Technical Report 0644

Numeric Nutrient Endpoint Development for San Francisco Bay Estuary: Literature Review and Data Gaps Analysis

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EXECUTIVE SUMMARY

The California State Water Resources Control Board (SWRCB) is developing nutrient water quality objectives for the State's surface waters, using an approach known as the Nutrient Numeric Endpoint (NNE) framework. The NNE establishes a suite of numeric endpoints based on the ecological response of an aquatic waterbody to nutrient over-enrichment (eutrophication, e.g. algal biomass, dissolved oxygen). In addition to numeric endpoints for response indicators, the NNE framework must include models that link the response indicators to nutrient loads and other management controls. The NNE framework is intended to serve as numeric *guidanc*e to translate *narrative* water quality objectives. The NNE framework is currently under development for estuaries. Because San Francisco Bay represents California's largest estuary (70% by area of estuarine habitat statewide), it merits development of an estuary-specific NNE framework. The purpose of this document is to review literature and data relevant to the assessment of eutrophication in San Francisco Bay, with the goal of providing information to formulate a work plan to develop NNEs for this estuary. The review had three objectives: 1) Evaluate indicators to assess eutrophication and other adverse effects of anthropogenic nutrient loading in San Francisco Bay, 2) Summarize existing literature in SF Bay using indicators and identify data gaps, and 3) Investigate what data and tools exist to evaluate the trends in nutrient loading to the Bay.

Recommended NNE Indicators for SF Bay

The NNE assessment framework is the structured set of decision rules that helps to classify the waterbody in categories from minimally to very disturbed, in order to determine if a waterbody is meeting beneficial uses, or to establish TMDL numeric targets. Development of an assessment framework begins by choosing response indicators, which were reviewed using four criteria: 1) strong linkage to beneficial uses, 2) well -vetted means of measurement, 3) can model the relationship between the indicator, nutrient loads and other management controls, and 4) has an acceptable signal: noise ratio to assess eutrophication. Indicators varied among four habitat types: 1) unvegetated subtidal, 2) seagrass and brackish SAV, 3) intertidal flats, and 4) tidally muted habitats (e.g. estuarine diked Baylands). Two types of indicators were designated. Primary indicators are those which met all evaluation criteria and would therefore be expected to be a primary line of evidence of the NNE assessment framework for SF Bay. Supporting indicators fell short of meeting evaluation criteria, but may be used as supporting lines of evidence. This terminology is used in order to provide a sense of level of confidence in how the indicators should be employed in a multiple lines of evidence context.

The review found four types of indicators met all evaluation criteria and are designated as primary: dissolved oxygen, phytoplankton biomass, productivity, and assemblage, and cyanobacterial abundance and toxin concentration (all subtidal habitats), macroalgal biomass and cover (intertidal habitat, tidally muted habitats, and seagrass habitats). Other indicators evaluated met three or fewer of the review criteria and designated as supporting indicators: HAB cell counts and toxin concentration, urea and ammonium (all subtidal), light attenuation and epiphyte load (seagrass/brackish SAV). Ultimately, the real distinction between "primary" and "supporting" and how these classes of indicators would be used as multiple lines of evidence in an NNE assessment is entirely dependent on indicator group and particular applications to specific habitat types. Some primary indicators (e.g. dissolved oxygen) could be stand-alone, while for others such as phytoplankton biomass, productivity and assemblage, the SF Bay Technical Advisory Team strongly recommends using them as multiple lines of evidence, as use of any one alone is likely to be insufficiently robust.

The use of ammonium as an indicator received review, due to its hypothesized role in limiting phytoplankton primary production via nitrate uptake inhibition in Suisun Bay and the lower Sacramento River. The SF Bay Technical Advisory Team chose to include it as a supporting indicator because the importance of ammonium inhibition of diatom blooms relative to other factors controlling primary productivity Bay wide is not well understood. Additional review and synthesis are recommended, pending currently funded studies, to identify potential ammonium thresholds.

