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San Francisco Bay Nutrient Management Strategy

San Francisco Bay Regional Water Quality Control Board

This document was prepared collaboratively by the San Francisco Bay Regional Water Quality Control Board, the San Francisco Estuary Institute and the Southern California Coastal Water Research Project with input from stakeholders, and funding support from the State Water Board and the Bay Area Clean Water Agencies (BACWA)

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1. Purpose of the Nutrient Strategy

This document presents a draft strategy for developing the science needed to make informed decisions about assessing nutrient impacts on water quality, protecting beneficial uses, and managing nutrient loads to San Francisco Bay. The document first provides relevant background, after which management decisions related to nutrients are highlighted. The document then lays out a plan, developed collaboratively by the San Francisco Regional Water Quality Control Board (Water Board) and Bay stakeholders, for the technical studies required to support decisions regarding nutrient management.

2. Background

San Francisco Bay has long been recognized as a nutrient-enriched estuary. Nonetheless, dissolved oxygen concentrations found in the Bay's subtidal habitats are much higher and phytoplankton biomass and productivity are substantially lower than would be expected in an estuary with such high nutrient enrichment, implying that eutrophication is controlled by processes other than straightforward nutrient-limitation of primary production. The published literature suggests that phytoplankton growth and accumulation are largely controlled by a combination of factors, including strong tidal mixing, light limitation due to high turbidity, and grazing pressure by clams (Cloern et al. 2012)

There is a growing body of evidence that suggests the historic resilience of San Francisco Bay to the harmful effects of nutrient enrichment is weakening. Since the late 1990's, regions of the Bay have experienced significant increases in phytoplankton biomass (30-105% from Suisun to South Bay) and significant declines in DO concentrations (2% and 4% in Suisun Bay and South Bay, respectively; J. Cloern, unpublished data). In addition, an unprecedented autumn phytoplankton bloom in October of 1999, and increased frequency of cyanobacteria and dinoflagellate (2004 red tide event) blooms occurring in the North Bay, further signal changes in the Estuary.

The indications of decreased Bay resilience have come to the fore at a time when the availability of resources to continue assessing the Bay's condition is uncertain. Since 1969, a USGS research program has supported water-quality sampling in the San Francisco Bay. This USGS program collects monthly samples between the South Bay and the lower Sacramento River to measure salinity, temperature, turbidity, suspended sediments, nutrients, dissolved oxygen and chlorophyll a. The USGS data, along with sampling conducted by the Interagency Ecological Program, provide coverage for the entire San Francisco Bay –Delta system. The San Francisco Bay Regional Monitoring Program (RMP) has no independent nutrient-related monitoring program, but instead contributes approximately 20% of the USGS data collection cost. Thus, there is currently an urgent need to lay the groundwork for a locally-supported, long-term monitoring program to provide information that is most needed to support nutrient-related management decisions in the Bay.

The timing also coincides with a major state-wide initiative, led by the California State Water Resources Control Board (State Board), for 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 a waterbody to nutrient over-enrichment and eutrophication (e.g. excessive algal blooms, decreased 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 guidance to translate narrative water quality objectives.

Since San Francisco Bay is the State's largest estuary, and one for which there is currently a relative wealth of data, it became a primary focus of a state-wide effort to develop NNEs for estuaries. This San Francisco Bay effort was initiated by a literature review and data gaps analysis to recommend indicators to assess eutrophication and other adverse effects of anthropogenic nutrient loading in San Francisco Bay and summarize existing literature in the Bay using these indicators and identify data gaps (McKee et al., 2011). The review made five major recommendations: 1) develop an NNE assessment framework for the 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, and 5) coordinate development of the Bay NNE workplan with nutrient management activities in Sacramento and San Joaquin Delta. The San Francisco Bay Water Board is the State lead for the current effort to develop San Francisco Bay nutrient water quality objectives.

At an RMP-sponsored workshop on nutrient management in the Bay (June 29-30, 2011), participants engaged in monitoring activities in the Bay-Delta were convened on day two to discuss elements of a monitoring strategy. They agreed that developing a NNE assessment framework and funding of a monitoring program were priorities, but that these efforts must begin with spatially–explicit conceptual models of the linkages between nutrient loads, ecological response indicators and Bay beneficial uses.

Another issue that has come to the attention of the Water Board and local stakeholders is that of the potential impact of ammonia/ammonium on Bay beneficial uses. While the USGS has documented a loss of resiliency throughout San Francisco Bay, productivity in Suisun Bay continues to be lower than the South Bay. Recent studies argue that elevated levels of ammonium limit primary productivity in Suisun Bay (Dugdale et al., 2007, 2012; Parker et al., 2012a), and perhaps elsewhere in the Estuary (Parker et al., 2012b). There is currently disagreement within the scientific community about the potential role ammonium plays in limiting primary productivity. To help resolve the issue, the Water Board supported studies in Suisun Bay in 2010 that explored the relationship between ammonium concentrations, nitrogen uptake, and phytoplankton biomass; in the spring of 2011 the Water Board initiated a two-year follow-up study. Additional follow-up studies that are currently underway or planned include toxicity tests and TIE method development to identify the cause of inhibition of diatom growth in Suisun, studies to evaluate copepod toxicity due to ammonium, spiking studies, investigations into the potential influence of nutrient ratios on system response, and the importance of nutrient fluxes from sediments. These data and information from additional studies being conducted in the Delta should be reviewed, synthesized and a process should be developed to resolve these outstanding questions and concerns about ammonium.

