DRAFT SCIENCE PLAN UPDATE: 2020-2024

San Francisco Bay Nutrient Management Strategy

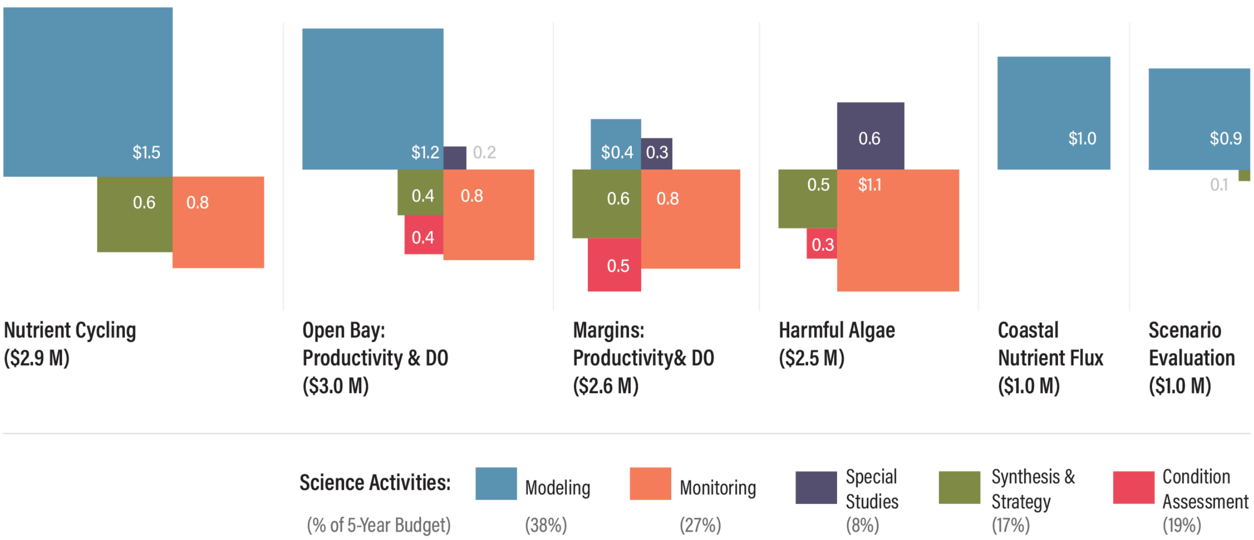
March 2019

CONTENTS

1. Executive Summary

In 2016, expert advisors and the Steering Committee of the San Francisco Bay Nutrient Management Strategy (SF Bay NMS) approved a 10-year Science Plan. This supplemental update considers anticipated activities projected to occur from 2019 to 2024—reflecting Steering Committee priorities in light of budget constraints and regulatory timelines.

Activities described in this Update fall into five program areas of the NMS Science Program, reflecting the most critical management questions. Five-year budgets, across all program areas, total $13 million, which exceeds anticipated discharger fees associated with the SF Bay Nutrient Watershed Permit by $2 million. Fundraising efforts and other sources may fill this gap, though this plan is flexible enough to enable modifications that prioritize projects of greatest need.



Over the course of 2018, the NMS Steering Committee and expert advisors expressed preferences for NMS Science Program priorities over the next 5-years. These priorities largely reflect a regulatory preference to identify the need and magnitude of nutrient load reductions, on the subembayment scale, prior to the close of the 2nd SF Bay Nutrient Watershed Permit, in 2024. To issue defensible provisional load allocations for the region's wastewater dischargers, significant efforts are required to:

- Improve model skill to quantify nutrient source attribution and nutrient dose-response;
- Finalize the Assessment Framework (AF) and reporting program;
- Establish the degree of adverse nutrient-mediated impacts on various SF Bay habitats;
- Implement a stable monitoring program for harmful algae, nutrients, and eutrophication indicators;
- Initiate investigations into coastal effects of nutrient loading from SF Bay; and
- Conduct quantitative risk assessments of future scenarios and management actions.

These priorities, developed in consultation with the Science Program Manager and stakeholders, shaped the formation of this Science Plan. They reflect the state of the knowledge, based on the last 5+ years of NMS research, monitoring, and modeling—while revealing the known constraints of the critical management questions, in terms of available time, funding, and lessons learned from other systems.

2. Introduction

San Francisco Bay (SF Bay) receives some of the highest nitrogen loads among estuaries worldwide, yet has not historically experienced the water quality problems typical of other nutrient-enriched estuaries. Recent observations, based on long-term monitoring data, have identified substantial inter-annual shifts in the Bay's response, or sensitivity, to nutrients. In addition, special studies, expanded monitoring, and modeling conducted since the formation of the Nutrient Management Strategy (NMS) revealed other water quality conditions (e.g., recurring low dissolved oxygen (DO) in some margin habitats and consistent detection of multiple toxins produced by harmful algae) whose effects on human and ecological health require evaluation and determination of causal factors.

Factors influencing the Bay's response to nutrients include suspended sediment concentrations, light availability, freshwater inputs, and ocean conditions. These factors are themselves variable due to local land and water management and climate oscillations. The number of variables involved demands a wide range of monitoring, modeling, and research efforts to understand ongoing and potential trajectories of change in water quality and ecosystem response resulting from increasing rates of nutrient loading and plausible scenarios leading to eutrophication-driven degradation.

2.1. Background and Objectives of the SF Bay Nutrient Management Strategy

The SF Bay NMS formally formed in 2014, following an effort of the State Water Resources Control Board (State Water Board) and SF Bay Regional Water Board to develop Numeric Nutrient Endpoints (NNE) instead of Water Quality Objectives for nitrogen and phosphorus. The NMS adopted many of the objectives of the NNE following recognition that nutrient-related management decisions for the Bay would benefit from a multi-stakeholder process.

A significant factor contributing to this recognition was growing uncertainty surrounding the availability of federal resources for USGS to continue assessing the Bay's condition. In response, the Regional Water Board prioritized development of a locally-supported, multi-interest, long-term science strategy and associated implementation program to support and inform nutrient-related management decisions affected SF Bay.

According to its Charter, the NMS defines and guides the development and implementation of the Science Program, information sharing, and public outreach approach related to nutrient management in SF Bay. Outputs and outcomes of the NMS inform on-going development of Water Board policy regarding regulation of nutrient discharges from wastewater facilities and other sources. The SF Bay Nutrient Watershed Permit for Municipal, and Industrial Wastewater Dischargers (NPDES No. CA0038873) formally articulates these policies. Adoption of the first Nutrient Watershed Permit occurred in 2014, subject to revisions and reissuance in 2019 and 2024.

Fundamentally, the NMS Science Program must characterize current and future risks of eutrophication-driven degradation associated with human contributions of nutrients. The NMS runs parallel to permit-specific activities, serving to develop, implement, and facilitate collaboration on efforts involving nutrient monitoring, condition assessment, load response modeling, and special studies.

2.2. Relationship to 2016 Science Plan

In 2016, NMS Science Advisers and its Steering Committee approved a 10-year Science Plan, intended to guide the NMS Science Program from 2014 to 2024 (SFEI, 2016). The priorities and major projects reflected in that plan underpin ongoing efforts and the overarching strategy. The 2016 Science Plan, however, was unconstrained by funding and relied on an ambitious set of objectives considered unrealistic by Science Advisors and stakeholders. Since that time, the Science Program team developed a realistic budget, informed by outreach to stakeholders and experts throughout 2018, which resulted in a distillation of which priorities are considered essential.

This update serves to characterize projects intended to take place in the latter half of the 10-year planning horizon from the 2016 Science Plan, from FY2020 and FY 2024. This report does not mean to duplicate efforts of the existing Science Plan, but to refine the priorities and better characterize the anticipated outputs and outcomes, in relationship to answering key management questions.

3. Overview of the NMS Science Plan Update, 2019–2024

Objectives of 2016 Science Plan included:

- Describe a multi-year progression of scientific activities to inform major management decisions;
- Develop an approach and rationale for sequencing and prioritizing among studies, and identify specific high-priority studies, in particular, those that should proceed in FY2016-2018; and
- Provide realistic estimates of the timeframe and funding needed to support a Science Plan that will successfully inform management decisions.

The 2016 Science Plan received input from key advisors, the NMS Steering Committee, and the NMS Nutrient Technical Work Group. Close details of projects envisioned beyond 2018 were not included, recognizing that Science Plan revisions will follow new insights gained as work progresses.

This 2019 Update follows a strategic process informed by input from the NMS Steering Committee and expert advisors throughout 2018. Updates to the current Science Plan reflect the alignment of the 2016 Plan with available resources envisioned from 2019-2024, to prioritize the most urgent science themes and management questions.

The program activities synthesized in this Science Plan will take place from 2019 to 2024 and align with four themes that reflect key management questions and objectives (Figure 1). Table 1 identifies the types of program-specific activities anticipated for completion over this Science Plan period (FY2020-FY2024). These activities are synthesized in Appendices A, B, C, addressing Monitoring, Nutrient Cycling, and Modeling, respectively.

Table 1. The framework of NMS science activities anticipated from FY2020 to FY2024

ACTIVITY CATEGORY	ACTIVITIES
Monitoring	• On-going ship-based monitoring of nutrients, phytoplankton biomass, phytoplankton composition, physical observations (salinity, temperature, SPM, etc.) • Moored sensors for biogeochemical and physical data • Future monitoring program design: data analysis and expert input on the spatial/temporal resolution, blend of ship-based vs. fixed-station continuous monitoring, integrating data from regional partners & optimizing regional monitoring network
Modeling	• Biogeochemical (Water Quality) and hydrodynamic model development and application to quantitatively explore a range of nutrient-mediated processes and responses. • Test scenarios of environmental change, population growth, and management actions on ecosystem-scale nutrient dose/response, to inform a range of management questions.
Special Studies	• Field investigations to

ACTIVITY CATEGORY	ACTIVITIES
	○ measure biogeochemical processes: e.g., primary production, nutrient transformations (water column, benthic), DO consumption (water column, benthic) ○ collect physical observations (temperature, salinity, velocities, light levels) to quantify mixing, transport, and stratification ○ study processes or test hypotheses at the ecosystem-scale (e.g., factors that influence HABs or toxin production) • Mechanistic studies in the laboratory
Condition Assessment	• Identify levels of DO, chl, and toxins, or characteristics of phytoplankton assemblages that are protective of beneficial uses. • Utilize monitoring and modeling outputs to inform nutrients loads or concentrations considered protective of beneficial uses. • Conduct annual assessments to compare monitoring results against assessment criteria to identify whether nutrients affect particular beneficial uses currently or if trends indicate future impairment.
Synthesis	• Analyzing/synthesizing data from monitoring and special studies to inform next steps in science plan implementation • Workshops to identify the highest priority science questions and experiments

Distribution of resources over 5-years, from overarching science theme to project activity type

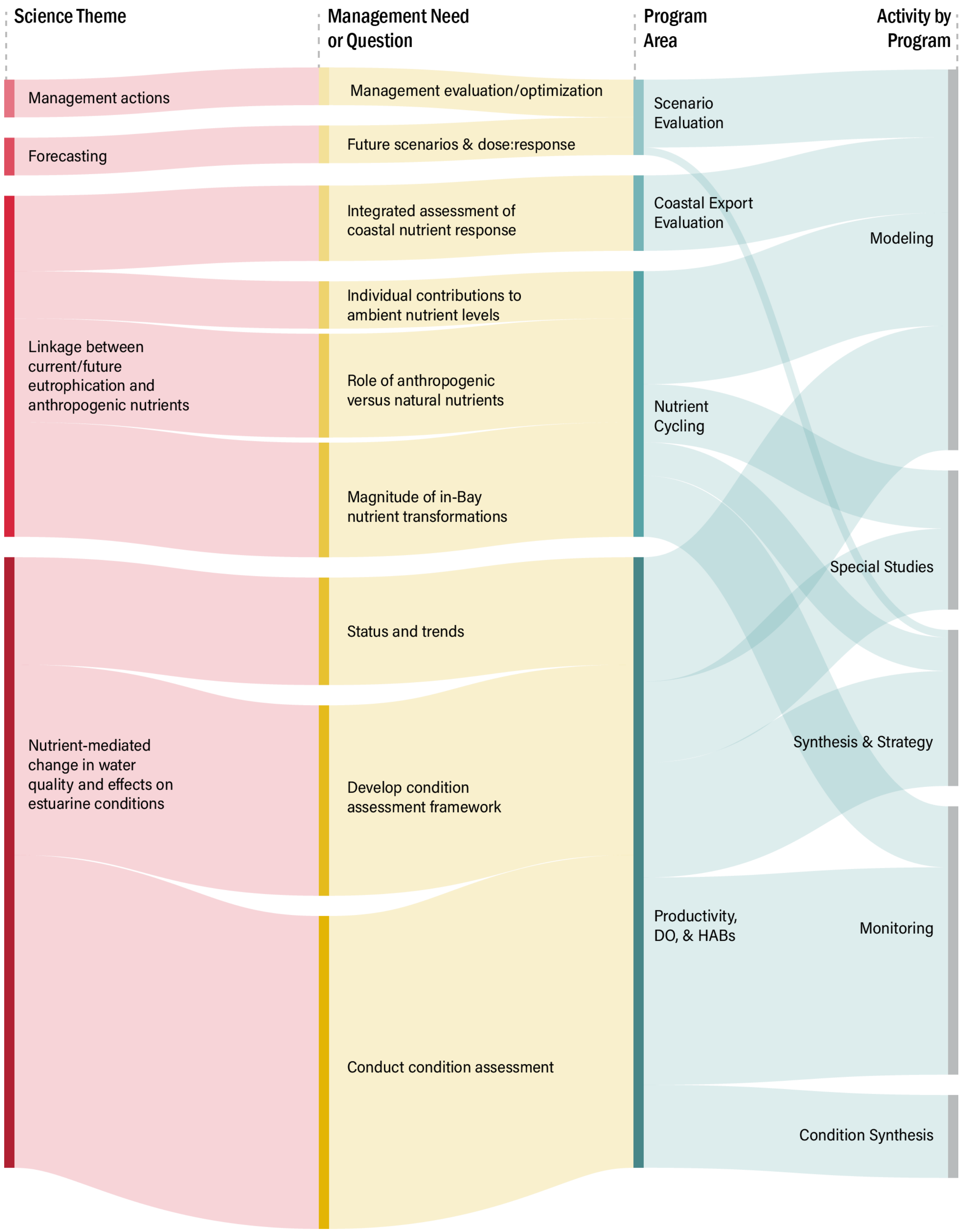


Figure 1. Distribution of resources for the NMS Science Program: FY2020 to FY2024

3.1. Relationship of Steering Committee Priorities to Management Questions

The distribution of resources illustrated in Figure 1 reflect priorities expressed by the NMS Steering Committee, developed in 2018:

- Improve hydrodynamic and biogeochemical model skill to facilitate source attribution and nutrient dose-response for chlorophyll and dissolved oxygen throughout SF Bay;
- Establish whether adverse dissolved oxygen conditions are observed in deep subtidal habitats and refine the relationship to chlorophyll-a;
- Establish the degree of adverse impacts to shallow margin habitats associated with low dissolved oxygen and improve the connection to chlorophyll-a;
- Implement a stable monitoring program for:
    - harmful algae;
    - nutrient species; and
    - chlorophyll-a & dissolved oxygen in deep subtidal and margin areas;
- Develop a Final Assessment Framework and reporting program;
- Begin investigations into coastal effects of nutrient loading from SF Bay;
- Conduct quantitative risk assessments of future scenarios;
- Conduct special studies involving biotic endpoints associated with low dissolved oxygen and chronic exposure to algal toxins; and
- Engage, on an opportunistic basis, in researching the mechanistic relationship between nutrients and harmful algae.

These priorities, developed in consultation with the Science Program Manager and stakeholders, shaped the formation of this Science Plan. They reflect the state of the knowledge, based on the last 5+ years of NMS research, monitoring, and modeling—while revealing the known constraints of the critical management questions, in terms of available time, funding, and lessons learned from other systems.

Table 2 synthesizes the critical management questions, the general priority of each subject over the next five years, and the strategic direction to answer these questions.

Table 2. Consequences of Steering Committee Decisions on Answering Management Questions

MANAGEMENT QUESTION	STEERING COMMITTEE PRIORITY	FUTURE DIRECTIONS
What conditions constitute adverse impacts or impairments?		
- DO/chl in deep subtidal		Increase confidence in chl-a:DO relationship and chl-a condition intervals for modeling & assessment
- DO in shallow margin habitats		Quantify ecological risk from low margin DO, in coordination with Water Board
- HA & toxin abundance, phytoplankton assemblage		Increase understanding of what constitutes HA impairment, based on international literature, though assessment will rely primarily on public health criterion
- Coastal ocean		No current intention to conduct condition assessment regarding impacts to the outer coast from Bay-sourced nutrients

MANAGEMENT QUESTION	STEERING COMMITTEE PRIORITY	FUTURE DIRECTIONS
Are adverse impacts occurring at observable temporal and spatial scales?		
- DO/chl in deep subtidal		Continue ship-based monitoring and development of a more extensive network of fixed moorings
- DO in shallow margin habitats		On-going/increased deployment of high-frequency sensors or other monitoring tools in margins
- HA & toxin abundance, phytoplankton assemblage		Establish a routine monitoring program for phytoplankton assemblage and toxins
- Coastal ocean		No field monitoring. Assessment based on modeling, in partnership with UCLA, UCSC, SCCWRP
How do SF Bay habitats respond to nutrient inputs?		
- DO/chl in deep subtidal		Field measurements of rates and on-going efforts to increase water quality model skill
- DO in shallow margin habitats		Conduct field measurements to develop models that inform dose:response in shallow habitats
- HA & toxin abundance, phytoplankton assemblage		Limited to monitoring and targeted funding to support mechanistic field and lab experiments to inform predictive power of modeling HABs
- Coastal ocean		Limited analysis based on modeling, in partnership with UCLA, UCSC, SCCWRP
What potential future impacts or impairments warrant pre-emptive management actions?		
- Effects of ecosystem drivers on dose-response?		Quantitative and qualitative analysis based on on-going modeling efforts and available data
- Likelihood and magnitude of these scenarios?		Risk quantification subject to significant uncertainty without data collection and collaboration
What are the contributions of individual nutrient sources to nutrient levels?		On-going assessment of primary point sources. Less attention to non-point sources beyond already-completed evaluations.
- How will individual loads change over time?		A better understanding of projected change in population, land use, & management practices
- The magnitude of nutrient transformations within SF Bay?		Focused biogeochemical field and lab studies to improve model skill with site-specific rates
- Contributions of individual sources within subregions?		Integrated hydrodynamic and water quality model will quantify pathways and fate of loads
What management actions or load reductions are needed to prevent or mitigate impairment?		Undertaken primary via Permit requirements to examing multi-benefit management actions
- What load reductions or other management actions can achieve the desired local effects?		Integrated model will be able to run scenarios of nutrient loading on chl-a and DO response
- What is the combination of management options available to achieve load reductions?		Limited attention paid to which 'optimal' combination of potential actions is most beneficial

3.2. Anticipated Progress toward Determining Eutrophication Risk in San Francisco Bay

Considering our current state of the science and priorities over the next 5-years, our ability to quantify eutrophication risk associated with anthropogenic nutrients will vary, in terms of risk to various nutrient indicators (e.g., dissolved oxygen, algae, or invertebrate communities).