To What Extent is SF Bay Demonstrating Symptoms of Eutrophication, Utilizing NNE Indicators?
Of the four habitat types, only unvegetated subtidal habitat had adequate data to make an assessment of eutrophication. Dissolved oxygen in SF Bay subtidal habitat is much higher and phytoplankton biomass and productivity is lower than would be expected in an estuary with such high nutrient enrichment, implying that eutrophication is controlled by processes other than a simple nutrient-limitation of primary production. However, all regions of the SF Bay have experienced significant increases in phytoplankton biomass since the late 1990's. Recent analysis of water quality data collected by USGS from 1978 to 2009 show a significant increase in water column chlorophyll <u>a</u> (30-50% per decade from Suisun to South Bay respectively) and a significant decline in DO concentrations (1.6 to 2.5% per decade in South Bay and Suisun Bay respectively). <u>Thus evidence is building that the historic resilience of SF Bay to the harmful effects of nutrient enrichment is weakening</u>. The causes for the Bay wide trends include changes in water clarity due to less suspended sediment, lower metal inhibition due to improvements in wastewater treatment, increased seeding from ocean populations, declines in consumption by bivalves due to increases in predation by juvenile English sole and speckled sanddabs, and declines in phytoplankton consumption by consumers due to recent new invasive species introductions. Data suggest that primary productivity in Suisun Bay is limited by strong grazing pressure by invasive clams, light limitation by high turbidity, and ammonium inhibition of diatom uptake of nitrate. Few harmful algal blooms (HABs) have been reported recently in SF Bay. However, there have been historical occurrences, and recently cyanobacteria and dinoflagellate blooms have been increasingly documented.

What Are the Nutrient Loads to SF Bay From Various Sources?
Nutrients loads to SF Bay from external sources are poorly understood, though data exist with which to improve published load estimates from some sources. For the most part, published load estimates are outdated by one or even two decades or based on data that were not collected for loads estimation.

Data Gaps and Recommended Next Steps

The SF Bay NNE framework consists of two principle components: 1) primary and supporting indicators used in an assessment framework to assess eutrophication of SF Bay habitats and 2) models that link these indicators back to nutrient loads and other management controls on eutrophication. There are five major recommendations: 1) develop an NNE assessment framework for SF Bay, 2) quantify external nutrients loads, 3) develop a suite of models that link NNE response indicators to nutrient loads and other co-factors, 4) implement a monitoring program to support the use of the NNE in SF Bay to manage nutrients, and 5) Coordinate development of the SF Bay NNE workplan with nutrient management activities in Sacramento and San Joaquin Delta. **The SF Bay Technical Advisory Team assumed the San Francisco Bay Water Board will prioritize these next steps, with review/feedback from its advisory groups.**

Develop an NNE assessment framework for SF Bay

Development of an NNE assessment framework for SF Bay involves specifying how primary and supporting indicators would be used as multiple lines of evidence to diagnose adverse effects of eutrophication. The table below summarizes data gaps and recommended next steps for development of an SF Bay NNE assessment framework by habitat type. Data gaps and recommendations generally fall into four categories: 1) Monitoring to assess baseline levels of indicators of interest where data are currently lacking, 2) Analysis of existing data, 3) Field studies or experiments to collect data required for endpoint development, and 4) Formation of expert workgroups to recommend approach to assessment framework development and synthesize information to be used in setting numeric endpoints.

Type	Indicator	Designation	Data Gaps	Recommended Next Steps
Subtidal Habitat	Dissolved oxygen	Primary	Wealth of data exists. Technical Advisory Team does not have expertise to review adequacy of DO objectives. Review did not address dissolved oxygen data in the tidally muted habitats of SF Bay.	Consider update of science supporting Basin Plan dissolved oxygen objectives, if warranted by additional review by fisheries experts. Review could be for entire Bay or limited to the tidally muted areas of the Bay.
	Phytoplankton biomass , productivity, and assemblage	Primary	Need a review of science supporting selection of endpoints. Improved prediction of factors controlling assemblage	Recommend development of a white paper and a series of expert workshops to develop NNE assessment framework for phytoplankton biomass, productivity, taxonomic composition/assemblages,