In addition, given that several factors (light-limitation/turbidity; grazing pressure by clams; tidal mixing) contribute to maintaining phytoplankton biomass at relatively low levels in this otherwise nutrient-rich estuary, improved understanding is needed with regards to the relative importance of these factors, including temporal and spatial considerations, and regarding susceptibility to future changes in the level of control they exert (e.g., decreases in suspended sediment loads).

Considering the compelling evidence of changing conditions in San Francisco Bay, uncertainty about future monitoring programs, and new nutrient policies on the horizon, there is a strong need for a coherent nutrient science and management strategy for the Bay. Section 3 identifies upcoming management decisions related to nutrient overenrichment and eutrophication. Section 4 lays out the goals of the nutrient strategy and a plan, developed collaboratively by the Water Board and Bay stakeholders, for the technical studies required to support decisions regarding nutrient management. The current version of the strategy focuses on priority work elements within a five-year planning horizon, with the recognition that this work will extend beyond that time period and will build upon these foundational early efforts. Some commitments have already been made by various groups to fund or undertake priority tasks. These efforts will be tracked as part of the program management work element of this strategy.

There is considerable ongoing research on the role of nutrients in a changing San Francisco Bay ecosystem. Given that this is the case, this nutrient science and management strategy will likely require modification as new information becomes available. While the strategy has a five-year planning horizon, it will remain flexible and adapt to new information.

3. Key Nutrient Management Decisions and Questions

Several key management decisions and questions provide the context for the San Francisco Bay nutrient management strategy. The primary anticipated management decisions include:

1) Establishing Bay nutrient objectives
2) Evaluating the need for revised objectives for dissolved oxygen (in sub-habitats) and ammonium/ammonia
3) Developing and implementing a nutrient monitoring program
4) 303(d) listing decisions for the adverse effects of nutrients – whether impairment exists currently or is forecast in the future
5) Specifying nutrient limits in NPDES permits (e.g. municipal and industrial wastewater and municipal stormwater permits) as well as determining additional data collection needs

6) Determining whether management actions are necessary to prevent or address nutrient enrichment impacts and if so, the schedule, and nature for municipal wastewater treatment plant upgrades and stormwater treatment

Nutrient management issues may be influenced by, or can influence to some degree, decisions on other issues, such as the regulation of freshwater flow from the Delta, a regional sediment management strategy, recycling of wastewater, management of nutrient loading to the Delta, wetland restoration, and the development of nutrient TMDLs, e.g., Suisun Marsh, Sonoma Creek and Napa River.

These upcoming decisions are the foundation for five key management questions that, in turn, drive the elements of the nutrient strategy, and correspond to the recommendations laid out in a recent literature review and data gap analysis that was conducted as an early step in the NNE process (Table 1 below; McKee et al., 2011).

Table 1. Summary of management questions developed with input from the Nutrient Workgroup, and corresponding recommendations from the San Francisco Bay NNE literature review (McKee et al. 2011)

Type	Management Question	Recommendation From McKee et al. 2011 Review
Status and trends	Is there a problem or are there signs of a problem? Are trends spatially the same or different in San Francisco Bay? a. Is eutrophication currently, or trending towards, adversely affecting beneficial uses of the Bay? b. Are beneficial uses in segments of San Francisco Bay impaired by any form of nutrients (e.g. ammonium)? c. Are trends spatially the same or different in San Francisco Bay?	Implement a monitoring program to support regular assessments of nutrient support for the Bay beneficial uses. Coordinate with Delta nutrient monitoring and management.
Objectives	What are appropriate guidelines for identifying a nutrient-related problem?	Establish a nutrient assessment framework for the Bay
Sources and Pathways	Which nutrient sources, pathways, and cycling processes are most important to understand and quantify? (Get the loads right!) a. What is the relative contribution of each loading pathway (municipal wastewater, Delta inputs, NPS, etc.)? b. What are contributions of internal sources (e.g. benthic fluxes) from sediments and sinks (e.g. denitrification) to the Bay nutrient budgets?	Quantify external sources of nutrients to the Bay and develop a spatially-explicit budget of the Bay.
Fore-casting	What nutrient loads can the Bay assimilate without impairment of beneficial uses?	Develop load-response models
	What is the likelihood that the Bay will be impaired by nutrient overenrichment/eutrophication in the future?	

4. Nutrient Strategy Goals and Work Elements

Generating the scientific understanding needed to fully support all of the management decisions and questions will likely take a decade or more, and will require a significant investment of resources. Therefore, it is imperative that a well-reasoned and cost-effective nutrient strategy be adopted that identifies logical first steps, leverages existing resources, requires development of a funding plan and incorporates elements of adaptive management.