Key management questions, spread across all science themes involve condition assessment, establishing the linkage from nutrients to eutrophication indicators, and identifying the need and scale of load reductions or other management actions. General categories of endpoint indicators, as well as the characterization of scenarios influencing nutrient dose response, require independent series of investigations, yet addressing each of these in five years exceeds available resources. This graphic depicts Steering Committee priorities, in terms of the anticipated ability to reduce uncertainty over the five-year duration of this planning period.

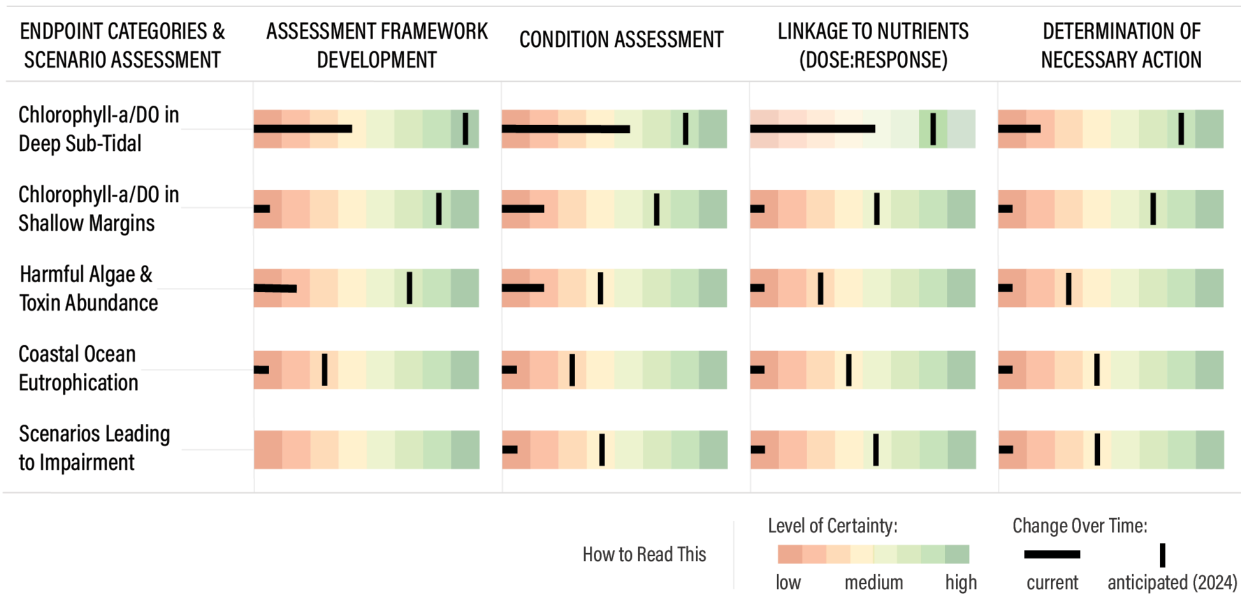


Figure 2. Current and expected level of certainty concerning endpoint categories or scenario refinements, and steps towards determining necessary management actions

This qualitative assessment of certainly is informed by current modeling capacity and data synthesis results. Improvements to these confidence intervals will evolve, pending expert workgroup outputs regarding monitoring, modeling, and biogeochemistry. Annual reports will detail progress towards addressing NMS management questions, as well as status and trends of eutrophication-related indicators, in comparison with numeric guidelines.

Variables influencing this current assessment of certainty anticipated by 2024 include:

<u>Chlorophyll a and DO in deep sub-tidal habitats</u>: Confidence in this endpoint category is highest given the attention given to hydrodynamic and biogeochemical modeling in this habitat category, the presence of a long-term ship-based dataset, and current confidence in model skill (SFEI, 2017 and SFEI, 2018a). The modeling team anticipates the ability to model the hydrodynamics of the system for several water years and biogeochemical studies will further improve model skill.

Summary: With coupled monitoring and modeling outputs, the NMS can expect a high level of confidence regarding recommended nutrient load allocations to meet a range of assessment criteria.

<u>Chlorophyll a and DO in shallow margin habitats</u>: Confidence in the ability to assess condition and model nutrient dose/response in the margins is lower, compared to deep subtidal habitats. The hydrodynamic model for Lower South Bay is in development and contains considerably higher complexity, compared to the open bay model. This complexity translates to an order of magnitude increase in the time required to conduct model runs—hence reducing the range of scenarios and durations subject to analysis. Modeling experts may recommend means for accelerating the pace of model development and run time. Considerable uncertainty currently exists regarding model objectives and constraints in various margin habitats.

Summary: The NMS can expect modeling activity targeting nutrient dose/response in the margins sufficient to make provisional assessments regarding recommended load allocations to meet numeric DO objectives.

Harmful algae and toxin abundance: Since the formation of the NMS, expert advisors have warned against committing a significant proportion of resource towards quantifying the linkages between nutrients, harmful algae abundance, and toxin concentrations (SFEI, 2016). Science and management initiatives in other systems have struggled to achieve this objective–attributable in part to a limited understanding of the basic ecology of target communities and a paucity of regulatory limits for toxins, concerning human health and wildlife risk. This Science Plan update allocates some funding for mechanistic studies, while committing more resources towards toxin monitoring, data synthesis, and assessment. Assessments will rely in part on available regulatory limits, literature review, and consultation with the CA Department of Public Health.

Summary: By 2024, stakeholders should not anticipate the ability to characterize nutrient dose response, concerning harmful algae in SF Bay, with a level of certainty matching that of the relationship between nutrients and phytoplankton/DO.

Coastal ocean eutrophication: SF Bay benefits from several factors that cap phytoplankton productivity and reduce utilization of dissolved inorganic nitrogen (DIN) in the system (e.g., high turbidity and strong tidal mixing). While those factors tend to increase SF Bay's internal DIN carrying capacity, this translates into greater DIN exports to the coastal ocean. Early coupled biogeochemical- hydrodynamic model simulations suggest that, while substantial fractions of SF Bay's DIN loads are 'lost' via denitrification, SF Bay serves as a significant point source of DIN to the coastal ocean via efflux through the Golden Gate. Despite the large magnitude of these DIN loads, we currently know very little about their potential effects on ecological conditions along the coast. In collaboration with UCLA, UC Santa Cruz, and the Southern California Coastal Water Research Project (SCCWRP), the NMS plans on increasing our understanding of nutrient processes in the outer coast, based on advanced modeling and available monitoring resources.

Summary: In the absence of a robust monitoring system outside the Golden Gate and an agreed-upon assessment framework for coastal eutrophication, the expected level of certainty is low, regarding the nexus between anthropogenic nutrients sourced within SF Bay and eutrophication condition along the coast.

Scenarios leading to impairment: Scenarios influencing nutrient dose response do not represent eutrophication endpoints or indicators, though to understand the range of circumstances under which physical and chemical changes to the system may result in a cascade of eutrophication-related impacts, the NMS must characterize a variety of plausible scenarios. SF Bay has undergone rapid and unanticipated regime shifts (Cloern and Jassby, 2012). To assess short- and long-term risk, via application of well-calibrated models, the NMS must understand the critical drivers of system change (e.g., reduced turbidity, changes in ocean temperature, human population-induced nutrient load increases).

Summary: The level of certainty currently assigned to our anticipated ability to judge how future scenarios will influence condition assessments; the linkage between nutrients and endpoints of interest; or the need for management actions, by 2024, is moderate based on a limited agreement regarding scenario selection and model skill. Following expert input, we anticipate agreement on which scenarios are the highest priority and what constitutes acceptable model skill, allowing refinements to this assessment.

4. Science Program Plans, by Program Area

Projects and activities proposed over five years fall into those six Program Areas shown in Figure 3, which depicts the relative allocation of resources, according to the several categories of science activities. This section synthesizes each of these Program Areas to provide an overview of the projects under consideration and their relationship to priority management questions.

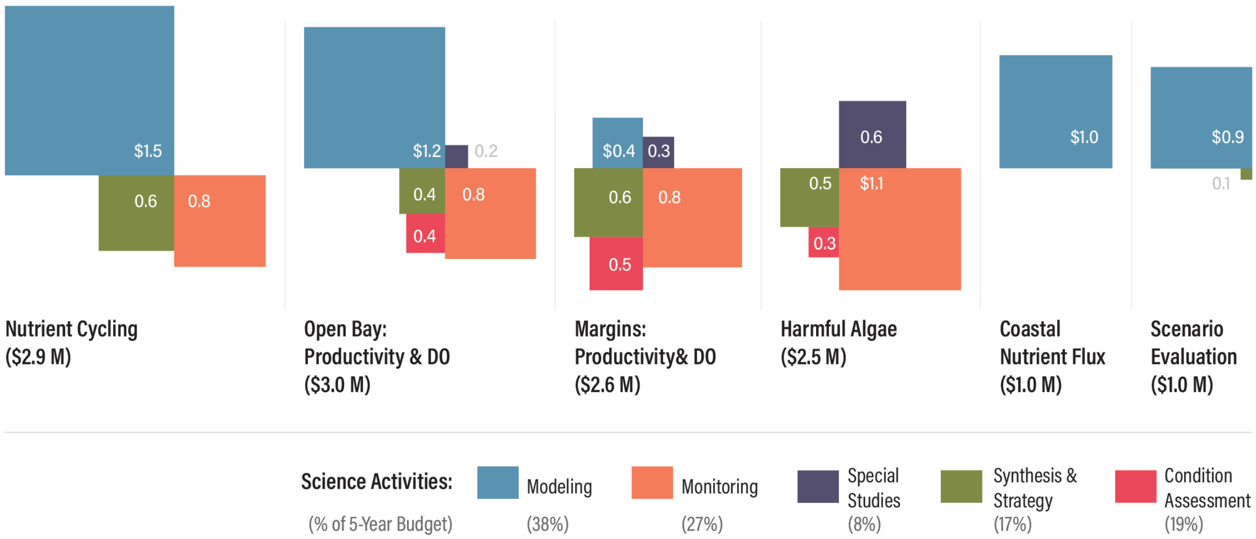


Figure 3. Distribution of resources, by Program Area and science activities

Budget estimates across all Program Areas total $13 million, which exceeds fees associated with the Nutrient Watershed Permit by $2 million. However, some of this total includes ongoing FY2019 projects. To account for the difference in funding the Science Program anticipates contributions from the SF Bay Regional Monitoring Program, partnerships that leverage additional resources, and anticipated fundraising efforts. Much of this difference is due to the difference in core monitoring requirements and potential projects, as described in Appendix A, *Monitoring Work Plan*. Expert workgroups and collaborators will inform the finalization of specific monitoring activities.

4.1. Nutrient Cycling

Objective:

Improve understanding of nutrient cycling processes to better characterize nutrient dose/response, through monitoring, research, and modeling.

Related Management Questions and Associated Science Questions

- What is the magnitude of various in-Bay nutrient transformations?
    - How do nutrient concentrations and forms vary spatially and temporally, particularly in margin habitats where limited monitoring has occurred to date?
    - What are the dominant processes controlling nutrient fate, and how do their magnitudes vary spatially and temporally?
- How do individual nutrient sources contribute to nutrient levels?
    - What are the magnitudes of loads from individual POTWs?
    - What is the zone of influence and magnitude of contributions of individual POTWs and Delta loads, and how do these vary seasonally and interannually?

  - Can models, paired with loads and export data, be used to develop an N budget for SF Bay subembayments?
- How do subtidal habitats respond to nutrient inputs?
  - Which water column and sediment rates are most critical to best model nutrient dose/response?
  - What nutrient loads can SF Bay assimilate without adverse impacts concerning chl-a, DO and algal toxins?
  - What effects are salt pond restoration activities having on nutrients in the margins? The open bay?

Science Needs

Whereas significant initiatives of the NMS to date have focused on providing the monitoring and modeling framework to document water quality status and trends, this program area focuses on explaining the processes influencing water quality. Data analysis and recent modeling indicate that substantial nutrient transformations (e.g., nitrification) and losses (denitrification) occur within SF Bay, yet the significance of those processes vary temporally and spatially. Limited experimental or field data is available to constrain rates for important biogeochemical processes, despite significant advances in modeling capabilities over the past ~5 years. We currently maintain the ability to develop nutrient mass balances and track individual nutrient sources at management-relevant spatial and temporal scales and work is underway to simulate phytoplankton blooms (SFEI, 2017 and SFEI, 2018a).

Despite progress, uncertainty in model results at this time likely exceeds the levels desirable for significant management decisions, due to data limitations (i.e., transformation rates; space/time heterogeneity in basic water quality parameters). To improve model skill and understand the magnitude of various nutrient transformations in SF Bay, the implementation of advanced biogeochemical studies will occur over the next several years, as described in detail within Appendix B. This information will supplement data collected through ship- and mooring-based monitoring efforts to improve biogeochemical modeling capabilities under development in-house and through diverse collaborations.

This monitoring and experimental results will inform modeling efforts (Appendix C, *Modeling Work Plan*), serving to calibrate and test the consequences of changes in biogeochemical processes and other scenarios. Explaining nutrient cycling processes and differences in response to human actions utilizes approaches at a variety of scales and with the support of agencies. To meet this objective, SFEI has fostered partnerships with USGS Menlo Park, the San Francisco State University's (SFSU) Estuary & Ocean Science (EOS) Center—formerly the Romberg Tiburon Center, US Geological Survey California Water Science Center, University of Florida, and others. An expert working group will be convened in FY2020, leading to other potential partnerships.

Anticipated Activities

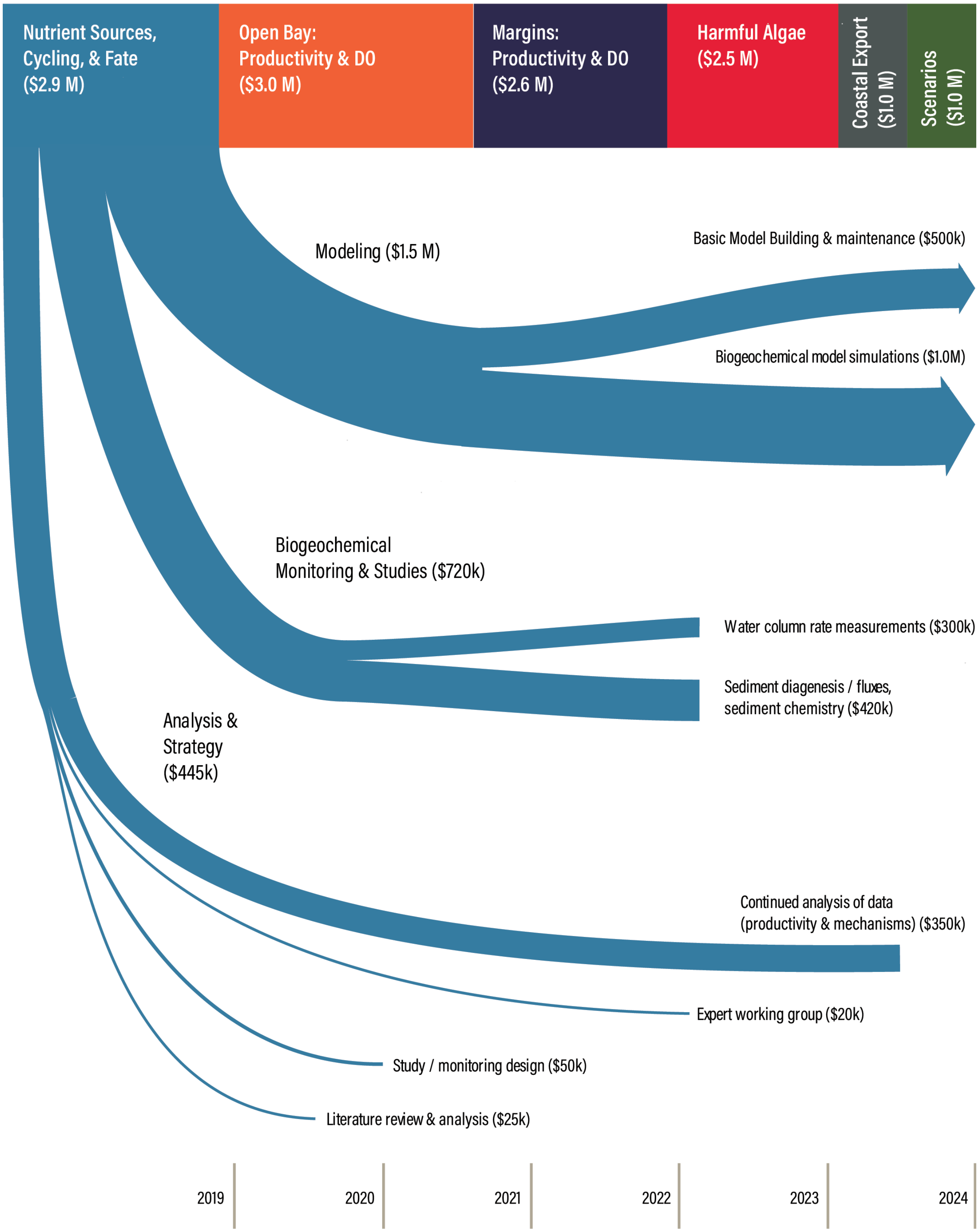
The fulfillment of science needs for this objective requires a crosscutting approach involving expert input, new field studies, and analysis of long-term monitoring data. The budget for this program area is $2.9 million over the 5-year term or ~22% of the total NMS budget.