Type	Indicator	Designation	Data Gaps	Recommended Next Steps
	HAB species abundance and toxin conc.	Cyanobacteria = primary; Other HAB =supporting	Little data on HAB toxin concentrations in surface waters and faunal tissues.	abundance and/or harmful algal bloom toxin concentrations. Recommend augmentation of current monitoring to include measurement of HAB toxin concentrations in water and faunal tissues.
Subtidal Habitat (Continued)	Ammonium and urea	Supporting	Lack of understanding of importance of ammonia limitation of nitrate uptake in diatoms on Bay productivity vis-à-vis other factors. Lack of data on urea in SF Bay	Recommend formulation of a working group of SF Bay scientists to synthesize available data on factors known to control primary productivity in different regions in the Bay, and evaluate potential ammonium endpoints. Recommend collecting additional data on urea concentrations in SF Bay via USGS's water quality sampling over a two year period.
	Macrobenthos taxonomy, abundance and biomass	Co-factor	Lack of information on how to use combination of taxonomy, abundance, and biomass to assess eutrophication	Recommend utilization of IE-EMP dataset to explore use of macrobenthos to be used reliably to diagnose eutrophication distinctly from other stressors in oligohaline habitats. This may involve including biomass in the protocol to improve ability to diagnose eutrophication.
Seagrass Habitat	Phytoplankton biomass, epiphyte load and light attenuation	Phytoplankton biomass = primary, epiphyte load and light attenuation = secondary	Poor data availability of data on stressors to SF Bay seagrass beds. Studies needed to establish light requirements for seagrass and to assess effects of light attenuation	Recommend 1) Continued monitoring of aerial extent of seagrass every 3-5 years (currently no further system scale monitoring is planned beyond 2010), 2) studies to establish light requirements for SF Bay seagrass species, 3) development of a statewide workgroup to develop an assessment framework for seagrass based on phytoplankton biomass, macroalgae, and epiphyte load and 4) collection of baseline data to characterize prevalence of macroalgal blooms on seagrass beds. Studies characterizing thresholds of adverse effects of macroalgae on seagrass currently underway in other California estuaries should be evaluated for their applicability to SF Bay.
	Macroalgae biomass and cover	Primary	Data gaps include studies to establish thresholds of macroalgal biomass, cover and duration that adversely affect seagrass habitat	
Intertidal Flat Habitat	Macroalgal biomass and cover	Primary	Lack of baseline data on frequency, magnitude (biomass and cover) and duration of macroalgal blooms in these intertidal flats	Recommend collection of baseline data on macroalgae, microphytobenthos and sediment bulk characteristics. Recommend inclusion of SF Bay scientists and stakeholders on statewide workgroup to develop an assessment framework for macroalgae on intertidal flats.
	Sediment nutrients	Supporting		
	MPB taxonomy and biomass	Supporting		

Type	Indicator	Designation	Data Gaps	Recommended Next Steps
Muted Subtidal Habitat	Macroalgae	Primary	Lack of baseline data on biomass and cover in muted habitat types	Recommend collection of baseline data on macroalgae, dissolved oxygen, phytoplankton biomass, taxonomic composition and HAB species/toxin concentration in these habitat types. Recommendation to develop an assessment framework based on macroalgae, phytoplankton and dissolved oxygen in these habitat types. One component of this discussion should be a decision on beneficial uses that would be targeted for protection and to what extent the level of protection or expectation for this habitat type differ from adjacent subtidal habitat.
	Phytoplankton biomass, assemblage, HAB toxin conc.	Phytoplankton biomass, cyanobacteria = primary; assemblage and other HABs= supporting	Lack of baseline data on biomass and community composition, HAB toxin concentrations	
	Dissolved oxygen	Primary	Some data on dissolved oxygen exist. Unclear what levels of DO required to protect muted habitat beneficial uses	

Quantify Nutrient Loads

The table below provides a summary of data gaps and recommended next steps. Recommendations generally fall into two categories: 1) Revising and updating estimates of nutrients from the different sources, based on existing data and 2) Identification of data needed to develop a dynamic loading model.

Source	Data Gaps Identified	Recommended Next Steps
Atmospheric Deposition	No recently published data on wet & dry atmospheric deposition	Loads likely relatively small. Literature review to determine range of N and P deposition rates for West Coast coastal urban areas. Recommend baseline atmospheric deposition monitoring of wet and dry N and P deposition over 1-2 year period to better constrain estimates.
Terrestrial Loads from Delta	Dry weather concentrations available through RMP. No data available on wet weather concentrations	Loads likely large. Recommend analysis of existing RMP data to estimate dry weather nutrient loads. Initiate wet weather data collection of nutrients at the Mallard Island DWR sampling location (head of Suisun Bay) to support improved daily loads estimates for 1995-present.