With this philosophy in mind, the five-year strategy has six principal goals:

1. Define the problem (develop conceptual models, synthesize and interpret the available data)
2. Establish guidelines (water quality objectives; i.e., assessment framework) for eutrophication and other adverse effects of nutrient overenrichment, including ammonium;
3. Implement a monitoring program that supports regular assessments of the Bay;
4. Develop and utilize nutrient-load response models to support nutrient management decisions;
5. Evaluate control strategies to reduce nutrient inputs from wastewater treatment plants and other sources; and
6. Consider alternative regulatory scenarios for how to move forward with nutrient management in SF Bay.

Work elements and a list of major tasks associated with each goal are detailed in the sections below. Workplans and/or scopes of work will be developed to accomplish many of the tasks in this strategy and stakeholder review is necessary step in the process. The phasing and timeframe of these work elements and major tasks is provided in Table 2.

WORK ELEMENT 1. NUTRIENT PROGRAM ADMINISTRATION

The SFB Nutrient Management Strategy is being developed and implemented through a collaborative process between the Water Board and multiple partners and stakeholders.Generating the scientific understanding needed to fully support all of the management decisions and questions will likely take time and significant resources, and will involve complex decisions. This work element lays out the basic components of the program for implementing the Nutrient Strategy.

Task 1.1 Develop Governance Structure

A straightforward and transparent governance and decision-making structure for funding and implementing the Nutrient Strategy is needed to

- maximize the effectiveness of stakeholder input;
- identify and allocate limited resources toward research, monitoring, and modeling that will most effectively inform management decisions;
- determine when it is appropriate to carry out external scientific review of approaches that are developed within key work elements (e.g., assessment framework, monitoring, modeling), and major work products, including scientific studies, and what the process for these reviews will be.

Task 1.2 Develop Funding Plan

While this document focuses in detail on activities that should be completed during the next 5 years, implementation of the Nutrient Strategy work elements will likely be a carried out over a substantially longer period. The cumulative costs of sustaining the nutrient-related research, monitoring, and modeling are anticipated to be high. SFB is an ecosystem of regional, state-wide, and national significance, and a valued resource for both the public and private sectors.

As such, a funding plan will be developed that casts a wide net, targeting resources from the discharger community, federal science agencies (e.g., NSF, NOAA), state funding, and foundations, as well as developing partnerships with other SFB science and monitoring programs, and partnerships with regional university and research institutes. This task involves developing initial costs estimates of the work, developing a funding plan, and on-going fundraising.

Task 1.3 Nutrient Program Management

This task involves managing the Nutrient Strategy implementation. Activities will include scientific oversight, stakeholder engagement, coordinating SAG meetings, coordinating external scientific review, information dissemination, fundraising, and overall program management (e.g., overseeing projects, project and contract management).

WORK ELEMENT 2. DEFINE THE PROBLEM

Task 2.1 Develop Conceptual Models of Ecosystem Response to Nutrient Loads

The goal of this task is to develop conceptual models for SFB that characterize important processes linking nutrient and organic matter loading, biological responses, and indicators of adverse effects of nutrient over-enrichment.

The approach to nutrient objectives proposed for San Francisco Bay involves: 1) the use of response indicators to diagnose adverse effects from nutrient overenrichment in an assessment framework 2) the use of models to link response indicators to nutrient loads that will sustain and protect beneficial uses. The conceptual models developed in this task are needed to confirm appropriate indicators and their linkages to SF Bay beneficial uses; identify the spatial and temporal scales of importance in monitoring; and frame the questions that may eventually be explored through quantitative modeling efforts. The conceptual models will identify the key drivers/factors that need to be incorporated into models (e.g., internal processes of biogeochemical cycling of nutrients and carbon, including important internal sources and sinks, important physical drivers, and interactions between nutrients and other stressors). Because of the large differences in hydrography and nutrient dynamics between regions of the Bay, the Bay will be divided into a manageable number of segments and habitat-types, and conceptual models will be evaluated across these sub-embayments and habitat types.

Task 2.2 Develop Problem statement and future scenarios

A problem statement will be developed for SFB that addresses the question “If SFB had a nutrient problem, how would it manifest itself?” A nutrient problem can take multiple forms, and the form(s) may vary by subembayment, habitat, and seasonally. The problem statement will address this spatial and seasonal variability, and be linked to beneficial use impairment.

With the problem statement identifying states of the SFB ecosystem that would result in beneficial use impairment, and the conceptual models from Task 2.1 serving as a framework for evaluating change, a list of plausible future scenarios for the Bay will be developed that identify changes that could lead to a problem, and changes under which a problem would be less likely to occur. Two broad categories of scenarios are envisioned: i) changes in management actions (e.g., increases or decreases in nutrient loads via various sources, changes in the timing or quantity of freshwater flows); and ii) changes in environmental factors outside of human control (e.g., changes in suspended sediment load and water clarity, changes in temperature, interannual variability in freshwater flow, large-scale climate forcings and climate change).