Table 2 and Figure 4 summarize the anticipated activities, including the relative estimated budget and schedule. Please refer to Appendix B (Nutrient Cycling Work Plan) for additional details.

Table 3. Proposed projects related to nutrient cycling, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
Analysis of the model to inform study design	50	25	25				
Literature review, analysis of existing data	25	25					
Expert working group	20	10			10		
Field measurements	720	40	290	350	40		
Program management	250		50	50	50	50	50
Continued analysis of data, productivity, mechanisms	350		100	100	75	50	25
Basic model building	500		100	100	100	100	100
Biogeochemical model simulations	1,000		200	200	200	200	200
Total	**$2,915**	**$100**	**$765**	**$800**	**$475**	**$400**	**$375**

Figure 4. Nutrient Sources, Cycling, and Fate - Project Timeline and Budget



4.2. Open Bay: Relationship between Nutrients, Productivity, and Dissolved Oxygen

Objective:

Refine our understanding of open—bay processes and the relationship between productivity and dissolved oxygen, while ensuring the maintenance of a long-term monitoring program to detect trends and abrupt shifts.

Management Questions and Associated Science Questions

- What conditions constitute adverse impacts or impairments, concerning DO and chl-a in subtidal habitats?
    - What level of phytoplankton biomass likely results in adverse impacts in open bay habitats?
    - Does the first iteration of the Assessment Framework best characterize the relationship between productivity, DO, and HABs in the open bay and would the inclusion of additional data refine this relationship?
    - Do evolving trend detection techniques used in other estuarine systems (i.e., generalized additive models) serve to model long-term trends and characterize causative factors? For instance, do these models well integrate explanatory variables (nutrient concentrations, light penetration, temperature) into trend outputs for chl-a and DO?
    - What range of ecological indicators is essential to include in a long-term status and trends program?
- Are adverse impacts, in subtidal habitat, occurring at observable temporal and spatial scales?
    - Is our monitoring and modeling capacity sufficient to detect temporal- and spacial-dependent changes that may shift abruptly?
    - Does the hydrodynamic and biogeochemical model characterize a range of hydrologic conditions and site-specific nutrient transformations?
    - What are likely future trajectories of production and DO in the open Bay? Will biomass concentrations level off or continue increasing? What will be the response of DO?
- What are the contributions of individual nutrient sources to ambient concentrations, within subregions?
    - What is the most defensible approach to allocating nutrient loads to pre-defined subembayments and are models best capable of informing those allocations?
    - What are the model performance metrics most appropriate to test model skill, in terms of source apportionment of nutrients measures in the open Bay?

Science Needs

Considerable progress occurred over the last five years toward addressing several important science questions, concerning condition assessment and modeling in the open Bay. In that time, monitoring in indicates that despite high nutrient concentrations, DO levels in deep subtidal habitats appear at acceptable levels the vast majority of the time, due to factors (physics, biology) that limit primary production rates and ventilate the water column. Some elements have changed (suspended sediments, grazers), leading to increased phytoplankton biomass during some times of year and in some regions.

Also during that period, a diverse collection of experts collaborated on an Assessment Framework for chl-a in deep subtidal habitats, based on relationships to harmful algae and dissolved oxygen (Sutula et al., 2017). These relationships relied on a limited dataset that has expanded considerably. Future analyses include refining the chl-a/HA/DO relationship and introducing a status and trends element based on recent work using Generalized Additive Models (GAMs) for trend detection (SFEI, 2018b).

Long-term trends of several eutrophication drivers (e.g., DIN concentration) and indicators (chl-a and DO) have trended in worsening directions over the last several decades, and our understanding of site-specific nutrient cycling processes is limited. Ongoing data collection and special studies discussed under the Nutrient Cycling program enables refinement of the Assessment Framework, improvements to the hydrodynamic and biogeochemical models, and detection of trends or abrupt shifts that change our understanding of the open Bay's response to nutrient loading.

Uncertainty over the future of USGS' long-term ship-based monitoring program puts into question the future of data collection on a routine basis along the spine of the Bay, requiring significant planning and collaborations to optimize and modernize the monitoring program for what may likely be the next multi-decade phase of water quality monitoring in SF Bay (Appendix A). The long-term record provided by the USGS research program has yielded important insights into the mechanisms that shape SF Bay's response to nutrients, including physical and biological processes that regulate that response, and how that response has changed over time. Maintaining and building upon this program will be critical for anticipating future changes, and for assessing the effectiveness of any management actions.

Appendix C describes modeling activities anticipated over this planning period. A significant proportion of that effort involves refining the hydrodynamic and coupled biogeochemistry models to characterize the effects of anthropogenic nutrient loading in the open bay and margins, and how the dose/response may shift over time under a range of future scenarios, with respect to productivity (i.e., chlorophyll-a concentration) and resulting dissolved oxygen concentrations. Critical to our ability to monitor and model nutrient cycling processes is having a set of assessment tools to determine thresholds. This program area involves finalization of a set of assessment and trend detection tools and thresholds, to compare against model outputs.

Anticipated Activities

Addressing the science needs regarding nutrient-related effects of nutrients in deep sub-tidal habitats involves all major science activities. The budget for this program area is $3.0 million over the 5-year term or ~20% of the total NMS budget.

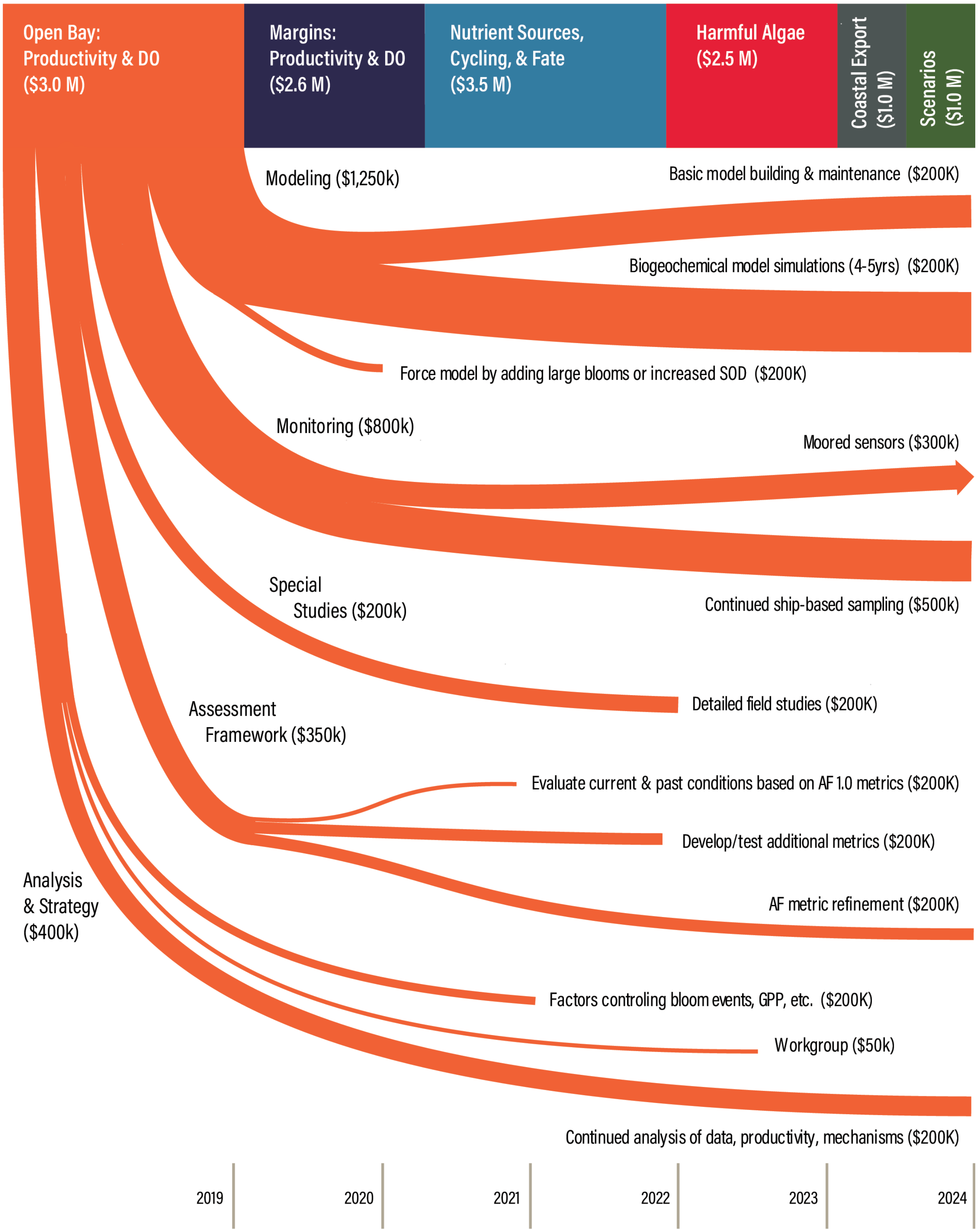
Table 4 and Figure 5 summarizes the anticipated activities, including the relative estimated budget and schedule. Please refer to Appendix A (Monitoring Work Plan) and Appendix C (Modeling Work Plan) for additional details.

Table 4. Proposed projects related to productivity and DO in open bay subtidal habitat, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
Continued ship-based sampling, informing status and trends	500	0	100	100	100	100	100
Moored sensor work, including new shoal moorings	300	0	100	100	50	50	0
Detailed field studies	200	0	100	100	0	0	0
Continued analysis of data, productivity, mechanisms	250	50	100	100	0	0	0
complete current reports on factors controling bloom events, GPP, etc.	100	50	50	0	0	0	0

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
expert group (#2,3,4)…guidance on future projects	50	25	0	0	25	0	0
Basic Model Building, maintenance, etc.	400	0	100	100	100	50	50
Force model by adding large blooms (immediate after effect), or by increasing SOD during summer months	100	0	100	0	0	0	0
Biogeochemical model simulations, broad range of conditions (4-5yrs)	750	0	150	150	150	150	150
AF…Developing/testing additional metrics	150	50	0	100	0	0	0
AF…Evaluate current // past conditions based on AF1.0 metrics	50	25	25	0	0	0	0
AF…Refine AF metrics chl-a/DO	150	0	0	0	50	50	50
Total	**$3,000**	**$200**	**$825**	**$750**	**$475**	**$400**	**$350**

Figure 5. **Open Bay: Productivity & DO - Project Timeline and Budget**



4.3. Margins: Relationship between Nutrients, Productivity, and Dissolved Oxygen

Objective:

Improved understanding of nutrient processes in sloughs/margins and the relationship between productivity and dissolved oxygen, to inform degree of impairment and potential management actions.

Management Questions and Associated Science Questions

- What conditions constitute adverse impacts or impairments, concerning DO and chl-a in margin habitats?
    - What level of phytoplankton biomass likely results in adverse impacts in margin habitats?
    - What DO thresholds and metrics cause adverse impacts (e.g., risk thresholds related to the spatial extent, duration, and frequency)?
    - What form of Assessment Framework is most appropriate for margin/slough habitats?
    - How can available trend techniques utilize high-frequency mooring data to inform status and trends in margin/slough habitats?
- Are adverse impacts, in margin habitats, occurring at observable temporal and spatial scales?
    - Given our current understanding of observed DO depression in Lower South Bay (LSB) sloughs, are biota adversely affected by low DO in these and other margin habitats?
    - Will monitoring in the shoals improve our understanding of nutrient transformations and phytoplankton productivity?
    - Based on observed (or modeled) conditions relative to conditions that have adverse impacts, are margin habitats adversely impacted by low DO?
- How do margin habitats respond to nutrient inputs?
    - How can the whole Bay hydrodynamic and biogeochemical model be modified to characterize margin conditions?
    - To what extent do anthropogenic nutrient loads contribute to or cause increased severity of DO depression?

Science Needs

Following recommendations developed early in the NMS process, implementation of a moored sensor network took place in Lower South Bay margin sites (SFEI, 2014). This element of the monitoring program resulted in the collection of valuable high temporal resolution data for chl-a, DO, nutrients, turbidity, and other parameters at multiple locations (Appendix A, Monitoring Plan). Additional data will improve our quantitative understanding of ecosystem response to nutrients, including the processes that influence phytoplankton blooms, affect oxygen budgets, and regulate nutrient fate. An on-going collection of high temporal resolution data in margin habitats is essential to calibrate water quality models and conduct on-going mechanistic studies involving nutrient dose-response and effects on biota.

Sampling along the shoals and sloughs will improve our understanding of phytoplankton and nutrient processes, and improve model calibration. Most of the water quality data available from SF Bay is from stations along the deep channel. The shoals are essential areas for phytoplankton and MPB production, and significant lateral heterogeneities in phytoplankton biomass and suspended particulate matter, which influences light availability and growth rates, are common in SF Bay. Also, a substantial proportion of nutrient transformations likely take place along the shoals (benthic nitrification and denitrification). Shoal monitoring can be accomplished through boat/ship-based transects or with moored sensors, and the best approach will vary depending on the relevant questions. Couple with biota monitoring, this information will inform the development of an assessment framework for DO in margins, in coordination with the SF Bay Regional Water Quality Control Board and other regulators.

In the last two years, SFEI launched a study to investigate the potential effects of low-DO on habitat quality in Lower South Bay (LSB) to inform decisions about nutrient regulation. The goal of the study was to understand where and when regions of LSB provide adequate DO to support resident fish species. Analysis of high-frequency measurements indicates low DO concentrations occur in LSB and likely originate in sloughs and other perimeter habitats. In particular, sloughs that receive treated wastewater or pond discharge with high organic matter have higher oxygen demand. As a result, DO in the sloughs is depleted as water is transported through the estuary by diurnal tides.

DO concentrations typically meet the Basin Plan water quality objective of 5 mg/L in the deep channels. In the sloughs, however, DO levels fell below 5 mg/L for 11-65% of the observations throughout the year and as much as 90% of the summer months at some stations (MacVean et al., 2018). The influence of excess nutrients versus natural conditions on driving low DO occurrence is uncertain. It stands to reason that elevated nutrients are contributing to high phytoplankton biomass. Development of a Lower South Bay (LSB) model serves to help quantify this contribution.

Based on recent recommendations, the NMS requires mechanistic models of DO concentrations throughout LSB and additional analyses and targeted studies of fish responses to environmental conditions to advance our understanding of the drivers of abundance and the relative importance of hypoxia to fish communities. Alternative approaches for deriving protective thresholds for DO in LSB are also possible. For example, it is possible to develop site-specific DO objectives for LSB using the Virginian Province Approach (e.g., USEPA, 2000). This approach uses information on the species of fish of management interest in LSB and a database of species-specific tolerances to derive protective thresholds. Another method would be to investigate the link between temperature, DO and the metabolic requirements of fish. Elevated water temperature leads to reduced oxygen solubility, increased respiratory oxygen demand, and could lead to habitat compression for fish species. Making predictions of fish responses to increasing temperature is possible based on the thermal tolerances of target species and DO conditions.

Anticipated Activities

Addressing the science needs regarding nutrient-related effects of nutrients in deep sub-tidal habitats involves activities involving monitoring, modeling, condition assessment, special studies, and synthesis. This budget for this area of work is $3.0 million over the 5-year term or ~20% of the total NMS budget.

