such as sustained northeast winds (Codiga et al., 2009; summarized as "different processes govern event variability in different regions, each influenced by local hydrodynamics"). Monitoring and reporting is specific to areal extent and duration of hypoxia, rather than using an indirect proxy like chlorophyll-*a*. The timing of monitoring is linked to the fish recruitment period, during which there is potentially a direct beneficial use impact.

Delaware Bay receives substantial nutrient loads from its watershed, but has generally not shown effects of nutrient over-enrichment (Sharp et al., 2009). Ongoing studies of Delaware Bay may benefit development of San Francisco Bay approaches, given that this system may be more similar than Chesapeake Bay in terms of flushing, stratification, residence time, and nutrient sensitivity.

The overall San Francisco Bay Nutrient Management Strategy effort, and the *SB* specifically, could benefit from a more comprehensive review of publications on nutrient-driven processes in other similar estuary systems. This would include well-flushed systems with developed watersheds in the North Sea and Baltic Sea regions, as well as other settings with generally cool water such as Puget Sound, British Columbia, New England, Korea, Japan, New Zealand, southern Australia, and Chile. For reference, the average temperature near the mouth of San Francisco Bay ranges from 12°C (January) to 16°C (September) (NOAA NODC).

5.10 Scientific test drive of the Scientific Basis

We found the idea of a scientific test drive for the *SB* well-founded, given the uncertainties and gaps the authors identified. The details of how such a test drive would be conducted are lacking, however. It would be valuable to spell out the protocols for exactly what will be tested; how its degree of success will be evaluated, including criteria for acceptance; how the results will be used; and the process by which the assessment approach will be refined based on the outcomes of initial testing. Alternatively, it may be the case that most of the components of a proposed scientific test drive are already being evaluated and incorporated into the ongoing monitoring, modeling, and research programs that are part of the Nutrient Management Strategy.

6
References

Anderson, D.M., B.A. Keafer, J.L. Kleindinst, D.J. McGillicuddy, Jr., J.L. Martin, K. Norton, C.H. Pilskaln, J.L. Smith, C.R. Sherwood, and B. Butman, 2014, *Alexandrium fundyense* cysts in the Gulf of Maine: Long-term time series of abundance and distribution, and linkages to past and future blooms, Deep-Sea Research II, 103, 6-26.

Cade, B.S., and B.R. Noon, 2003, A gentle introduction to quantile regression for ecologists, Frontiers in Ecology and the Environment, 1, 421-420.

Carstensen, J., Sánchez-Camacho, M., Duarte, C.M., Krause-Jensen, D., and Marbà, N., 2011, Connecting the dots: responses of coastal ecosystems to changing nutrient concentrations, Environmental Science & Technology, 45, 9122-32, doi: 10.1021/es202351y.

Chenillat, F., P. Rivière, X. Capet, E. Di Lorenzo, and B. Blanke, 2012, North Pacific Gyre Oscillation modulates seasonal timing and ecosystem functioning in the California Current upwelling system, Geophysical Research Letters, 39, L01606, doi:10.1029/2011GL049966.

Cloern, J.E., 2001, Our evolving conceptual model of the coastal eutrophication problem, Marine Ecology Progress Series, 210, 223-253.

Cloern, J.E., Schraga, T.S., Lopez, C.B., Knowles, N., Grover Labiosa, R., and Dugdale, R, 2005[b], Climate anomalies generate an exceptional dinoflagellate bloom in San Francisco Bay, Geophysical Research Letters, 32, L14608, doi:10.1029/2005GL023321.

Cloern, J.E., Malkassian, A., Kudela, R., Novick, E., Peacock, M., Schraga, T., and Senn, D., 2014[b], The Suisun Bay problem: Food quality or food quantity? Interagency Ecological Program Newsletter, 27, 16-23.

Codiga, D.L., H.E. Stoffel, C.F. Deacutis, S. Kiernan, and C.A. Oviatt, 2009, Narragansett Bay hypoxic event characteristics based on fixed-site monitoring network time series: Intermittency, geographic distribution, spatial synchronicity, and interannual variability, Estuaries and Coasts, 32, 621-641.

DiLorenzo, E., Schneider, N., Cobb, K. M., Chhak, K., Franks, P. J. S., Miller, A. J., McWilliams, J. C., Bograd, S. J., Arango, H., Curchister, E., Powell, T. M., and Rivere, P., 2008, North Pacific Gyre Oscillation links ocean climate and ecosystem change. Geophysical Research Letters, 35, L08607, doi:10.1029/2007GL032838.

Duarte, C.M., Conley, D.J., Carstensen, J., and Sánchez-Camacho, M., 2009, Return to *Neverland*: Shifting baselines affect eutrophication restoration targets, Estuaries and Coasts, 32, 29-36, doi:10.1007/s12237-008-9111-2.

Evans, M. A., and Scavia, D., 2013 Exploring estuarine eutrophication sensitivity to nutrient loading, Limnology & Oceanography, 58, 569-578.

Harding, L.W., Jr., C. L. Gallegos, E. S. Perry, W. D. Miller, J. E. Adolf, M. E. Mallonee, H. W. Paerl, 2016, Long-term trends of nutrients and phytoplankton in Chesapeake Bay, Estuaries and Coasts, 39, 664-681.

Liu, Q., 2016, A modeling study of the San Francisco Bay and Delta ecosystem in high and low river flow years, AGU-ASLO-TOS Ocean Sciences Meeting, 21-26 February 2016, New Orleans, Abstract number 88813.

Moftakhari, H. R., Jay, D. A., Talke, S. A., and Schoellhamer, D., 2015, Estimation of historic flows and sediment loads to San Francisco Bay, 1849–2011, Journal of Hydrology, 529,1247-1261.

Newman, M., M. Alexander, T. R. Ault, K. M. Cobb, C. Deser, E. Di Lorenzo, et al., 2016, The Pacific decadal oscillation, revisited, Journal of Climate, 29, 4399-4427, doi: 10.1175/JCLI-D-15-0508.1

Paerl, H. W., and Huisman, J., 2008, Blooms like it hot, Science, 320(5872), 57-58.

Paerl, H. W., and Otten, T. G., 2013a, Harmful cyanobacterial blooms: causes, consequences, and controls, Microbial Ecology, 65, 995-1010.

Paerl, H. W., and Otten, T. G., 2013b, Blooms bite the hand that feeds them, Science 342 (6157), 433-434.

Parchaso, F., Thompson, J. K., Crauder, J. S., Anduaga, R. I., and Pearson, S. A., 2015, Benthic response to water quality and biotic pressures in lower south San Francisco Bay, Alviso Slough, and Coyote Creek: U.S. Geological Survey Open-File Report 2015–1234, 44 p., http://dx.doi.org/10.3133/ofr20151234.

Sharp, J. H., K. Yoshiyama, A. E. Parker, M. C. Schwartz, S. Curless, A. Y. Beauregard, J. E. Ossolinski, and A. R. Davis, 2009, A biogeochemical view of estuarine eutrophication: lessons from seasonal and spatial trends and correlations in the Delaware Estuary, Estuaries and Coasts, 32, 1023-1043.

Shoemaker, L., Dai, T., Koenig, J., and Hantush, M. M., 2005, TMDL Model Evaluation and Research Needs, EPA 600-R-05-149, U.S. Environmental Protection Agency, Cincinnati, Ohio, USA, 386 p.

Smith S. V., and Hollibaugh, J. T., 2006, Water, salt, and nutrient exchanges in San Francisco Bay, Limnology & Oceanography, 51, 504–517.