The combination of the conceptual models and evaluation of future scenarios will assist in visualizing the spectrum of current, suspected, or potential future sources of impairment.

Task 2.3 Synthesize and Interpret Existing Ambient Water Quality Data and Identify Major Data or Conceptual Gaps in Bay Response to Nutrients

Through nearly 40 years of Bay-wide research by the USGS[1], and nearly 40 years of California-sponsored research and monitoring in northern San Francisco Bay and the Delta[2], there is an enormous archive of nutrient and phytoplankton related data. Some of this data has been analyzed in scientific publications. Other data has received limited attention to date.

This task will synthesize and interpret nutrient and phytoplankton-related data in SFB’s subembayments. The data will be interpreted within the context of the conceptual models developed in Task 2.1, and where necessary conceptual models will be modified to reflect new insights. Goals will include: i) identifying spatial, seasonal, and temporal trends in ecosystem condition or response; ii) developing improved understanding of ecosystem response to nutrients; and iii) compiling and preparing data for eventual use in numerical modeling.

Based on analysis in Tasks 2.1-2.2, this task will also identify major data and knowledge gaps, and identify monitoring priorities and additional scientific investigation (e.g., Special Studies) that will be required in order to adapt conceptual models into quantitative models (Work Element 6).

Task 2.4 Develop Nutrient Loading Conceptual Model

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[1] http://sfbay.wr.usgs.gov/access/wqdata/index.html
[2] http://www.water.ca.gov/iep/products/data.cfm

A conceptual model for external loads to SFB will be developed that considers major sources and pathways through the watershed, airshed, and oceanic sources. This conceptual model will identify differences in important loads between subembayments.

Task 2.5 Synthesize Existing Loading Data, Identify Data Gaps, and Refine load estimates

The purpose of this task is to synthesize existing information to develop, to the extent possible, spatially and temporally explicit estimates of nutrient and organic carbon external loads via major pathways. This task will also identify major data gaps that contribute to current uncertainty in total loads, speciation of those loads, and the relative importance of various sources. In addition, the Water Board is requiring a two year effluent characterization data collection effort (July 2012 through 2014) by Bay area municipal wastewater dischargers and industrial dischargers which can be used to refine the wastewater load estimates

WORK ELEMENT 3. NUTRIENTS AND POTENTIAL IMPAIRMENT IN SUISUN BAY

The Interagency Ecological Program's (IEP) conceptual model for the Pelagic Organism Decline (POD) recognizes that multiple factors may be acting in concert to degrade habitat and contribute to the sudden decline in native and non-native pelagic fish species (Baxter et al., 2010) in Suisun Bay and in the Delta. Factors considered include physical alterations to habitat; water withdrawals and changes in flow regime; land use changes; invasive species (including the Asian overbite clam, *Potamocorbula amurensis*, and multiple invasive copepods and other zooplankton); and changes in nutrient concentrations. Recent studies have argued that anthropogenic nutrient loads, in particular ammonium (NH4), play a role in ecosystem change and degradation. Dugdale et al (2007, 2012) and Parker et al. (2012a,b) present the case that elevated NH4 concentrations in Suisun and the Delta inhibit primary productivity (Dugdale et al., 2007; Parker et al., 2012a,b), and potentially contribute to low phytoplankton biomass in Suisun, with cascading effects up the food web. Elevated NH4 levels have been suggested to contribute to the increased frequency of *Microcystis* blooms in the Delta (Lehman et al., 2008). Changes in nutrient ratios (N:P) and forms of N have been hypothesized to be exerting additional bottom-up pressures on Delta and Suisun food webs, through influencing phytoplankton community composition and other pathways (e.g., Glibert et al., 2011).

Given the scientific and regulatory attention that issues such as elevated NH4 and shifts in N:P are receiving in Suisun Bay, and in order to resolve the differing scientific perspectives on the issues, a separate work element was created. Nutrient related issues can be divided into four broad categories: 1. NH4 inhibition of primary production; 2. NH4 toxicity to copepods (e.g., Teh et al., 2011); 3. NH4 concentration increases and N:P shifts, and effects on phytoplankton community composition and the Suisun/Delta food web; and 4. other potential causes of low primary productivity in Suisun. A detailed accounting of all relevant projects and their timelines is beyond the scope of this document, but is under development in Task 3.2.

Task 3.1 Field studies and experiments to assess potential impairment due to elevated ammonium or changes in N:P

A number of field and laboratory studies are underway, some affiliated with the Nutrient Strategy (e.g., SWAMP Suisun Bay studies) or funded by the Delta Science Program or the State and Federal Contractors Water Agency (SFCWA). Other studies are currently under review, planned or are funded and slated to start in late 2012 or 2013. These studies will be tracked, results synthesized (Task 3.2), and where applicable conceptual models will be refined to incorporate new understanding.

Task 3.2 Synthesis of Research to Date and Suisun Ambient Water Quality Data

A series of synthesis reports will be prepared on the following topics: 1.) NH4 inhibition of primary production; 2.) NH4 toxicity to copepods; and, 3.) NH4 concentration increases and N:P shifts, and effects on phytoplankton community composition and the Suisun/Delta food web.