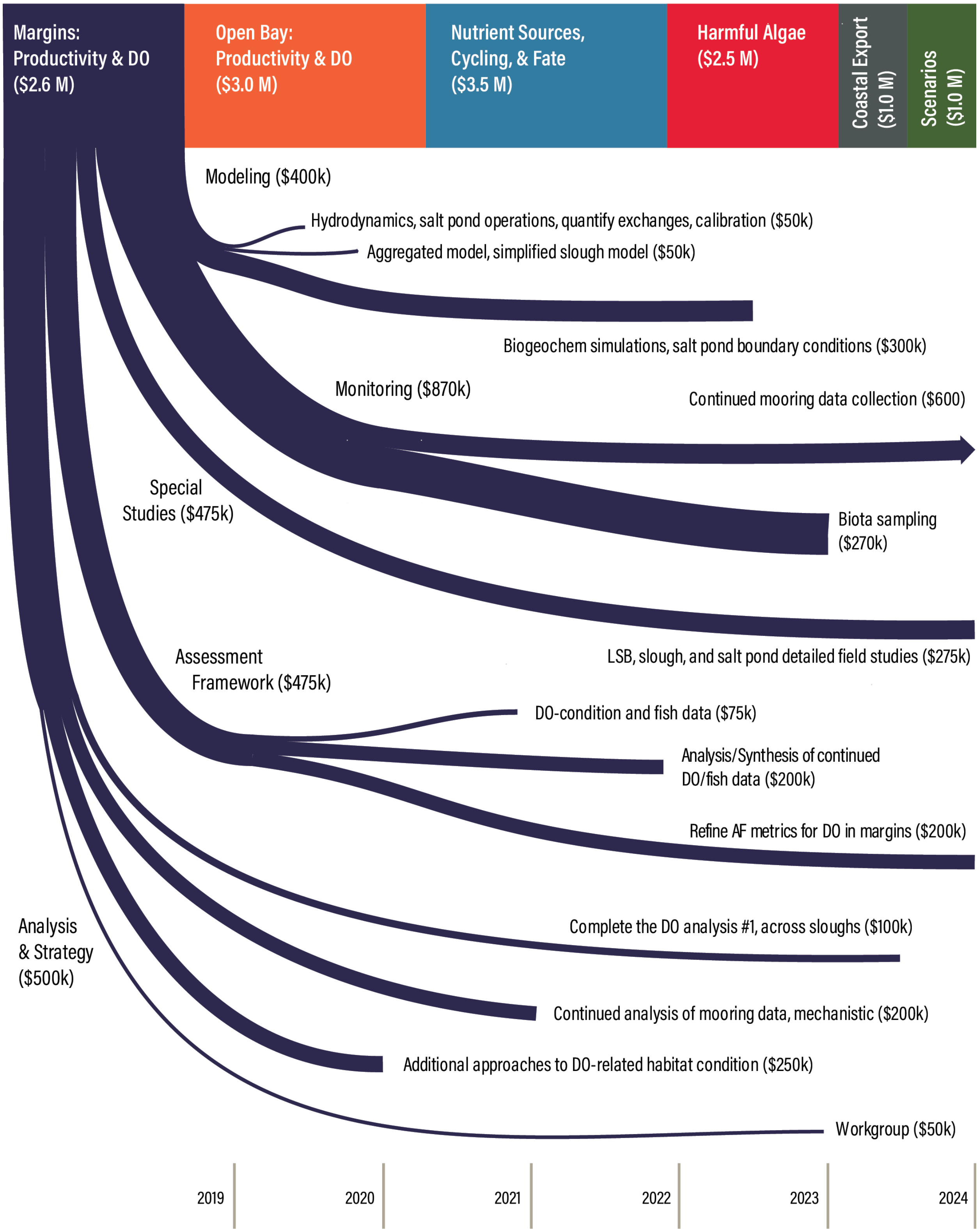
Table 5 and Figure 6 summarize the anticipated activities, including the relative estimated budget and schedule. Please refer to Appendix B (Monitoring Work Plan) and Appendix C (Modeling Work Plan) for additional details.

Table 5. Proposed projects related to productivity and DO in the margins, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
Continued mooring data collection	600	0	150	150	150	150	0
Biota sampling	270	30	60	60	60	60	0

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
LSB, slough, and salt pond detailed experiments	275	25	100	100	50	0	0
LSB modeling#1…further refinements to hydrodynamics, salt pond operations, application for quantifying exchanges, calibrate for one relevant time period	50	50	0	0	0	0	0
LSB modeling#2…aggregated model, simplified slough model	50	0	50	0	0	0	0
LSB modeling#3…biogeochemical simulations, salt pond boundary conditions, etc	300	0	100	100	100	0	0
Complete the DO analysis #1, across sloughs	100	25	75	0	0	0	0
Continued analysis of mooring data, mechanistic	200	0	100	100	0	0	0
Additional approaches to DO-related habitat condition	250	0	75	100	50	25	0
Workgroup	50	0	0	25	0	25	0
AF…Further analysis/exploration of of DO-condition and fish data.	75	50	25	0	0	0	0
Analysis/Synthesis of continued DO/fish data	200	0	0	100	100	0	0
Assessment Framework…Refine AF metrics for DO in margins	200	0	0	0	50	100	50
Total	$2,620	$180	$735	$735	$560	$360	$50

Figure 6. **Margins: Productivity and Dissolved Oxygen - Project Timeline and Budget**



4.4. Harmful Algal Blooms and their Toxins

Objective:

Focus efforts on instituting a robust monitoring framework to assess status and trends of harmful algae abundance and the concentrations of associated toxins in water and biota. Allocate a modest level of funding to pursue mechanistic harmful algal bloom (HAB) studies to characterize sources and nutrient dynamics.

Management Questions and Associated Science Questions

- What conditions constitute adverse impacts or impairments, concerning harmful algae and associated toxins?
  - How may the existing assessment framework be refined, through literature review and expert input, to integrate status and trends of toxin data?
  - How may the existing assessment framework be refined, through data analysis and synthesis, to improve the relationship between phytoplankton biomass and harmful algae abundance?
- Are adverse impacts, concerning HABs and associated toxins, occurring at observable temporal and spatial scales?
  - Are HABs/toxins present? If so which ones, how abundant?
  - What are the sources of toxins: in-Bay production vs. transport from the coastal or local tributaries?
  - Are HABs causing impairment, based on existing data on what causes adverse impacts elsewhere?
  - Have there been detectable changes over time, based on existing data?
  - Which strategies are most effective and efficient to characterize HAB-related effects on biota?
  - Is acute or chronic impairment from toxins evident in resident organisms?
- How do SF Bay habitats respond to nutrient inputs, concerning HABs and associated toxins?
  - What are the large-scale drivers of HAB formation (i.e., nutrients, physical/biological factors)?
  - Do appropriate phytoplankton community models exist to inform nutrient-related risks?
  - To what extent do nutrients cause, contribute to, or enable increased abundance/blooms?
  - What future scenarios could increase the frequency or severity of HAB events or increase toxin abundance? For instance, restoration and reconnection of salt ponds/wetlands, future water management practices in the Delta, and climate change. How likely are those changes in a 20-30 year time horizon?

Science Needs

Identifying the sources of harmful algae and toxins, determining whether they grow in SF Bay, and the degree to which anthropogenic nutrients drive HAB formation represents a highly relevant, yet challenging series of investigations. Science managers in other estuaries and coastal systems have struggled to develop models that predict HAB formation and magnitude based on nutrient loading. As a result, NMS advisors and the Steering Committee have recommended limited investments in mechanistic studies and predictive models examining harmful algae and associated toxins.

Efforts over this planning period concerning HABs and toxins will focus on the first two management questions and associated science questions identified above. Activities focus on expanding monitoring efforts and synthesizing data to refine condition assessment thresholds and trend detection capacity. Targeted investments to address the third management question involves mechanistic field and lab experiments and limited modeling efforts centered on phytoplankton community structure and scenario-based investigations. Currently, little is known regarding the extent to which SF Bay-sourced nutrients influence HAB growth or toxin production, within the Bay or west of the Golden Gate. Modest investments in mechanistic studies and modeling of the outer coast serve to inform the scope of potential future projects.

Monitoring yields common detections of HAB-forming species throughout SF Bay and multiple HAB-toxins occur in water and biota, including domoic acid (DA), microcystins (MCY), saxitoxin (STX). To summarize results to date (2016 Science Plan citation):

Water: MCY and DA were consistently detected (>70% and >90%, respectively) by Solid Phase Adsorption Toxin Tracking (SPATT). Based on particulate testing, MCY and DA levels varied substantially in space and time, with a high number of non-detects.

Biota: DA and MCY regularly detected in mussels. DA levels typically fall well below regulatory thresholds for human consumption. MCY levels regularly approached and sometimes exceeded regulatory thresholds. STX is commonly detected in mussels, generally well below regulatory thresholds, though levels exceeded human health thresholds at Central Bay sites in Spring 2018, resulting in a California Department of Public Health advisory against shellfish consumption.

The prevalence of HAB-forming organisms in the Bay and the frequent detection of toxins Bay-wide warrants expansion of monitoring efforts centered on phytoplankton composition, the occurrence of HAB-forming microorganisms, and toxins in the Bay as well as sources from the outer coast and local tributaries. Composition and bio-volume data collected for HAB-related work would also support assessment and improved mechanistic understanding of other hypothesized nutrient-related shifts in phytoplankton community composition. The abundance and forms of nutrients are two among many factors that can influence phytoplankton community composition and the occurrence of HABs. Managers and scientists have a limited understanding of the relative contribution of factors toward causing adverse shifts in composition or HAB occurrence. Synthesis of phytoplankton composition and toxins data, in combination with special studies, will improve our understanding of these mechanisms and assess potential linkages to nutrients.

Development of a set of HAB-related studies will be refined based on expert input and the degree to which the NMS can leverage partner-based funding. Under current consideration is a partnership with SF Statue University's (SFSU) Estuary and Ocean Science (EOS) center and UC Santa Cruz to leverage a state-funded project to study growth requirements of the toxic phytoplankton *Pseudo-nitszchia* spp. The current planned set of studies will examine P-N growth and toxin production as a function of temperature and salinity, with a primary focus being on conditions encountered outside the Golden Gate. SFEI staff will join the project as co-PIs and will contribute to study design and interpretation.

Contributions from the NMS allows investigators to pursue issues involving:

- Temperature/salinity ranges of the species to capture relevant conditions within SF Bay; and
- Effects of light limitation, along with temperature and salinity, on growth and toxin production.

Finally, a limited set of regulatory or advisory limits inform condition assessment criteria for harmful algae abundance and associated toxin concentrations. These serve primarily to protect public health, and we know little regarding effects on wildlife from chronic algal toxin exposure. The NMS does not intend to develop site-specific or new assessment criteria and will rely on available assessment criterion used in other locations or literature-based expert recommendation. Status and trends reporting will involve reporting monitoring data in comparison with regulatory or advisory limits found from available literature.

Anticipated Activities

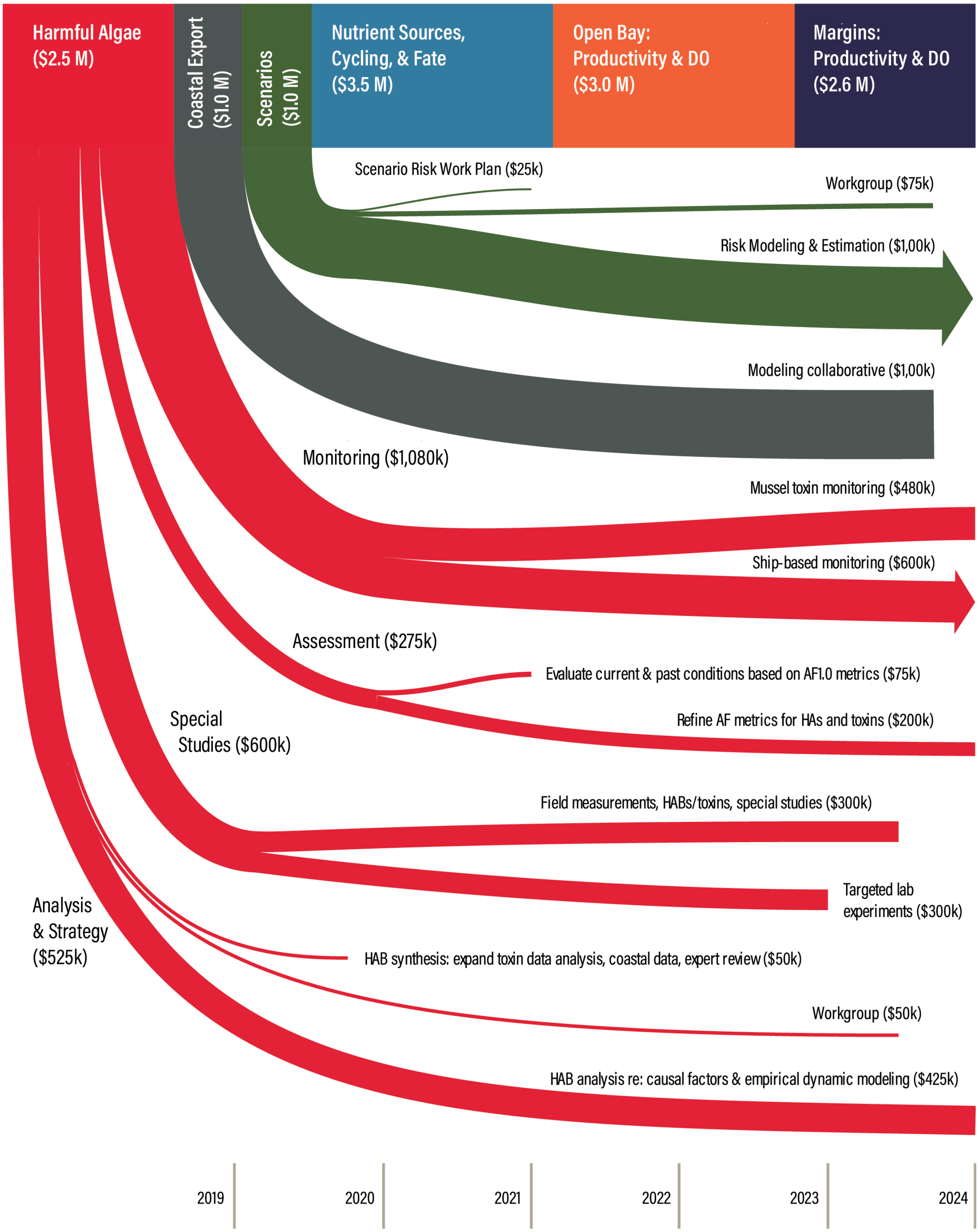
Addressing the management and science needs surrounding HABs requires resources and a time horizon beyond the scope of this Science Plan. Table 6 and Figure 7 summarize anticipated activities to implement a robust monitoring program, conduct targeted studies and perform analyses and synthesis to inform assessment protocols and better understand nutrient-mediated shifts in phytoplankton community composition.

The budget for this area of work is $2.5 million over the 5-year term or ~18% of the total NMS budget.

Table 6.Proposed projects related to harmful algae and toxins, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2020	2021	2022	2023	2024
Ship-based monitoring, incorporating HABs/toxins	600	120	120	120	120	120
Mussel / toxin monitoring (field, lab, data management, basic reporting)	480	120	120	120	120	0
Additional field measurements, HABs/toxins, special studies	300	75	75	75	75	0
HAB Mechanistic studies (SFSU/UCSC partnership)	300	100	100	100	0	0
HAB synthesis: complete current report, expand toxin data analysis, coastal data, expert reviewer	50	50	0	0	0	0
Deeper dive into HAB data analysis/interpretation/causal factors	425	150	100	75	50	50
HAB expert group to provide guidance on future projects	50	25	0	0	25	0
Condition assessment: Evaluate current/past conditions based on AF1.0 metrics	75	75	0	0	0	0
Assessment Framework: Refine AF metrics for HAs and toxins	200	0	0	50	100	50
Total	**$2,480**	**$715**	**$515**	**$540**	**$490**	**$220**

Figure 7. **Harmful Algae, Ocean Exports, & Risk Scenarios - Project Timeline and Budget**



4.5. Coastal Nutrient Flux

Objective:

Address our limited understanding of nutrient flux to and from the ocean and begin investigations regarding how SF Bay-derived nutrients influence ecosystem condition along the Central California Shelf (CCS).

Management Questions and Associated Science Questions

- What conditions constitute adverse impacts or impairments, concerning eutrophication indicators along the outer coast?
  - The NMS has not prioritized questions regarding the development of an assessment framework for the outer coast. In response to modeling and special studies recently initiated, future questions may involve whether a eutrophication-related Assessment Framework for coastal habitats is warranted.
- Are adverse impacts to coastal habitats occurring at observable temporal and spatial scales?
  - Does outflow from SF Bay influence particular areas of the CCS?
  - What factors regulate the SF Bay plume's trajectory, areal extent, and duration of influence?
  - In impacted zones, what is the magnitude of the perturbation resulting from the outflow and SF Bay-sourced DIN?
- How do coastal habitats respond to nutrient inputs?
  - What is the fate or nutrients that exit SF Bay through the Golden Gate and how do they influence water quality in the Gulf of Farallones or other coastal areas?
  - Over meaningful temporal averages (e.g., monthly or seasonal), what are the quantitative changes to primary production, phytoplankton concentrations, and community structure resulting from the outflow?
  - What quantitative effects do these have on dissolved oxygen and acidity?

Science Needs and Approach

The Bay Area's 37 publicly owned treatment works (POTWs), which treat wastewater from the region's 7.4mill people, discharge ~50,000 kg d-1 DIN to SF Bay. Loading from these wastewater facilities account for the vast majority of dry season DIN inputs, and are relatively constant year-round (±15%); however, recent analysis indicates POTW loads have increased substantially over the past decade. The Sacramento and San Joaquin Rivers carry water from California's Central Valley, delivering 90% of SF Bay's freshwater inputs to northern SF Bay along with large, seasonally varying DIN loads.

Although SF Bay is highly enriched in DIN, the system has not historically experienced eutrophication problems typical of other nutrient-enriched estuaries. SF Bay's resistance to high nutrients stems from several factors (e.g., high turbidity, strong tidal mixing) that cap phytoplankton primary productivity and reduce DIN utilization within the system. While those factors tend to increase SF Bay's internal DIN carrying capacity, they necessarily translate into greater DIN exports to the coastal ocean. Early coupled biogeochemical- hydrodynamic model simulations suggest that, while substantial fractions of SF Bay's DIN loads are 'lost' internally via denitrification, SF Bay serves as a large DIN point source to the coastal ocean via efflux through the Golden

Gate. Despite the large magnitude of these DIN loads, we currently know very little about their potential effects on ecological conditions along the coast.

Over the next five years, the NMS will leverage partnership funding to begin examining the effects of nutrients sourced from SF Bay on habitats along the outer coast. This project will apply coupled atmospheric-physical-biogeochemical ocean models to investigate how SF Bay-derived DIN influences ecosystem conditions along the CCS. Work will focus on two sets of questions related to 1) physical processes and 2) biogeochemical or ecological responses, as reflected in the identified management and science questions.