Municipal Effluent	Data available through 15 of approx. 40 Publicly Owned Treatment Works	Loads likely large. Synthesize nutrient discharge and concentration data to estimate loads over period of last 10-20 years. Encourage all treatment plants that discharge to the Bay to begin analyzing effluent for total and dissolved inorganic nutrients and to submit these data to the SFRWQCB on a regular basis. Recommend that the POTWs conduct a laboratory inter-comparison on nutrient methods to assure comparability of estimates.
Industrial Effluent	Some data available from the 1990s	Loads likely small relative to municipal wastewater. Synthesize available data to provide information for prioritization of any future steps.
Stormwater	Lack of wet weather data sufficient to develop a dynamic loading model	Loads likely large. Synthesize data to provide an updated estimate of stormwater contributions to assist prioritization of next steps. Scope the data needs associated with the development of a dynamic loading model.
Groundwater	Data available from 79 USGS monitoring stations. Flow data not well understood	Loads likely small. Refine current loads estimates after review by local USGS groundwater experts in order to support prioritization of next steps if any.
Exchange with Coastal Ocean	Some data available for fluxes of water and sediments during selected tides and seasons	Initiate a workgroup of local experts to design a sampling program for nutrient flux at the Golden Gate boundary. The intent with this program would be to develop models that simulate flux at the ocean-bay interface.

Develop Load-Response Models

An important component of implementing the NNE framework in SF Bay is the development of load-response models that can simulate the ecological response of the Estuary to nutrients and other important co-factors. Several types of models need to be developed, fitting into two general categories: 1) Air, oceanic and watershed loading model(s), which estimate the amount of nutrients and sediment reaching the SF Bay estuary and where they originate, and 2) an Estuary water quality model, which simulates the ecosystem response to nutrient loads and other management controls. Sufficient data and knowledge of SF Bay must exist to support the development of system wide dynamic simulation models to predict phytoplankton biomass/community response and relationships to models of secondary productivity. This is not likely in the short term, so it is important to consider that the development of a more complex model should follow the testing out of key concepts and assumptions in smaller, simpler models.

Scoping the development of these NNE load response models should begin through use of empirical data and studies to develop coarse nutrient budgets for SF Bay. Existing data that describe the timing and magnitude of external sources, internal sources, sinks, and pathways of transformation such as benthic nutrient flux, nitrification, denitrification, etc. would be compiled in order to synthesize current understanding of sources and fate of nutrients as well as identify critical data gaps in advance of the modeling strategy development.

Second, a review of existing models and their applications should be undertaken, with the intent of understanding what existing tools may be used to leverage efforts.

During this strategy workshop, participants would describe the modeling objectives, determine whether existing tools can be used in this effort, identify key data gaps and studies, and identify additional work elements needed to begin this major work element. The product of this effort would be the identification of the appropriate models, a phased workplan, timeline and budget to develop these models, and identification of and coordination among key institutions, programs and stakeholders. This information could be synthesized into a workplan to develop the loading and estuary water quality models and a preliminary timeline and budget for Phase I of the effort.

Conduct a Monitoring Program to Develop and Implement the NNE Framework in SF Bay

The development and use of an NNE framework for San Francisco Bay is completely contingent on the continued availability of monitoring data to formulate, test and periodically assess the status of the Bay with respect to eutrophication. Over the past forty years, the USGS has conducted a research program in the subtidal habitat of SF Bay, with partial support by the SF Bay Regional Monitoring Program (RMP) since 1993. This USGS research program cannot be considered replacement for a regularly funded monitoring program. The SF Bay Technical Advisory Team strongly recommends that a nutrients/eutrophication monitoring strategy be developed and funded for successful development and implementation of the NNE in SF Bay.

Coordinate Development of the SF Bay NNE Framework with Nutrient Management in the Delta

Development and implementation of a NNE framework for SF Bay will require improve coordination with nutrient management activities in the San Joaquin and Sacramento River Delta. Preliminary discussions on this topic have just begun with the Central Valley Water Board staff. Other entities, for example, the Interagency Ecological Program should be engaged. Coordination should be improved, at minimum, with respect to any future monitoring and/or modeling of nutrient loading, transport and source identification, as SF Bay and the Delta exchange nutrients across their aquatic and terrestrial boundaries. Coordination would be further enhanced by a similar review of NNE candidate indicators, summary of existing science, and identification of data gaps and recommended next steps specifically for the Delta.

Full Text

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/644_SFBayNNE_LitReview.pdf