These reports will summarize results of peer-reviewed studies or reports from Suisun and the Delta to date, as well as relevant studies from other systems. In addition to reviewing published work, new analyses and data interpretation will be carried out, utilizing the abundant monitoring data collected by IEP/DWR and USGS, with the goal of characterizing temporal and seasonal trends, quantifying loads and internal transformations of nutrients, and using statistical tools to identify potential causal mechanisms underlying ecosystem change.

Task 3.3 Assess Science Related to Ecosystem Impacts in Suisun Bay and Relationship to Nutrients

An approach is necessary to resolve issues that have been raised relative to nutrient impacts in Suisun Bay and develop a coordinated science plan. The strategy recommended here is to convene one or more expert panels and sponsor technical workshop(s) to address the three broad categories of proposed nutrient-related impairment in Suisun Bay. The goals of these expert panels will include: 1. evaluating existing scientific evidence for nutrient-related impairment in Suisun Bay; 2. identifying areas of agreement and disagreement within the scientific literature and among the regional research community; 3. recommending studies that can address critical conceptual gaps and data gaps. The results of these panels and the reports from Task 3.2 will be used to refine conceptual models and inform monitoring and special studies (Work Element 5) and modeling (Work element 6). Consideration will be given to involving an external third party, e.g., the Delta Science Program or the USEPA or some other entity in convening or sponsoring the technical workshops.

WORK ELEMENT 4. ESTABLISH GUIDELINES

The purpose of this work element is to develop the technical foundation for policy decisions to establish nutrient-related water quality objectives. This strategy assumes that the development of nutrient related water quality objectives would be accomplished using an approach consistent with the "nutrient numeric endpoint framework"—the numeric guidance that would serve as a means to translate narrative nutrient water quality objectives. This numeric guidance will be centered on an "assessment framework," a structured set of indicators and associated thresholds that can be used to categorize potential ecological states of the Bay from supporting to impairment of beneficial uses. These assessment frameworks also specify the spatial and temporal density and types of data needed to make an assessment of beneficial uses support.

The Bay NNE literature review and data gaps analysis proposed a suite of indicators appropriate to assess the effects of eutrophication and other adverse effects of nutrients on Bay beneficial uses (McKee et al. 2011). Indicators were proposed for three principal habitat types: 1) subtidal unvegetated habitat, 2) vegetated subtidal (seagrass and other SAV), and 3) intertidal flats. The review proposes specific tasks to develop the NNE assessment framework for each habitat types. These tasks are given in Table 3. An initial rank of high, medium, and low priority was assigned to each by the Water Board. Prioritization of work elements reflects: 1) percentage of habitat type represented in the Bay and 2) best professional judgment as to whether an indicator represents the most sensitive assessment of potential impacts to beneficial uses. Based on these two criteria, phytoplankton (biomass and community composition), dissolved oxygen, HABs and HAB toxins were the primary NNE indicators of interest in unvegetated subtidal habitat. Ammonium, N:P ratio and other nutrient forms are also indicators of interest, pending the outcome of studies being conducted in Suisun Bay (see Work Element 3) and assessment by a working group of scientists.

Indicators representative of other habitat types such as intertidal flats and seagrass are of high interest in the Bay as well as other estuaries around the state. Several studies are ongoing to support decisions on NNE thresholds in California estuaries outside of the Bay. Thus, these work elements are designated as moderate priority, with the intention of evaluating the applicability of these studies to assessment of these habitats in San Francisco Bay sometime in the future.,

Five tasks were designated as high priority and as such they are components of planned activities during the first four years.

Task 4.1 Nutrient Assessment Framework

The purpose of this task is to develop an assessment framework that considers the use of phytoplankton, algal toxins and nutrient forms (e.g. ammonium and other nutrient species or ratios) to assess the condition of the Bay. This will be done by choosing the precise indicators and metrics; specifying how and when they will be measured; and creating decision rules for how the indicators will be combined in order to classify Bay segments into categories of degree of beneficial use support (from supporting to impairing beneficial uses). Existing data on phytoplankton, nutrients and other co-factors will be used to graphically illustrate options with respect to how to use data to make an assessment.

Task 4.2 Review of Dissolved Oxygen Objectives

McKee et al. (2011) found that dissolved oxygen monitoring data taken along the longitudinal "spine" of the SF Bay typically meets established DO objectives. However, SF Bay dissolved oxygen objectives were established in the first Basin Plan in 1975 and the science of supporting derivation of dissolved oxygen objectives has evolved considerably since that time. The main focus of this review is on the application of the DO objectives to shallow water habitats, tidal marshes, managed ponds and tidal sloughs, although it can be argued that a comprehensive review should be conducted. Near-term tasks consist of: 1) synthesizing existing dissolved oxygen data; and 2) evaluating the adequacy of existing dissolved oxygen objectives.