Completion of this work will take place through collaborating with an on-going multi-institution project (UCLA, SCCWRP, University of Washington, and NOAA) that is applying coupled physical/biogeochemical models for the CCS to predict the effects of ocean acidification and hypoxia (OAH) along the CA coast. That project, led by investigators at UCLA and SCCWRP and funded by the CA Ocean Protection Council and NOAA, has a specific emphasis on quantifying the degree to which local anthropogenic nutrient inputs influence OAH, via their influence on phytoplankton productivity. As a result, while the NMS and UCLA-SCCWRP projects differ somewhat in their specific goals or focus, the state-of-the-art models they are developing are ideal for addressing the NMS' management questions along the CCS.

The sequencing of tasks in Years 1, 2 and 3 follow:

- Contribute to the development and set-up of a physical model for CCS, physical model validation;
- Focus on CCS biogeochemistry and productivity, quantifying contributions; and
- Refine physics, biogeochemistry/productivity, and application to OAH endpoints.

Project deliverables will include progress reports or technical reports at the end of Years 1-3, with technical reports written as journal manuscripts if relevant. Investigators anticipate three (3) publications will result from this study:

a) Validation and preliminary pollution impact of collective atmospheric and terrestrial sources on the CCS;
b) Physical evolution and fate of the SF Bay outflow plume; and
c) Biogeochemical impacts resulting from plume outflow.

Additional publications relating to these calculations and analysis are likely.

Anticipated Activities

Projects or activities proposed in this planning period related to assessing nutrient effects on the outer coast are limited to the multi-institution collaborative project summarized above. The budget for this program area is $1.0 million over the 5-year term or ~8% of the total NMS budget.

Table 7. Proposed projects related to science needs for the coastal flux of nutrients to and from the ocean, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2019	2020	2021	2022	2023	2024
Coastal Modeling	1,000	200	200	200	200	150	50

4.6. Scenario Assessment and Planning

Objective:

Assess the risk of undesirable environmental conditions in the bay such as high magnitude algal blooms and persistent low DO through modeling Bay dynamics under projected future scenarios.

Management Questions and Associated Science Questions

- What is the risk (likelihood & magnitude) of eutrophication-based impacts under future scenarios?
  - Effects of ecosystem drivers on dose-response? For instance, what range in response, of phytoplankton biomass and DO, is expected if suspended sediments continue decreasing at rates similar to the past 20 years? Do adverse impacts become increasingly likely at environmentally relevant suspended particulate matter values?
  - What scenarios could heighten the likelihood of adverse impacts? For instance, will salt pond and wetland restoration efforts result in more extended periods of stratification or higher production? Will climate change result in similar consequences?
- What combination of management actions or load reductions are needed to prevent or mitigate impairment?
  - What load reductions or other management actions can achieve the desired local effects?
  - What is the potential for wetland restoration/treatment to mitigate adverse impacts of nutrients?

Needs to Address Science Questions and Evaluation of Management Alternatives

Rates of anthropogenic nutrient loading to SF Bay ranks among the highest in the world, and ambient nutrient concentrations in SF Bay are high relative to many urbanized estuaries. Yet the system does not exhibit acute symptoms of eutrophication observed in similarly enriched estuaries. Hypotheses regarding the source of this resistance include a combination of the light-limiting effects of suspended sediments and the presence of benthic grazers, both of which exert strong controls on the phytoplankton population. The presence of high ambient nutrient levels has the potential to fuel large-scale phytoplankton bloom events capable of triggered a cascade of adverse effects. The relationship between nutrients and primary producers, however, is far from linear and co-determined by a number of other factors, including water residence time, nutrients, water temperature, grazers (zooplankton and clams), solar radiation, turbulence, and turbidity, all of which can vary in space and time.

The NMS has begun modeling Bay dynamics under projected future scenarios to forecast the risk of undesirable environmental conditions in SF Bay, such as increasing magnitude and frequency of HAB events and persistent low DO through (Nuss et al. 2018a, Nuss et al. 2018b). Due to the complexity and uncertainty of HAB and DO dynamics, the NMS modeling team has focused on modeling phytoplankton dynamics and other relevant drivers of HABs and DO as proxies. Preliminary efforts focused on physical controls of phytoplankton blooms: stratification dynamics through freshwater flows and precipitation, wind effects on stratification and suspended sediment concentrations, and light levels through suspended sediment inputs.

Appendix C (Modeling Work Plan) describes anticipated modeling activities involving scenario-based risk assessments (Project 3). This involves convening experts to inform the approach for evaluating future scenarios. Investigators will use the coupled hydrodynamic and biogeochemical model to conduct targeted sensitivity tests aiming at investigating potential scenarios of physical forcings and management actions. This information will inform management actions by testing various nutrient levels as a management knob to target specific DO requirements; judge whether management practices at restored salt ponds may contribute to or mitigate future impacts; and which population growth scenarios are most likely to result in significant impairments.

In parallel with scenario modeling efforts, wastewater dischargers and the NMS Science Program has pursued the evaluation of management alternative evaluations. Under the first Nutrient Watershed Permit, Dischargers funded an Optimization and Upgrade Report. The second iteration of the Permit involves two efforts to quantify nutrient reduction alternatives achievable via nature-based solutions as well as wastewater recycling. SFEI will likely undertake the regional assessment of nature-based nutrient load reduction alternatives over the same period considered for this Science Plan (FY2020 to FY 2024).

Integrating possible management strategies is outside the scope of consideration over the next 5-years. Pending additional funding, SFEI may pursue an integrated assessment of the optimal mosaic of grey- and green-infrastructure alternatives, including wastewater recycling.

Anticipated Activities

Activities proposed in this planning period related to forecasting the consequences of future scenarios involves modeling actions following the refinement of the coupled hydrodynamic and biogeochemical model described in Appendix C. SFEI will solicit expert input to inform an appropriate range of scenarios and drivers of ecosystem change. A final report will serve to inform management decisions as the third iteration of the Nutrient Watershed Permit approaches (~2023).

The budget for this program area is $1.0 million over the 5-year term or ~8% of the total NMS budget.

Table 8. Proposed projects related to scenario-based forecasts and potential management actions, schedule (fiscal year), and budget (thousands of dollars)

PROJECT TITLE	TOTAL	2020	2021	2022	2023	2024
Develop a Risk/Scenario Work Plan (workshop/goal setting, stakeholders, planning)	25	25	0	0	0	0
Quantifying effects/modeling	900	200	200	200	200	100
Workshops, expert input	75	25	0	0	50	0
Total	**$1,000**	**$250**	**$200**	**$200**	**$250**	**$100**

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APPENDIX A: MONITORING WORK PLAN

MONITORING WORK PLAN: FY2020-FY2024

San Francisco Bay Nutrient Management Strategy

March 2019

1. Introduction

The Nutrient Management Strategy Observation Program (NMSOP) was conceived to provide a framework for monitoring environmental conditions in an effort to guide future nutrient management decisions. It is well established that San Francisco Bay (SF Bay) receives large nutrient loads from treated wastewater effluent and agricultural inputs, yet has historically exhibited resistance to the classic symptoms of nutrient-impaired waters. However, more recent studies have indicated that SF Bay's response to nutrients is changing (Cloern and Jassby 2012, SFEI 2016), and there is growing concern that SF Bay may be teetering on a 'tipping point' between impairment and healthy conditions as a result of high nutrient loading. With pending decisions regarding the future of nutrient removal standards at Publicly Owned Treatment Works (POTWs), this uncertainty has led to a need for an increased understanding of SF Bay's response to nutrient loading, as well as the development of potential future scenarios under changing environmental conditions.

The NMSOP brings a valuable new monitoring program to a historically well-studied estuary – providing a structure and funding mechanism for new environmental measurements, as well as a mechanism to unite and leverage an array of well-established monitoring campaigns throughout SF Bay.

NMSOP version 0.1 (SF BayNMSOP) was first implemented in CY 2017, which involved bringing already existing monitoring efforts under the official umbrella of the NMSOP. This included:

- SFEI's Lower South Bay Moored Sensor Program (a network of 8 water quality sondes collecting high frequency, nutrient related water quality data in a previously sparsely monitored region of SF Bay);
- SFEI's toxins in mussels program;
- SFEI's involvement with the long-standing USGS water quality cruises; and
- Data integration efforts between SFEI, USGS, and DWR-IEP monitoring programs.

When NMSOP v0.1 was established, the goal was to continue to build the program to v1.0 by 2020, and to arrive at a refined, sustainable v2.0 by 2022. The program has been moving well along the path toward v1.0, with continued improvements and sustained efforts in the moored sensor and toxins in mussels programs. In addition, the NMS Science Program provides sustained support and adding key nutrient related and model calibration analytes to the USGS water quality cruises, initiated pilot moored sensor monitoring efforts in the shoal environment northeast of the San Mateo Bridge, integrated monitoring network data into water quality modeling efforts, and is pursuing extensive QAQC and data analysis efforts.

2. Management Questions

The nutrient monitoring program is designed to monitor environmental conditions in order to directly address nutrient management questions. The program should 1) allow regulators to determine whether the system is experiencing nutrient-related impairment, 2) provide data at relevant spatial and temporal scales for model calibration/validation, and 3) allow stakeholders to identify nutrient-related changes in ecological condition or changes in factors that regulate ecosystem response to nutrients. The following guiding management questions are a subset of the overall science plan management questions, and are designed to guide the design of the NMSOP for the next five years:

- Is there a nutrient problem or signs of a future problem in San Francisco Bay?
- What are the appropriate guidelines for identifying a problem?
- What nutrient loads can the bay assimilate without impairment of beneficial uses?
- What are the relative contributions of loading pathways?
- When nutrients exit the Bay through the Golden Gate, where (and how) are they transported?

3. Current Monitoring Efforts

The nutrient monitoring program began in 2013 and has since grown to include a host of concurrent monitoring initiatives. The monitoring efforts were taken under the umbrella of the NMSOP in 2017.

The program has stayed true its initial goal of starting monitoring initiatives from scratch, as well as leveraging well-established monitoring programs to include more specific nutrient related efforts (e.g., the USGS ship-based deep channel monitoring). The nutrient monitoring program has established a strong relationship with the USGS ship-based deep channel monitoring program. Funds from the NMS have helped to support ongoing ship-based measurements, as well as add new analytes to the normal measurement procedures. Figure 1 provides a map of the location of the current monitoring efforts throughout the Bay, and Table 1 provides a list of all current monitoring efforts, along with the analytes being measured in the effort and the estimated annual cost. We note that the sum of the current estimated yearly costs is $858,000.

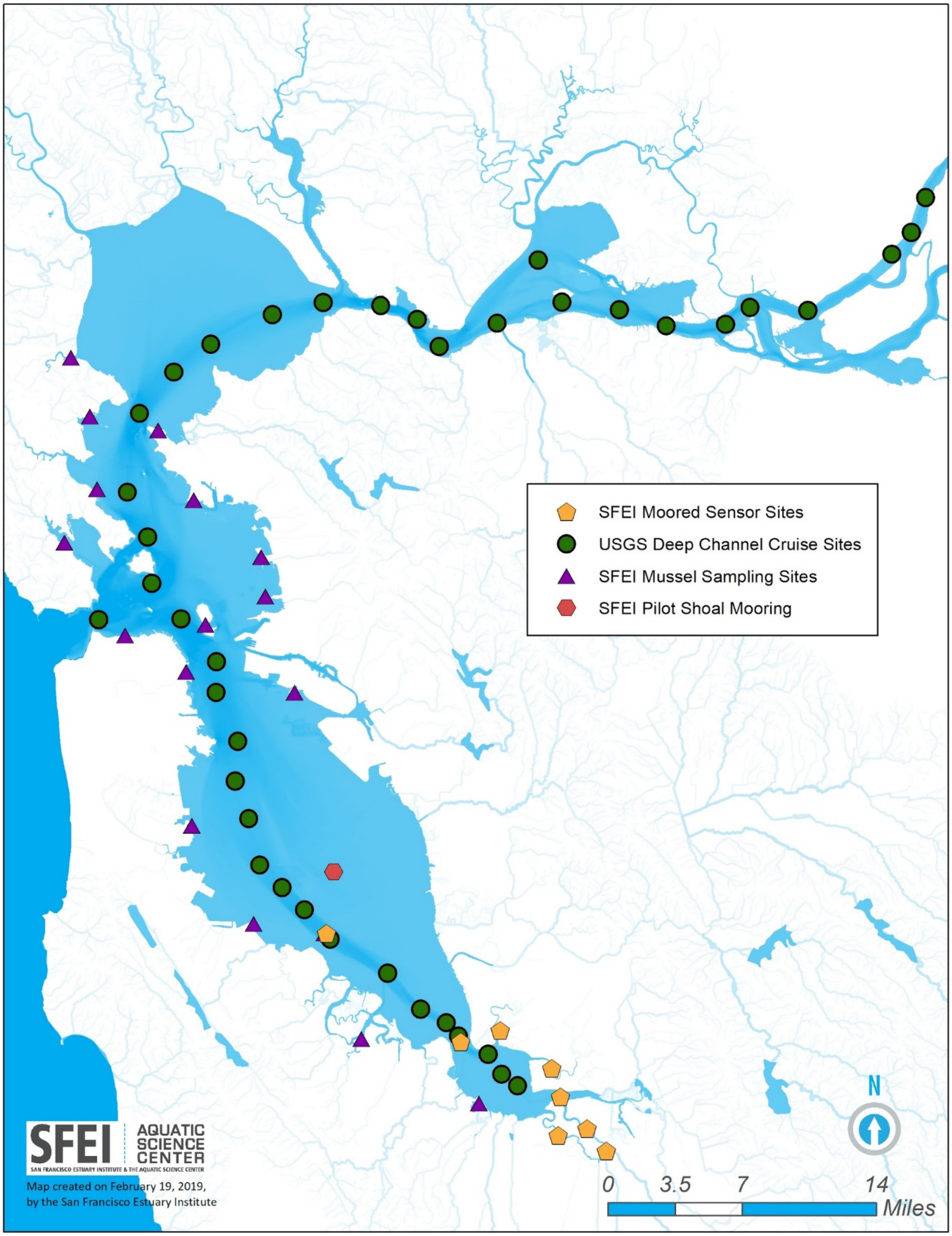

Figure 1: Site locations of all current monitoring program efforts

Table 1: List of current NMSOP monitoring efforts, including analytes measured, measurement frequencies, comments, and estimated yearly costs.

MONITORING EFFORT	PRIMARY AGENCY	ANALYTES	MEASUREMENT FREQUENCY	COMMENTS	ESTIMATED YEARLY COST
Moored Sensor Program	SFEI	· Dissolved Oxygen · Chlorophyll-a · Blue-Green Algae · Temperature · Salinity · Dissolved Organic Matter · Depth	High-frequency measurements collected at 15-minute intervals. Servicing every 3-6 weeks.	Data used for mechanistic understanding of potential nutrient impacts, as well as water quality model calibration. The program is set up in the Lower South Bay, which is a strong indicator of the status of water quality in the Bay.	$362,000
Deep-Chanel Ship-Based Monitoring	USGS	· Dissolved Oxygen · Chlorophyll · Light Extinction Coefficient · Susp. Particulate Matter · Salinity · Temperature · Optical Backscatter · Nitrate · Nitrate + Nitrite · Ammonium · Phosphate · Silicate · Zooplankton · Phytoplankton (Imaging Flow Cytobot and lab testing) · Phytoplankton microscopy	2-4 week measurement intervals	This USGS ship-based channel monitoring has existed since 1969. Since 2013, NMS funds have helped support the baseline monitoring, as well as add the following analytes to normal monitoring procedures. These analytes will directly inform nutrient related processes: · Zooplankton (year) · Imaging flow cytobot (year) · Total N and Total P (year) Additionally, SFEI has provided funds to increase the frequency of microscopy sampling and discrete chlorophyll sampling. Previously these samples only gathered when chl-a was above a threshold; now they are collected with each cruise.	$175,000
Shoal Monitoring (yearlong deployment at one location)	SFEI	· Dissolved Oxygen · Nitrate · Chlorophyll-a · Blue-Green Algae · Temperature · Salinity · Dissolved Organic Matter · Depth	4-6 week high-frequency deployments in spring/fall of 2018, as well as the spring of 2017	The three separate shoal monitoring deployments have indicated that there are notable differences in chlorophyll patterns in the shoal compared to the adjoining deep channel, and thus have warranted a continued and/or expanded shoal monitoring program	$125,000
Toxins in Mussels	SFEI	· Domoic Acid · Microcystin · Saxitoxin	Bi-weekly sampling	The mussel sampling occurs around the perimeter of the Bay. In addition to the benefits of long-term monitoring, this program has also provided a public health benefit, with one occurrence of leading to closed	$116,000

MONITORING EFFORT	PRIMARY AGENCY	ANALYTES	MEASUREMENT FREQUENCY	COMMENTS	ESTIMATED YEARLY COST
				public fisheries due to a measured saxitoxin exceedence.	
Anchovy Collection	SFEI	· Domoic Acid · Microcystin · Saxitoxin	Monthly (DWR) and 1-4 times 3 days per week (Marine Science Institute)	This is currently a pilot monitoring study, providing a separate method of measuring biotoxins to compare with the mussels collected on the Bay's perimeter.	$80,000

4. Potential Program Additions

Figure 2 provides a visual of the core monitoring operations, the guaranteed addition for CY 2019 (year-long mooring deployment in the shoal northeast of the San Mateo Bridge), future monitoring uncertainties (the USGS deep channel cruise monitoring program, discussed in detail in section 5, as well as potential program additions to be considered as we move forward. Table 2 provides more detailed descriptions of the planned and potential additions to the program.

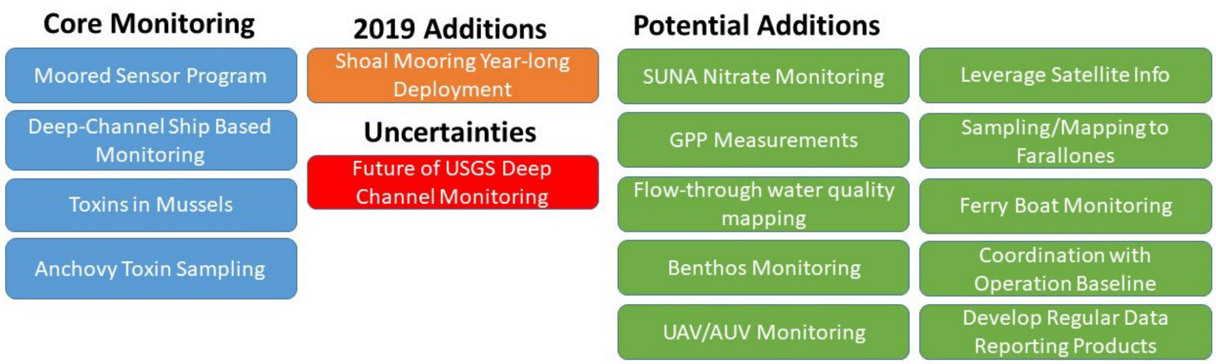

Figure 2: Schematic of the current monitoring program focuses, planned and potential additions, as well as program uncertainties.

Table 2: Descriptions of planned and potential monitoring program additions.

MONITORING PROGRAM ADDITIONS/AMENDMENTS	DESCRIPTION
Shoal Monitoring	SFEI has piloted three high-frequency shoal monitoring studies (Spring 2017, Spring/Fall 2018) to the northeast of San Mateo Bridge. Results have demonstrated that there are potentially significant differences between gross primary production between the shoals and deep-channel. Sustained monitoring in the shoals would allow for these differences to be better understood.
SUNA Monitoring	Integrate SUNA instruments into the observation program to collect high-frequency nitrate data. SFEI has deployed a SUNA in the three shoal monitoring efforts but has yet to deploy a SUNA to collect year-round nitrate measurements.

MONITORING PROGRAM ADDITIONS/AMENDMENTS	DESCRIPTION
Gross Primary Productivity (GPP) Measurements	Regularly collect discrete measurements of GPP to calibrate GPP estimation models, as well as to ground-truth satellite information
Flow-Through Water Quality Mapping	Conduct real-time flow-through water quality mapping in various locations throughout the Bay in collaboration with partners at the USGS.
Observation Program Optimization	Still being in its early development, the NMSOP is in a crucial stage to re-evaluate the efficiencies of current monitoring efforts, as well as to look for new opportunities to collaborate and consolidate collected information through partnerships with the USGS, the RMP, and the IEP. This would also include continuing efforts to standardize approaches to instrument setup and analysis (efforts already underway with the chlorophyll intercalibration project).
Benthos Monitoring	Conduct regular benthos flux measurements, as well as directed biological population count studies. In addition to the importance of ecological assessment, knowing types of organisms and density is important for estimating grazing rates. There is currently no sustained sampling south of San Pablo Bay, which is an important potential important data gap.
Leverage Satellite Information	This would involve both 1) collecting data to ground-truth satellite measurements and 2) building capacity to analyze satellite data. Expanding the satellite data monitoring could be an effective manner for keeping the program sustainable/cost effective. Ground data to collect could involve specialized discrete sample collection, timing USGS cruises with specific satellite flyovers, and/or experimenting with a boat-mounted or drone-mounted radiometer for on the ground calibrations with satellite measurements.
Sampling/Mapping out to the Farallones	Conducting semi-regular sampling and mapping expeditions through the Golden Gate and out toward the Farallon Islands to better understand nutrient fluxes between the bay and ocean
UAV/AUV Monitoring	Integrate UAV (underwater) and AUV (aerial) technologies into monitoring efforts.
Ferry Boat Monitoring	Integrate water monitoring instruments onto the ferry boats that take multiple daily trips across various regions of SF Bay
Coordination with Operation Baseline	Operation Baseline is designed to measure the baseline nutrient related conditions in the Sacramento River before the pending nutrient removal upgrades to the Sacramento Regional Wastewater Treatment Plant. The plant upgrades will lead to a shift in the river's biogeochemistry and will be a relevant example for the Bay and Delta ecosystems as to the effects of reducing nutrient loading. This provides an opportunity for the NMSOP to coordinate with Operation Baseline.
Develop Regular Data Reporting Products	Ensure that the monitoring and observational data collection efforts are reported on a regular schedule and in an effective manner.

5. Recommended Approach

Continuing to develop the NMSOP will be a joint effort to refine the current observation program, as well as to add new elements to the program that are specifically aimed at addressing the guiding management questions. The current monitoring program (discussed in section 3) has provided a solid foundation, and it is recommended to continue each of these monitoring efforts. Adding more data to this already valuable monitoring program will continue to provide a basis for addressing primary management questions. With that said, we should evaluate which portions of the current plan should be modified and/or streamlined. For example, we recommend keeping a certain number of LSB moored sensor high-frequency sites active (there is high value in keeping running a proportion of this well-established monitoring system in region of the Bay that is vulnerable and relatively unmonitored), but also looking for opportunities to relocate a certain number of sites to areas of the Bay that may provide more insightful information on nutrient-related water quality parameters. This process will involve determining which sites may be presenting us with duplicate information, and then identifying priority relocation sites.

More broadly, a closer evaluation of different organizations' monitoring programs in SF Bay (SFEI, DWR-IEP, USGS, RMP) will likely identify areas of overlap between the programs and offer insight into streamlining data collection processes and continue to expand and strengthen partnerships. For example, there is likely overlap between data collected between USGS cruises and DWR-IEP cruises. We recommend including this evaluation process as a top priority in the 1-1.5 year timeframe. SFEI should also look for all opportunities possible to collaborate and contribute to Operation Baseline (see table 2) and other monitoring efforts related to the upgrade of the Sacramento Regional Wastewater Treatment Plant.

Additionally, we strongly recommend expanding the current monitoring network to include the following on-the-ground efforts in the 1-year timeframe:

- Expand shoal monitoring to the greatest extent that funding and person-power will allow. As of February 2019, there will be a "long-term" shoal mooring station to be deployed for one year (starting at the end of February or early March 2019). Looking beyond this year, it may prove valuable to keep the station running longer than one year, and/or to deploy shoal mooring packages simultaneously at multiple locations. The pilot monitoring studies in the shoals have demonstrated that there are key differences between the shoals and deep channel, but more data is needed to fully analyze the mechanisms and implications of these differences. Notably, the one-year shoal mooring to be deployed in Spring, 2019 will include a high-frequency SUNA nitrate sensor.

- Including at least one more high-frequency SUNA nitrate sensor (in addition to the shoal SUNA sensor) to be running full time in the Bay, whether co-located with one of our current moored sensor sites or at another chosen location. Potential site locations include Dumbarton Bridge, San Mateo Bridge, or Coyote Creek. There is also the potential to include a SUNA in the flow-through system of the USGS deep-channel cruise program. Including SUNA nitrate sensors into the monitoring network will allow for more detailed analysis of nitrate concentrations in relation to water quality parameters.

Also within this next 1-3 year timeframe, we should look to conduct pilot monitoring efforts to evaluate additional observation approaches. This may include conducting additional pilot runs of high-frequency mapping with the USGS, doing basic satellite analysis to explore the potential of satellite data (potentially important for keeping the program sustainable/cost effective), conducting initial GPP measurements, developing a preliminary plan for a benthos monitoring program, and conducting mapping/sampling efforts through the Golden Gate and out toward the Farallons (pending initial results of the coastal flux study). These pilot efforts will be essential for future decisions regarding the NMSOP. While some of these ideas could be funded directly by the NMS, others would be useful as pilot projects to seek additional outside funding. For example, initial efforts in leveraging satellite data could be useful in applying for NASA and NOAA grants. Other efforts that are a lower priority but could add valuable new components include utilizing the ferry boat network for monitoring, as well as exploring the utility of UAVs and AUVs.

With any high-quality monitoring program should also come intensive data quality and data management efforts, as well as the development of informative tools for data reporting and dispersion. This should not be overlooked as the program continues to develop, and will require dedicated funds to develop and maintain.

Finally, and importantly, we note that the funding for the future of the USGS deep-channel cruise monitoring program is uncertain in the one-year timeframe. This program, throughout its nearly fifty years of operation, has been without rival in its contributions to water quality assessments of SF Bay. It has also been a key platform for the expansion of SFEI's nutrient observation program, as funding and person power from the NMSOP has contributed to adding key new analytes (zooplankton net tows, imaging flow cytobot for phytoplankton) to the cruise's normal monitoring, as well as increasing the frequency of collection of discrete samples of chlorophyll, nitrogen and phosphorous, and HAB microscopy (which were previously only measured when chlorophyll was above a minimum threshold). There is the potential that the cruise monitoring program will cease to exist. Another potential is that the program will be adopted by another agency or branch of USGS, which would likely require increased funds from NMSOP to help keep the program running. While a potential increase in funds from the NMSOP would offset some of the planned funding increases, it would be money well spent to keep the invaluable deep-channel monitoring program afloat. There could also be options to keep the program running while decreasing its scope (e.g., dropping certain in-between stations, or dedicating the northern half of the Bay to the DWR-IEP cruise and the southern half to the USGS cruise). More concrete information will likely become available in spring 2019, but the NMSOP should prepare for all possible scenarios, as well as do all that is possible to keep the cruise up and running.

6. References

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APPENDIX B: NUTRIENT CYCLING WORK PLAN

NUTRIENT CYCLING WORK PLAN: FY2020-FY2024

San Francisco Bay Nutrient Management Strategy

March 2019

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1. Summary

This report is the first phase in refining the Nutrient Management Strategy (NMS) science questions and fieldwork plan for 2019 to 2024. This research will inform the management objectives of the program. However, there are many ways the field program can address these goals. In order to refine our approach, we will convene an expert working group to provide input on the design of our research program. The research program will focus on quantifying nutrient related processes but will measure other variables concurrently (e.g., primary production) that are linked to nutrient cycling and biogeochemical processes. Some options and proposed approaches for targeted field studies are listed below, and this suggested approach will be refined iteratively. The near term goals are to quantify rates of nutrient cycling in SF Bay and to improve our understanding of spatial and temporal patterns of biogeochemical rates. The long term goals are to compare current data to historical measurements to assess changes in the Bay over the last 40 years, and to improve the biogeochemical components of our SF Bay model and its ability to link nutrient concentrations to environmental conditions in the Bay.

2. Introduction

High levels of nutrient inputs to estuarine systems can cause ecosystem impairment through the stimulation of large phytoplankton blooms and subsequent low oxygen conditions (hypoxia) (Conley et al. 2009). Increases in nutrient loading from anthropogenic sources have resulted in hypoxia and faunal mortality in several coastal systems in North America, including the Chesapeake Bay, the Louisiana Shelf, and parts of Puget Sound (Diaz 2001). The nutrient budget in San Francisco Bay (SF Bay), however, differs from these other systems due to the Bay's high turbidity, abundant filter feeders, and rapid tidal exchange which limit phytoplankton productivity, despite high nutrient loads from agricultural and urban sources (Cole and Cloern, 1984; Alpine and Cloern, 1992).

Historically the Bay has been resilient to anthropogenic nutrient inputs. However, recent increases in phytoplankton blooms (Cloern et al. 2010) suggest the ability of the system to buffer nitrogen (N) inputs could be declining. Furthermore, ongoing increases in the surrounding urban population and consequently nutrient loads could continue to impact SF Bay water quality. Our ability to predict the effects of increased nutrient loads is limited because the relationship between nutrient inputs and phytoplankton blooms and low oxygen is not well constrained. It is, therefore, becoming more important to better constrain rates of biogeochemical processes.

Despite the long-term monitoring of nutrient concentrations in SF Bay, very little work has quantified rates of N transformations (Damashek et al. 2016). Preliminary models of the Bay suggest biogeochemical nitrogen transformations are important processes (e.g., nitrification and denitrification). However, the experimental/field data is limited to a handful of studies, mostly conducted in the '80s and 90's when conditions in the Bay were very different (e.g., Hammond et al. 1985; Caffrey et al. 1994). Reports of research gaps have repeatedly identified biogeochemical cycling as an area requiring further study, both for our overall understanding of the Bay and for constraining rates in biogeochemical models.

Nitrogen cycling is complex (Fig. 1) and difficult to fully constrain. Field studies will, therefore, be limited to addressing the highest priority questions, as a large scale field collection is not feasible. Literature analysis and synthesis will help us identify the most important data gaps and prioritize the collection of data needed for numerical models of biogeochemistry in the Bay. A targeted field study will then be undertaken to address these gaps. The combined approach of analysis, synthesis, and field collection will address the ultimate goal of this research, which is to establish a nitrogen cycling budget for the South SF Bay and improve current models of nitrogen transport and fate.

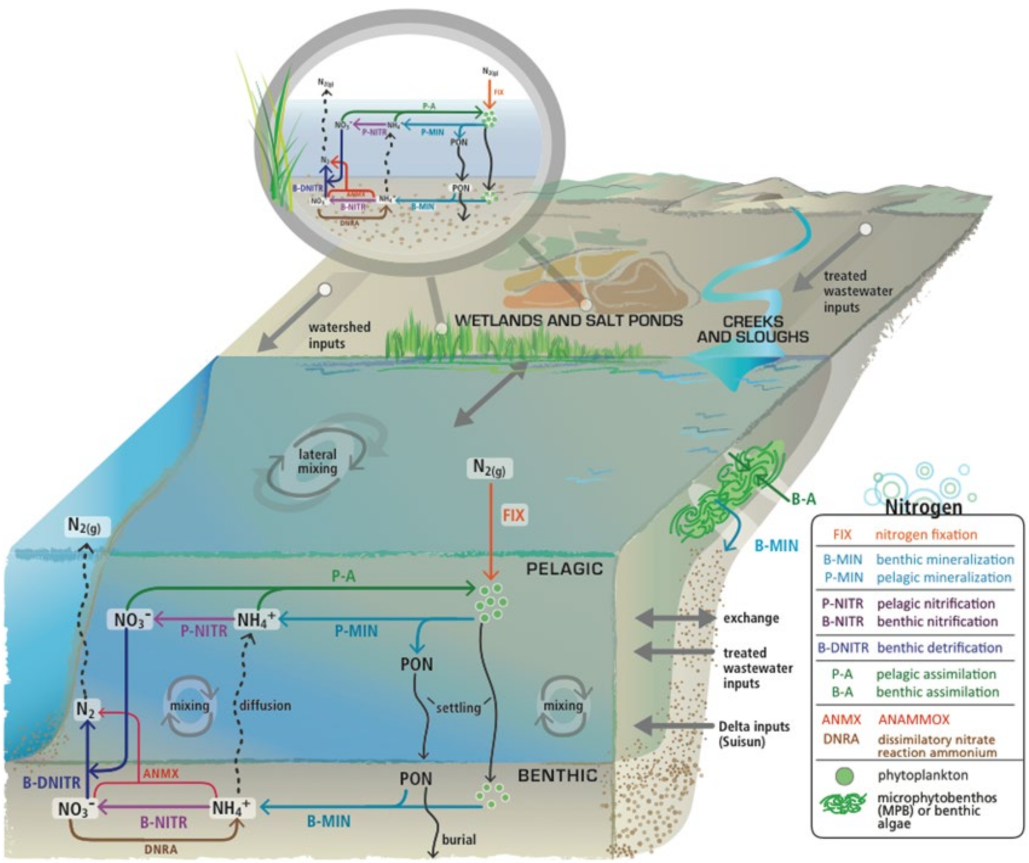


Figure 1. Conceptual diagram of the nitrogen cycle in coastal systems.

3. Management questions

1. What conditions would be considered adverse impacts or impairments?
   1.1. DO/chl in deep subtidal habitats
   1.2. DO in shallow margin habitats
   1.3. HAB abundance, toxin abundance, phytoplankton assemblage
   1.4. Coastal ocean
2. Monitoring and condition assessment: are adverse impacts or impairment currently occurring?
   2.1. DO/chl in deep subtidal habitats
   2.2. DO in shallow margin habitats
   2.3. HAB abundance, toxin abundance, phytoplankton assemblage
   2.4. Coastal ocean
3. How do SF Bay habitats respond to nutrient inputs- dose:response?
   3.1. DO/chl in deep subtidal habitats
   3.2. DO in shallow margin habitats
   3.3. HAB abundance, toxin abundance, phytoplankton assemblage
   3.4. Coastal ocean
4. Risk of impacts under future scenarios (changing system behavior)?
5. What are the contributions of individual nutrient sources to nutrient levels throughout SF Bay over space and time?
   5.1. Magnitudes (± variability) of individual nutrient loads at the point of entry (present, future)
   5.2. Magnitudes of nutrient transformations and losses within SF Bay and space/time variability?
   5.3. Contributions of individual nutrient sources to loads/concentrations in 'subregions'?
6. What management actions or load reductions are needed to prevent or mitigate current or future?
   6.1. What reductions/changes are needed within subregions to mitigate impairments?
   6.2. What load reductions or other management actions can achieve local effects?
   6.3. Evaluation combinations of options: feasibility, effectiveness, cost-efficiency

The special studies field program should ultimately contribute to answering all of these questions. However, it will specifically target questions 3 and 5. These management questions have been set through multiple iterations with the NMS Steering Committee but can be discussed with the advisory team.

4. Science Questions

4.1. High-level science questions

These questions are modified from the Lower South Bay Synthesis Report. They are tightly linked to management goals.

1. How do nutrient concentrations and forms vary spatially and temporally, particularly in margin habitats?
2. What are the dominant processes controlling nutrient fate, and how do their magnitudes vary spatially and temporally?
3. What nutrient loads can SF Bay assimilate without adverse impacts with respect to chl-a, DO and algal toxins?
4. What effects are salt pond restoration activities having on nutrients in the margins? The open bay?
5. What would be protective nutrient levels in terms of biomass, DO, and phytoplankton assemblage or toxins?