4.2a Synthesize existing dissolved oxygen data

This task will synthesize existing dissolved oxygen data Bay-wide and for specific habitats, such as tidal sloughs, and shallow subtidal areas. This topic was not covered in the Bay NNE literature review and data gaps analysis (McKee et al. 2011). The synthesis effort will include analysis of data currently being collected (since 2011) at 6 USGS moored stations (DO, chlorophyll, and fluorescence), as well as other data sources, including historical studies conducted in the Lower South Bay. This synthesis will assess status and trends of dissolved oxygen relative to Basin plan standards, and will assess whether objectives are being met and whether there is evidence of impairment.

4.2b Evaluate existing dissolved oxygen objectives

The purpose of this task is to synthesize data on dissolved oxygen requirements of species representing the variety of beneficial uses in SF Bay and to inform whether there is a need to revise dissolved oxygen objectives for SF Bay. The product would be a report that synthesizes methodology, summarizes availability of DO tolerance data for key indicator species, and, assuming data are available, calculates DO criteria protective under acute and chronic conditions for the range of beneficial uses represented in SF Bay. To the extent feasible, this analysis will also qualitatively consider naturally occurring low oxygen (e.g., in tidal wetlands or in waters exiting naturally low-oxygen habitats) versus low oxygen due to anthropogenic perturbations. Depending on available resources, this work may be phased so that shallow subtidal areas and tidal sloughs are initially the focus of the review. Based on the synthesis in subtask 4.3b, data gaps will be identified and, if necessary, recommendations for additional data collection to support the derivation of DO criteria will be made.

Task 4.3 Macroalgal Assessment Framework

The objectives of this task are: 1) to document baseline abundance of macroalgae in a variety of habitat types and regions of the Bay and 2) participate in statewide effort to develop an assessment framework for eutrophication in intertidal flats and shallow subtidal habitat, based on macroalgae. The intent is that progress on this work element would be monitored for applicability to the Bay and that SF Bay stakeholders have the opportunity to comment on studies supporting these work elements, while progress is made on other tasks.

WORK ELEMENT 5. MONITORING PROGRAM DEVELOPMENT AND IMPLEMENTATION

The purpose of this work element is to develop the San Francisco Bay monitoring program. Targeted habitats include unvegetated and vegetated subtidal and mudflat habitat in the Bay. Managed pond habitats will be excluded, as this habitat type will be addressed in a separate work element in the strategy. Two major tasks are associated with this work element.

Task 5.1 Develop a Monitoring Program

5.1a Identify elements of a core SF Bay monitoring program to assess status and trends of loads and Bay response.

The purpose of this task is to recommend specific indicators and methods, spatial and temporal density of sampling that should be included in a “core” monitoring program to make regular assessments of the status of the Bay with response indicators and to assess trends in external nutrient loads and response. An evaluation of existing monitoring data (predominantly USGS data) collected in the Bay will be considered, along with the potential for maximizing synergies and leveraging resources. The product of Task 5.1a will be used to develop a detailed nutrient monitoring program for the Bay (5.1c). This task will involve bringing together local or national level scientists and managers to determine the core elements of a SF Bay monitoring program, including spatial and temporal considerations, including the consideration of how to optimize the use of moored stations and boat cruise sampling collection efforts. In addition, decisions will need to be made on the spatial extent of the monitoring program, and how to coordinate monitoring efforts in the estuary and share data across programs.

Load monitoring may be included as an element of the monitoring program for point and non-point sources, including stormwater, wastewater, agriculture and Delta inputs to the northern estuary.

5.1b Develop a program of special studies to improve fundamental understanding and quantification of processes in the system

In addition to status and trend monitoring, special studies will be carried out to address fundamental data or conceptual gaps that need to be filled to support the assessment framework and model calibration and validation. Data or conceptual gaps identified in any of work completed under this strategy will be compiled and prioritized as part of this task.

5.1c Develop San Francisco Bay nutrient monitoring program Work Plan and QAPP

The purpose of this work element is to develop the work plan and quality assurance project plan (QAPP) for the Bay nutrient monitoring program. The work plan and QAPP covers monitoring to assess status and trends in external nutrient loads and ecosystem response of the Bay to those loads. This task includes development of field, sampling handling, laboratory analyses, data management and reporting procedures for data collection.

Task 5.2 Implement the San Francisco Bay nutrient monitoring program

The expectation is that the existing monitoring program currently conducted by the USGS will transition over a number of years to this locally sponsored program. The program is anticipated to be adaptively managed.

WORK ELEMENT 6. MODELING PROGRAM DEVELOPMENT AND IMPLEMENTATION

The purpose of this work element is to develop models to forecast the nutrient and carbon sources, pathways, and loads to SF Bay, and simulate the ecological response to those loads and other environmental factors in the Bay. These models will be used to engage stakeholders in discussion of options for nutrient management under a variety of different scenarios. Previous work elements will define conceptual models and scenarios of interest (Work Element 1), and management endpoints of concern (Work Element 2).