Note: The Special Studies Plan laid out here does not directly address questions related to salt ponds. However, we may be able to indirectly infer their impact on nutrient cycling through the use of models. If this analysis suggests their contribution may be important, we will add a study that specifically targets salt ponds.

4.2. Detailed science questions

The detailed science questions are based on the high-level science questions and are intended to help us identify priority processes and measurements to focus on as part of the field program. These questions can be discussed and further refined or amended.

1. How do the following parameters, identified as 'very high' priority nutrient issues in the Nutrient Conceptual Model Report, vary temporally and spatially?
    - Pelagic nitrification
    - Benthic nitrification
    - Benthic denitrification
    - Pelagic OM mineralization and release of NH_4^+ and PO_4^{3-}
    - Benthic OM mineralization and release of NH_4^+ and PO_4^{3-}
    - Phytoplankton C:N:P
    - Ambient concentrations of NO_3^-, NH_4^+, and PO_4^{3-}
2. How do these processes compare in terms of relative importance?
3. Are these the most important parameters to measure? Should others be added?
4. What processes and sediment characteristics can we measure to better understand the relationship between benthic fluxes/rates and sediment chemistry? Which relationships could be established so sediment data could be used to calibrate model coefficients, thus reducing the need for costly rate measurements?
5. What is the best combination of parameters we can measure to calibrate the biogeochemical model?
6. What would be the most efficient set of measurements to collect in the field to develop an N budget for SF Bay subembayments?

5. Proposed Fieldwork Program

5.1. Introduction

This is the recommended approach for the fieldwork program. Included in this approach is a plan that could be implemented; however, it will be further refined through the expert working group. Planning and pilot data collection are suggested as the first phase, followed by targeted field studies, and finally the use of the data for model calibration and validation. The field program will leverage the NMS Observation Program when possible to minimize costs but will need to go beyond water column nutrient concentration measurements to measure rates of pelagic and benthic biogeochemical processes.

5.2. Assess the current state of knowledge and identify data gaps to address

In order to identify what information is needed to improve our understanding of nutrient cycling in the Bay, first, we need to compile published data that are available. Data both in the Bay and from other estuarine systems can be leveraged. A literature review and analysis will allow us to identify high priority processes and important parameters for modeling before commencing costly field studies. Once we identify processes of relative importance, the field study program can focus on the highest priority data gaps.

Very few studies have quantified nitrogen transformation rates in the Bay. Most studies of benthic fluxes and biogeochemical rates were conducted in the ’80s and ’90s, although there have been some more recent field studies as well. A literature review will identify any published water column and benthic flux data that exist. These data will be collected and summarized to better understand what is already know about N cycling in SF Bay. These data can eventually be compared to current rates measured by our field program to evaluate what has changed across ~40 years.

Existing data compiled from SF Bay will then be compared to other estuarine systems, notably the Chesapeake Bay, where extensive benthic and water column data have already been collected and made publicly available (Boynton and Bailey, 2008). Chesapeake Bay data will be reviewed for similarities in physical, chemical and biological conditions (depth, salinity, turbidity, DO and other water column conditions such as chlorophyll-a levels) to subembayments in SF Bay to develop possible extrapolations of the findings from the Chesapeake Bay. The extrapolations will aim to develop bounds for SF Bay model calibration based on observed sediment oxygen demand, nutrient fluxes and decomposition/ mineralization rates used in corresponding locations in the Chesapeake Bay model. We will see if these existing datasets can be used to better parameterize rates in SF Bay

To ensure the field data collected will inform biogeochemical models of SF Bay, model scenario runs will be performed to estimate the importance of various biogeochemical processes by turning on/off the process. This will inform decisions if more data collection is needed to better resolve the particular processes. We can also do model sensitivity tests to external forcing conditions or parameters to identify data gaps. Note that while it may be possible for us to identify/rule out the major processes that have been hypothesized to affect biogeochemical processes in the system such as light, turbidity, and grazing, the importance of processes that severely lack validation data, such as sediment diagenesis, cannot be properly assessed by this exercise. It is also noteworthy that the confidence of model sensitivity runs depends heavily on how well the model is calibrated, so these model runs can only provide suggestions on data collection and should be used in conjunction with other clues from the literature and previous data collection to guide the fieldwork plan.

5.3. Determine spatial and temporal coverage of sampling

Existing datasets and models of the Bay will be used to identify sampling locations. The spatial coverage of the field program will span a range of habitats such as shoals, high depositional areas, and the deeper channel. Sampling along a range of habitat types will be targeted because establishing the relationship between sediment characteristics, sediment oxygen consumption and nutrient fluxes are especially important for calibration of models. In order to establish these relationships for TOC and SOD, for example, we will need a range of organic C concentrations to calibrate coefficients of the model.

The output from existing simulations will be used to determine the geographic regions that the special studies should target. Areas with high GPP, detrital material, and nutrient fluxes, etc. can be identified using the existing sediment diagenesis model with the default parameter settings. Existing data from the Bay can also be used, such as the Contaminant Data Display and Download (CD3) data from the Regional Monitoring Program (RMP). This dataset includes hundreds of sediment total organic carbon and total nitrogen measurements throughout the Bay (Fig. 2). The data can be used to identify areas with high organic C inputs, and areas with labile carbon (based on C:N ratio) which indicates fresher OM inputs.

Initial field collections will be focused on South Bay or Lower South Bay. If it’s within the budget, the study could also be extended to other subembayments. However, as the South Bay is heavily impacted by POTW outputs (Table 1; BACWA Nutrient Watershed Permit Annual Report, 2018), this region will be the primary focus.

The timing of sampling will be seasonal to capture temporal patterns in nutrient concentrations (Fig. 3), and based in part on water column (WC) chlorophyll. WC chlorophyll can drive sediment conditions (e.g., nitrogen and benthic chlorophyll) but with a two to three-month lag (Lesen 2006). We will plan to sample during bloom periods, after the bloom, and at times of high and low flow. Sampling over multiple growing seasons will give us a more comprehensive understanding of temporal variability in the system.

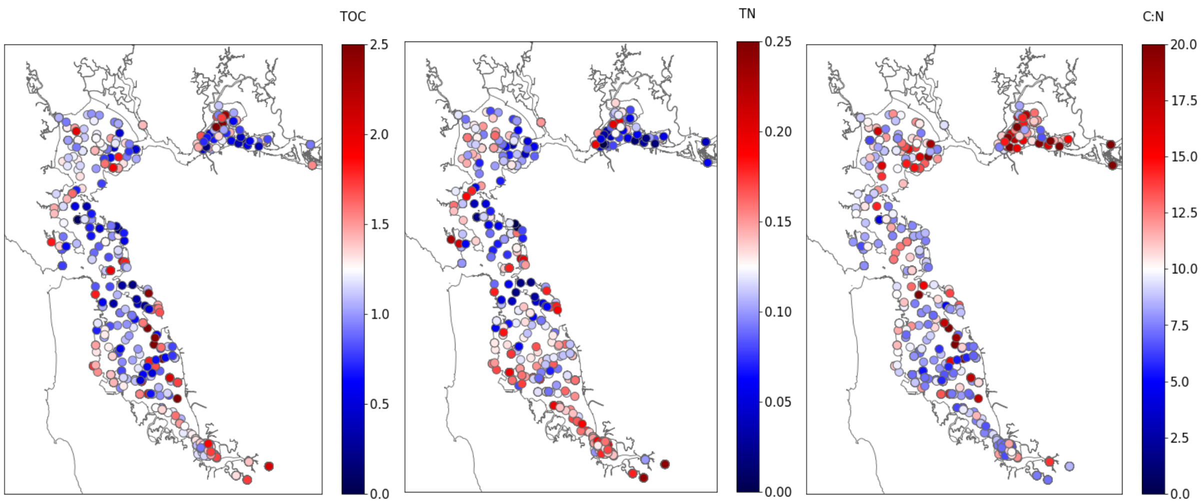


Figure 2. Map of sediment TOC (A), TN (B) and C:N (C) data from cd3.sfei.org. Data are averaged from 1993 to 2015.

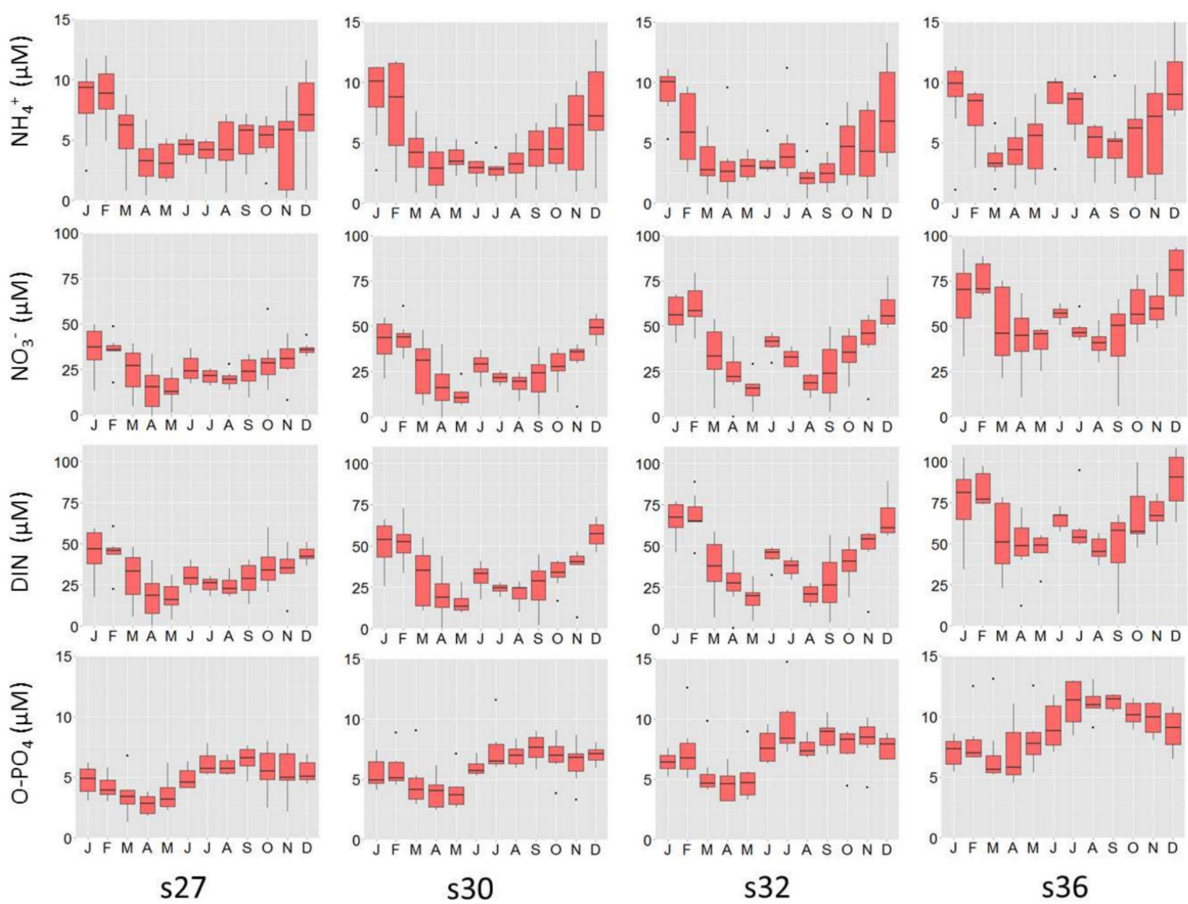


Figure 3. Seasonal variability in nutrient concentrations in South Bay from 1972 to 1980 and 1988 to 2012. S27, s30, s32, and s36 represent USGS sampling stations; stations with increasing numbers are further south. Modified from SFEI Lower South Bay Nutrient Synthesis Report. Data from USGS.

Table 1. Annual average daily discharges of TN (kg N/d) by subembayment adapted from BACWA Nutrient Watershed Permit Annual Report, 2018.

SUBEMBAYMENT	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Suisun Bay	7,323	7,141	6,774	6,487	6,734	7,300
San Pablo Bay	2,094	2,101	2,379	2,338	2,786	2,261
Central Bay	12,558	13,134	12,593	12,994	13,831	13,942
South Bay	22,471	24,644	25,150	25,130	25,927	25,300
Lower South Bay	8,647	7,978	8,888	8,499	9,635	8,340
Total	**53,093**	**54,998**	**55,784**	**55,448**	**58,913**	**57,144**

5.4. Proposed program for field collection of biogeochemical data

Once data gaps have been identified and spatial coverage determined, field collection can proceed. Potential projects are outlined here. However, these plans can be further refined after the expert working group, and preliminary analyses are complete.

The following processes and analytes could be measured in the water column. These water column parameters and processes can be used to validate the biogeochemical model for the year the data are collected.

- Nitrification rate
- Primary production
- Oxygen consumption/OM mineralization and release of NH_4^+ and PO_4^{3-}
- Nutrient concentrations (organic/inorganic)
- Microbial community
- Zooplankton biomass

The following processes and analytes could be measured in the sediment. At the moment, an out-of-the-box set of parameters (default values) have been applied to the sediment diagenesis model, and great uncertainty exists for the appropriate parameters or even model structure for the system. To properly evaluate the importance of sediment diagenesis processes, some baseline measurement is required to reduce the model uncertainties and improve the robustness of the model in general.

- Nitrification rate
- Denitrification rate
- Nutrient fluxes
- Sediment oxygen consumption
- Ancillary sediment characteristics:
    - Benthic chlorophyll
    - TOC/TN/TP/C:N
    - Organic carbon sources using lipid biomarkers
    - Porewater nutrients
    - Porosity
    - Sediment temperature
    - Porewater salinity

- Infaunal community
- Clam density
- Microbial community

There are several different methods that can be applied. We suggest measuring benthic fluxes using intact cores. This is more cost-effective than measuring *in situ* fluxes, which would allow us to sample at more locations, and ^{15}N tracers can be added during core incubations to quantify rates of nitrogen cycling. A limitation of using cores is they are modified systems and cannot exactly recreate field conditions. Ideally, at some locations, we will compare core incubations to potential slurry rates, which are easier to measure. If there is good agreement between the two methods, slurry rates could be measured at a higher spatial resolution and would allow for mechanistic comparisons at a lower cost. Other options should be discussed as well, including using N_2:Ar ratios to estimate denitrification and inferring system-wide rates through measuring water column nutrient concentrations and water velocity (discussed below).

Where possible we will make coupled sediment/water column measurements in the field because the WC and benthos can be tightly linked in shallow systems. Concurrent measurements are also important for model development. Benthic sampling stations could be similar to Caffrey (1996) to facilitate comparisons of multi-decadal data (Fig. 4). Measurements could also be made in similar locations as the moored sensors so data from both programs could be compared, and measurements could be made when the shoal mooring is being serviced. Water column sampling could coincide with monthly USGS cruises as well as the shoal mooring maintenance to minimize costs of the fieldwork.

After the first year of sampling, we will be able to compare our data to the Chesapeake Bay to see if any trends are consistent. The second year of data collection would allow us to make some initial observations about interannual variability. These studies will be novel enough that they will be stand-alone papers and reports. However, the data will also be used for refining SF Bay models.

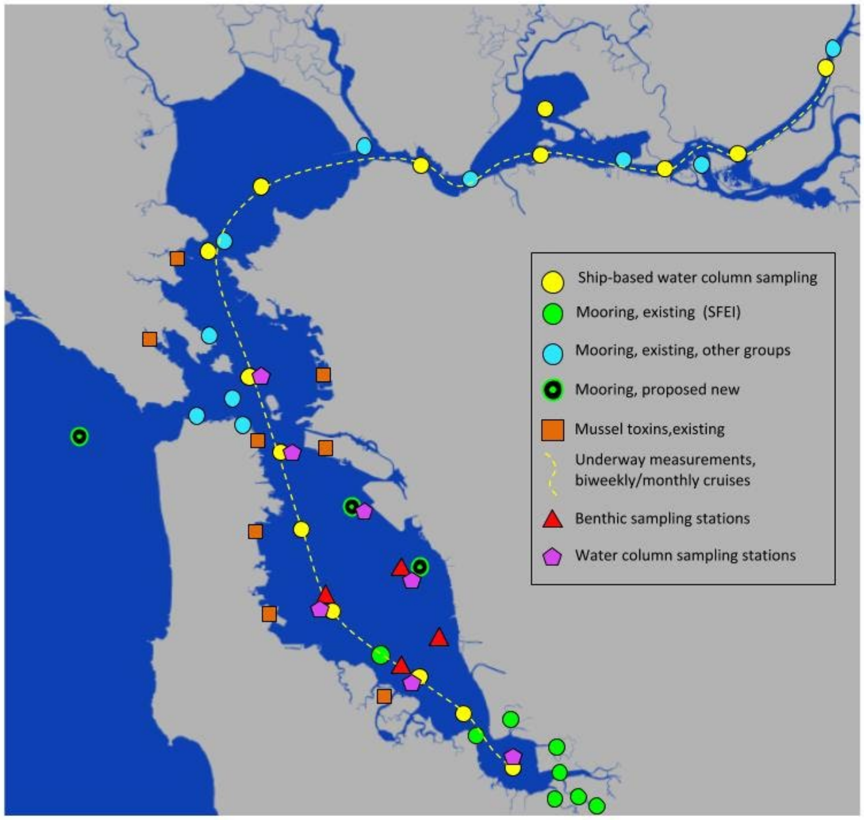


Figure 4. Map of current monitoring programs and proposed additional sites.