Task 6.1 Modeling of External Sources

Task 6.1a Basic Loading Estimates or Modeling

Building on the loading conceptual model and loading data compiled in Tasks 2.3 and 2.4, respectively, initial nutrient load estimates will be calculated. To the extent feasible, spatially explicit (e.g., subembayments) and temporally-explicit nutrient loads will be quantified. The nutrient sources considered will include: municipal and industrial wastewater discharges; stormwater discharges; flows from the San Joaquin and Sacramento Rivers entering through the Delta, along with other smaller downstream tributaries; exchange across the Golden Gate; and direct atmospheric deposition. Nutrient fluxes from Bay sediments to the water column will also be considered. Initial estimates of municipal and industrial wastewater loads will be based on treatment technologies employed (expected effluent nutrient speciation and concentrations) and flow. When historical data is available, these data will be used to refine municipal and industrial wastewater loads. In addition, the Water Board is requiring a two year effluent characterization data collection effort (July 2012 through 2014) by Bay area municipal wastewater dischargers and industrial dischargers. These data will be used to further refine load estimates.

Task 6.1b Review models for Estimating Nutrient/ Organic Carbon Loads

This task will review existing models or types of models that can be used to estimate the sources and pathways of nutrient load to the Bay and summarize the data requirements. The task will begin by identifying the types of questions that the model(s) or empirical data must answer. The intent is to review models and tools that can assist in decision-making on nutrient management strategies and test the cost-effectiveness of implementation scenarios. This work element will feed into the development of a modeling strategy.

Task 6.2 Modeling of Load-response

Task 6.2a Basic Numeric Modeling and Scenario Analysis

The purpose of this task is to develop and apply basic numeric biogeochemical models, as an early step in modeling efforts, to inform future model development and data collection. The models will be used to quantitatively synthesize existing data; develop nutrient budgets; support evaluation of proposed indicators as part of the NNE; test appropriate management endpoints; determine how key processes should be modeled and assess the relative importance of and uncertainty related to those processes; and identify major data gaps at an early stage to inform the monitoring program and the need for special studies. In addition, these models may be used to evaluate biological responses under future scenarios (e.g., changes in nutrient loads, changes in major physical drivers affecting productivity, decreases in suspended sediment concentrations).

Initial model development will focus on Suisun Bay and South Bay or Lower South Bay. A technical advisory group consisting of regional and national experts would be convened to develop a modeling study plan. A key task of this group will be to identify the main questions to be addressed through the modeling work, approaches for incorporating key processes into the model, and the appropriate model platform(s). It should be emphasized that the model(s) developed and used in this task are not intended to be the final models that may ultimately be required for the Bay (which may be more complex and computationally intensive), but rather as scoping tools.

Task 6.2b Review of existing models and available model approaches to model the ecological response of the Bay to nutrient loads and other co-factors

This task will produce a review of available models and/or modeling platforms that will be the basis for developing a modeling strategy for the Bay. A work group will identify the management questions and endpoints (indicators) of concern and relevant spatial and temporal scales, focusing on hydrodynamic, water quality (dissolved oxygen, nutrients, carbon) and a phytoplankton-zooplankton production and phytoplankton speciation models. A review will be conducted of existing Bay and Delta hydrodynamic and water quality models or other applicable types of models, from simple spreadsheet to complex dynamic simulation models, their data needs, and advantages and disadvantages.

Task 6.3 Develop and Implement Modeling Strategy

The purpose of this task is to synthesize information generated from Tasks 6.1 and 6.2 tasks to develop a modeling strategy for the Bay. The strategy will identify questions to be answered by the models and what policies will be informed; types of models needed (e.g. external loads, bay hydrodynamic and water quality); potential modeling platforms; amount of data required and estimates of cost; and schedule. Information will be presented as cost/benefits of model options with trade-offs in terms of what indicators can be modeled at varying levels of accuracy/precision or timescales. The strategy will also address what partnerships need to be created to build and maintain a model.

WORK ELEMENT 7. CONTROL STRATEGIES

This work element will identify control strategies that are feasible in the near-term and long-term for reducing nutrient loads to the Bay, and evaluate their potential effectiveness for addressing nutrient-related impairment in the Bay, and their cost-efficiency. This could be accomplished via a work group that would identify key decisions and environmental, technical, and economic considerations or individual groups of stakeholders may work on this task and present the results of their efforts to the wider stakeholder group. All major nutrient sources should be considered, including municipal and industrial wastewater loads, stormwater runoff, and agricultural and other loads from the Delta. Effort directed toward exploring control strategies for various sources will be prioritized based on their relative importance and potential for load reductions, and based on spatial/temporal considerations. The evaluation of control strategy options will also consider multiple benefits. Work Element 7 will be carried out in parallel with the other activities above so that implementation plan scenarios can be considered as part of development of nutrient objectives. Where applicable, implementation scenarios will be evaluated and refined through modeling work in Task 6.4. Where necessary and feasible, the potential effectiveness of control strategies will be evaluated through scenario modeling (Task 6.3).

WORK ELEMENT 8. REGULATORY APPROACHES

This work element will identify and evaluate potential regulatory approaches for achieving nutrient load reductions in SFB should reductions be necessary. A variety of approaches will be considered and evaluated for their applicability to the San Francisco Bay setting and for their potential effectiveness for achieving nutrient objectives. As with Work Element 7, this work will be carried out in parallel with other tasks so that, should nutrient regulations be necessary, a range of options will already have been evaluated to a certain degree. Where it is feasible, the potential effectiveness of different regulatory approaches (and related control strategies) may be evaluated through scenario modeling (Task 6.3).

Table 2. GANTT chart of approximate timing of work elements and tasks associated with 5-yr nutrient plan

Task No.	Brief Task Description	Yr1	Yr2	Yr3	Yr4	Yr5
Element 1 Nutrient Program Administration						
1.1	Develop Governance Structure					
1.2	Develop Funding Plan					
1.3	Nutrient Program Management					
Element 2: Define the Problem						
2.1	Create Conceptual Model(s) of Ecosystem Response to Nutrient Loads					
2.2	Develop Problem Statement and future scenarios					
2.3	Synthesize and Interpret Existing Ambient Water Quality Data; Identify Data Gaps					
2.4	Develop Nutrient Loading Conceptual Model					
2.5	Synthesize Existing Loading Data and Data Gaps Analysis					
Element 3: Nutrients and Potential Impairment of Suisun Bay						
3.1	Field studies and experiments to assess potential impairment due to elevated ammonium or changes in N:P					
3.2	Synthesis of Research to Date and Ambient Water Quality Data in Suisun Bay					
3.3	Assess science related to Ecosystem Impacts in Suisun Bay and Relationship to Nutrients					
Element 4: Establish Guidelines						
4.1	Nutrient Assessment Framework					
4.2	Review of Dissolved Oxygen Objectives					
4.2a	Synthesize existing dissolved oxygen data					
4.2b	Evaluate existing dissolved oxygen objectives					

Task No.	Brief Task Description	Yr1	Yr2	Yr3	Yr4	Yr5
4.3	Macroalgal Assessment Framework.					
Element 5: Monitoring Program Development and Implementation						
5.1	Develop a Monitoring Program					
5.1a	Identify elements of a core SF Bay monitoring program					
5.1b	Develop a program of special studies to improve fundamental understanding and quantification of processes in the system					
5.1c	Develop the Bay nutrient monitoring program Work Plan and QAPP					
5.2	Implement the Bay nutrient monitoring program and special studies program (some special studies will begin in Yr2)					
Element 6: Modeling Program Development and Implementation						
6.1	Modeling of External Sources					
6.1a	Basic Loading Estimates or Modeling					
6.1b	Review Models for Estimating Nutrient/Organic Carbon Loads					
6.2	Modeling of Load-Response					
6.2a	Basic Numeric Modeling and Scenario Analysis					
6.2b	Review of existing models/platforms to model Bay hydrodynamics & water quality					
6.3	Develop and Implement Modeling Strategy					
7	Control Strategies					
8	Regulatory Approaches					

Table 3. Specific recommendations for science to support development of habitat-type specific nutrient assessment frameworks

Habitat Type	Recommended Action	Priority
All subtidal	Sponsor a series of expert workshops or develop an expert panel to develop a draft assessment framework based on indicators of phytoplankton (biomass, productivity, assemblage, cyanobacteria cell counts and toxin concentrations) and dissolved oxygen	High
	Form a working group of Bay scientists to synthesize available data on factors known to control primary productivity in different regions in the Bay, developing consensus on relative importance of ammonium inhibition of phytoplankton blooms to Baywide primary productivity, and determining next steps with respect to incorporating ammonium into the NNE assessment framework for the Bay.	High
	Consider a review of the Bay dissolved oxygen objectives, either Bay-wide or for specific habitat types such as tidally muted areas (tidal sloughs, managed ponds)	High
Un-vegetated Subtidal	Utilize IEP-EMP data to explore use of macrobenthos to assess beneficial use impairment in oligohaline habitats. Consider including biomass in the protocol to improve diagnosis of eutrophication or other nutrient-related beneficial-use impairment. Determine whether combination of indicators can be used reliably to diagnose eutrophication and other nutrient-related beneficial-use impairment distinctly from other stressors.	Low
Submerged Aquatic Vegetation	Conduct studies to establish light requirements for the Bay seagrass species;	Low
	Collect baseline data to characterize prevalence of macroalgal blooms and other stressors on seagrass beds	Moderate
	Evaluate the findings of statewide NNE studies characterizing effects of macroalgae on seagrass for applicability to the Bay	Moderate
	Participate in statewide group to develop an assessment framework for eutrophication in seagrass, based on phytoplankton biomass, macroalgae, and epiphyte load.	High
Intertidal Flats	Evaluate the findings of studies characterizing effects of macroalgae on intertidal flats for applicability to the Bay	Moderate
	Participate in statewide group to develop an assessment framework for eutrophication in intertidal flats, based on macroalgae and other supporting indicators.	High
Tidally muted habitats - managed ponds	Synthesize existing DO oxygen data for tidally muted areas and collect baseline data primary and supporting indicators (macroalgal biomass and cover and phytoplankton biomass, taxonomic composition, and HAB toxin concentrations) in these habitats needed to make a full assessment of status of eutrophication.	High

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