5.5. Alternative approaches

There are other approaches to the fieldwork that could be used besides the plan outlined above. Below is a summary of other options with the strengths and weakness of each:

Extensive Direct Measurements:	Combined approach:	Observation/Inference:
Measure process rates and sediment chemistry directly	Observational program with some essential rate measurements, e.g., water column nitrification	Use moored sensors, high-frequency mapping, and models to develop mass balances and calculate rates

Strengths: Develops mechanistic relationships *Weaknesses*: Limited spatial scope in areas with high variability	*Strengths*: Allows ground truthing of observations/ inferences *Weaknesses*: Expensive to undertake both types of fieldwork	*Strengths*: Ecosystem-scale, integrates sediment heterogeneity *Weaknesses*: Difficult to identify drivers of patterns

We will discuss with the expert working group: what combination of these approaches takes best advantage of the relative strengths and mitigates limitations, and fits within our budget?

5.6. Analysis, synthesis, and model refinement

The field data will contribute to a better understanding of N cycling in the Bay. All of the data collected will be synthesized into a final report and interpretations will be made about rates of N cycling. Ancillary data will be used to determine potential drivers of rates, and temporal and spatial patterns will be examined. Data will be compared to rates measured at similar locations in the 80's and '90s in order to examine multidecadal trends in the Bay. Finalized datasets will be made publicly available for other researchers in the Bay to access.

The field data will also be used to improve existing models of biogeochemistry. Water quality in the Bay is modeled using paired hydrodynamic (D-Flow Flexible Mesh) and biogeochemical (D-Water Quality) models. N cycling data will be used to refine the DWAQ model, and the paired hydrodynamic/biogeochemical model can then be used to develop an N budget and examine transformations at the subembayment scale. Once field measurements have been used to parameterize rates in the biogeochemical model, the relationship between rates and environmental variables will be applied to other water years. The model can be used to inform the magnitude of nutrient load reductions needed to maintain acceptable healthy ecosystem targets. The model can also be used to predict responses of water quality in the Bay to future scenarios. The analysis and synthesis of the data will ultimately help make informed management decisions about nutrient loading in SF Bay.

6. Potential Timelines

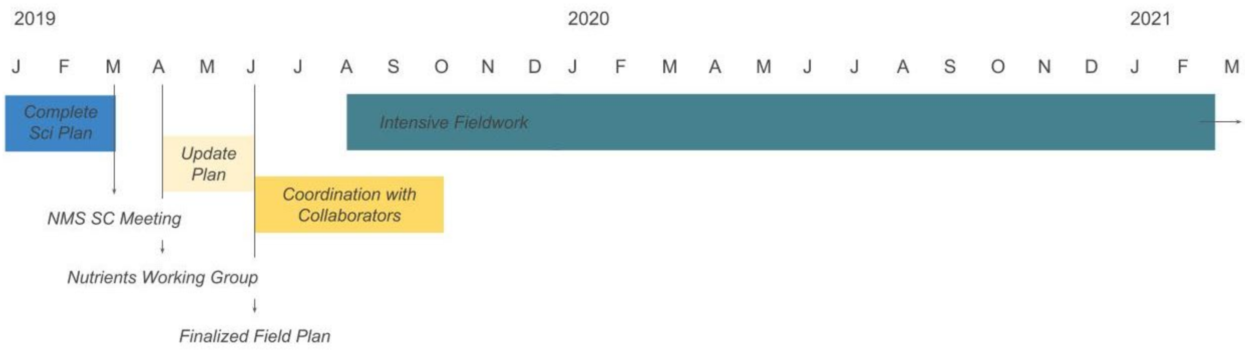
There are different options for a fieldwork program timeline. Here, three different timelines are proposed. Each timeline includes completing the Science Plan by the NMS SC meeting in March, convening an Expert Working Group in April, and work on an updated plan.

6.1. Option A

This timeline would involve starting intensive fieldwork as soon as August 2019, before conducting preliminary fieldwork. After the finalize field plan is complete in June, there would be two to three months of coordination with collaborators before intensive fieldwork commenced.

Pros: Would start fieldwork as soon as possible, data would be available for models sooner

Cons: Allows only limited time to plan and optimize fieldwork, it would be hard to predict important processes so we could miss measuring some key processes, would require more resources to measure the full suite of processes intensively.



6.2. Option B

Targeted field studies would be conducted from June until Oct 2019. This limited-scope fieldwork would inform the intensive fieldwork program. The fieldwork plan would be revised based on pilot fieldwork, and the full field program would commence in Oct 2019.

Pros: Limited-scope fieldwork will inform intensive fieldwork; it would still allow plenty of time for intensive fieldwork.

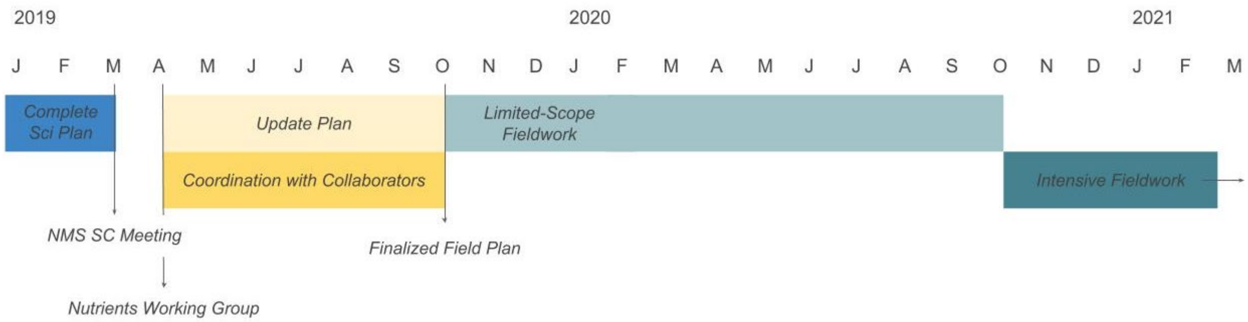
Cons: It would be difficult to start fieldwork this summer, there is limited time to plan.

6.3. Option C

In this timeline, preliminary fieldwork will be conducted over one full year starting in October 2019. This would allow more time for preliminary analysis of existing data and for conducting a sensitivity analysis to identify important processes. In the second year, we will conduct a more intensive field program that would last a full year.

Pros: More time for detailed analysis and synthesis of existing data and models, more time to coordinate with collaborators and bring on postdocs/students, limited-scope fieldwork will inform intensive fieldwork and full year of preliminary data will be a complete dataset on its own, potentially more cost-effective.

Cons: Only one year of intensive fieldwork data collected, data may not be ready for input into models until later.



7. Budget

The Special Studies budget includes line items for all aspects of the project, including assessing the current state of knowledge, field data collection, project management, and biogeochemical modeling. It is a draft working budget and will be updated as the field program continues to be planned. This budget assumes the ship-based sampling, and moored sensors programs are going forward. However, they are not accounted for here because they fall under the Observational Program.

Table 2. Nutrient Cycling Program Budget

PROJECT	2019	2020	2021	2022	2023	2024	TOTAL
Analysis of model for study design	$25,000	$25,000					$50,000
Literature review, analysis of existing data	$25,000						$25,000
Expert working group	$10,000			$10,000			$20,000
Field measurements	$40,000	$290,000	$350,000	$40,000			$720,000
Program management		$50,000	$50,000	$50,000	$50,000	$50,000	$250,000
Continued analysis of data, productivity, mechanisms		$100,000	$100,000	$75,000	$50,000	$25,000	$350,000
Basic model building		$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
Biogeochemical model simulations		$200,000	$200,000	$200,000	$200,000	$200,000	$1,000,000
Total	**$100,000**	**$765,000**	**$800,000**	**$475,000**	**$400,000**	**$375,000**	**$2,915,000**

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APPENDIX C: MODELING WORK PLAN

APPENDIX C: MODELING WORK PLAN: FY2020-FY2024

San Francisco Bay Nutrient Management Strategy

Draft-March 2019

1. Introduction

This work plan describes proposed Nutrient Management Strategy (NMS) activities related to the development and application of coupled hydrodynamic-biogeochemical models over the time period FY2020-FY2024 for informing nutrient management decisions for San Francisco Bay. Early NMS documents (SFEI 2014, SFEI 2015) laid out high-level goals and approaches for model development. Model development work began in Aug 2015, and two recent reports document the configuration of one of the main thrusts of the model (SFEI 2017; SFEI 2018).

The 5-year Modeling Workplan for FY2020-2024 describes the following:

1. Main management questions and related science questions
2. Proposed model development and application projects to answer those questions
3. Estimated time and budget required, and a proposed sequence of work

2. Modeling Approach

We selected the Deltares Flexible Mesh (DFM) model and the Deltares Water Quality model (D-WAQ) as our primary platforms for coupled hydrodynamic and biogeochemical modeling. This modeling platform was selected based on an extensive review of modeling options and input from modeling experts (SFEI, 2014). Additional background on model platform selection and planning can be founded in SFEI (2014, 2015). Other models and tools have been used over the past few years of work to provide valuable input or parameterize the model to best characterize the system (Table 1).

Status of NMS Modeling Work (February 2019)

Work began on development of NMS Hydrodynamic and Biogeochemical models in August 2015. Currently, the NMS uses 3 different model set-ups (different grids or domains) for pursuing studies in different regions of SFB (Figure 1). Our basic approach to pursuing modeling work is illustrated in Figure 2, and can be broken up into 3 categories -- hydrodynamic model development; biogeochemical model development; and modeling studies -- with the first two categories building capacity for pursuing the modeling studies, which target management relevant science questions (Figure 1). For some early Modeling Study work, we have used best-available or early-stage model implementations, to begin exploring relevant questions while model development is still on-going.

The status of model development for each model set-up is summarized in Table 1, with processes currently incorporated into the model shown in Figure 2.

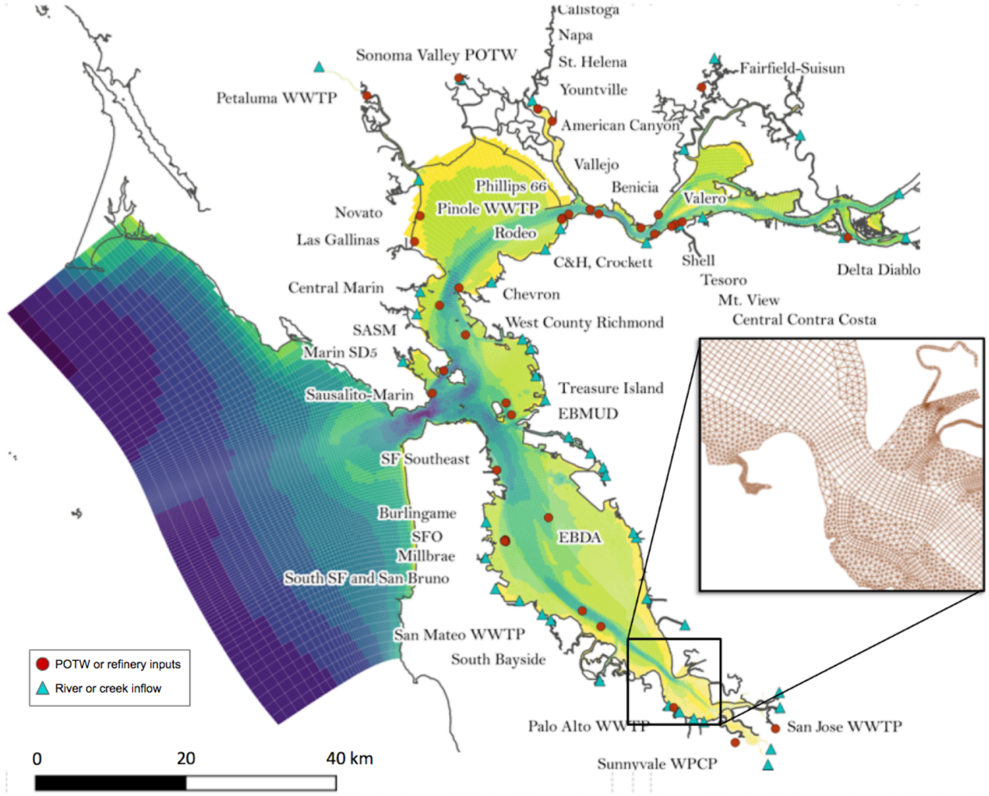
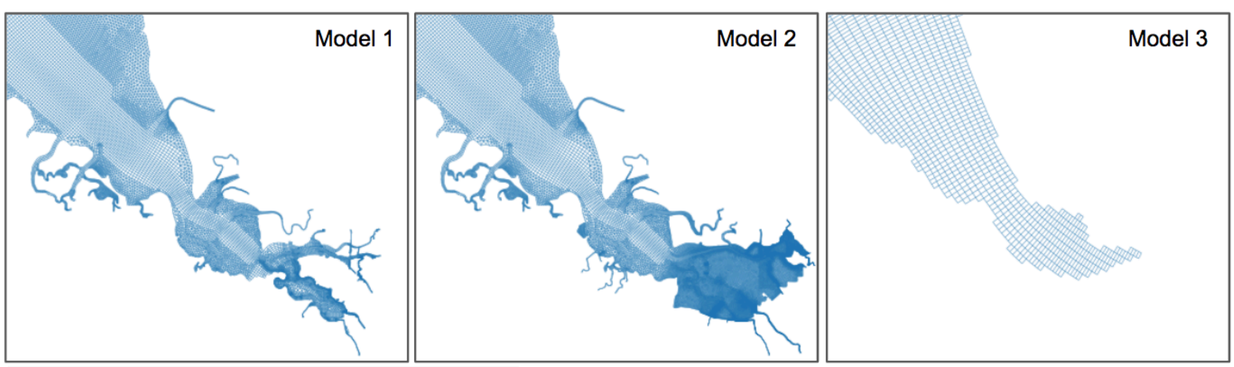


*Figure 1 Model domain and grid for **Model 1**, the full-Bay core model. Color indicates depth; zoomed inset illustrates grid resolution near the Dumbarton Bridge. This model is intended for high-resolution Bay-wide biogeochemistry simulations, focused on deep subtidal habitats. Note: Model 1 does not include a resolved Delta; instead, upstream boundary conditions (flows, concentrations) are imposed based on observations and upstream model output.*



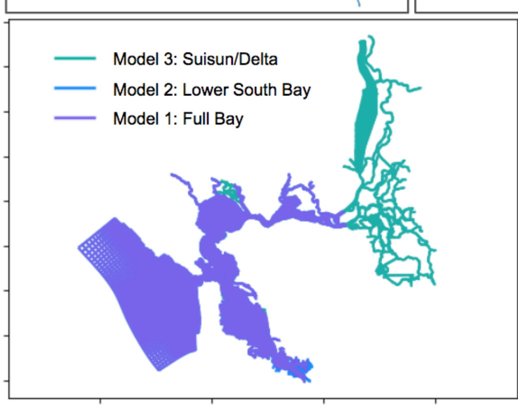


***Figure 2** Overall, the NMS is using three distinct model setups. **Model 1**: see Figure 1; **Model 2** LSB-focused model, which is the same as Model 1 north of the Dumbarton, but with a high-resolution grid and bathymetry for LSB, including exchange with restored salt ponds. **Model 3** Suisun-Delta focused model, has a fully-resolved grid for the Delta, but a lower resolution grid for Central, South, and Lower South Bays.*

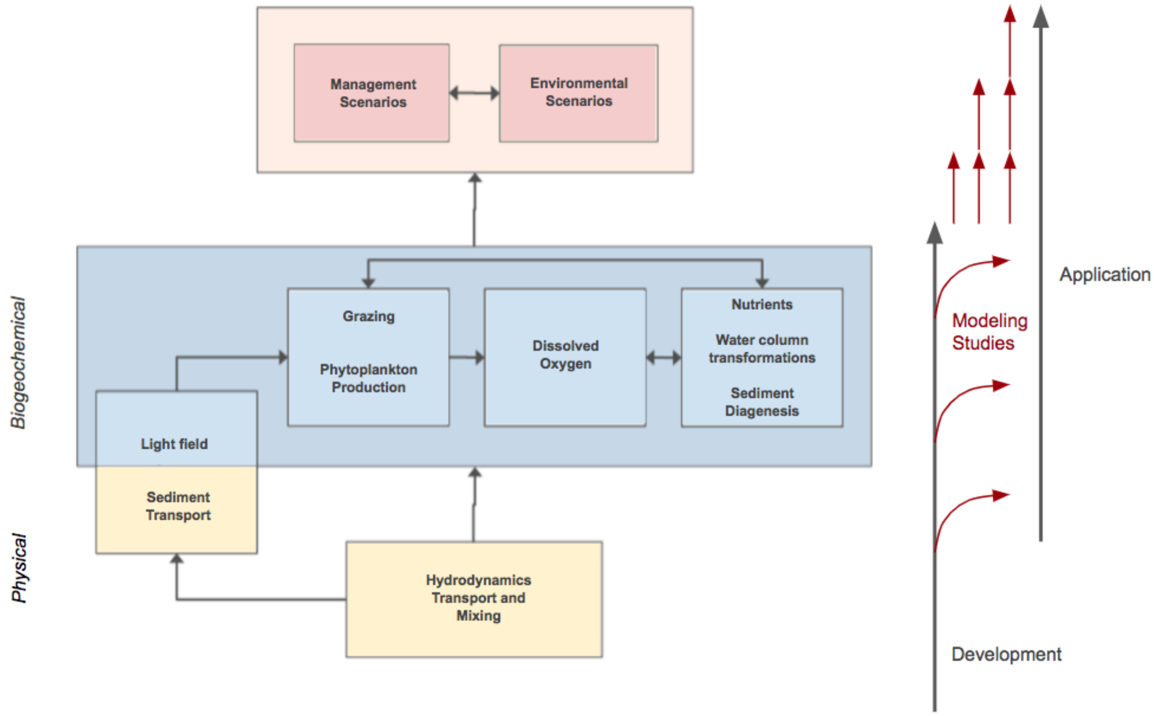


Figure 1 Schematic of Modeling Approach

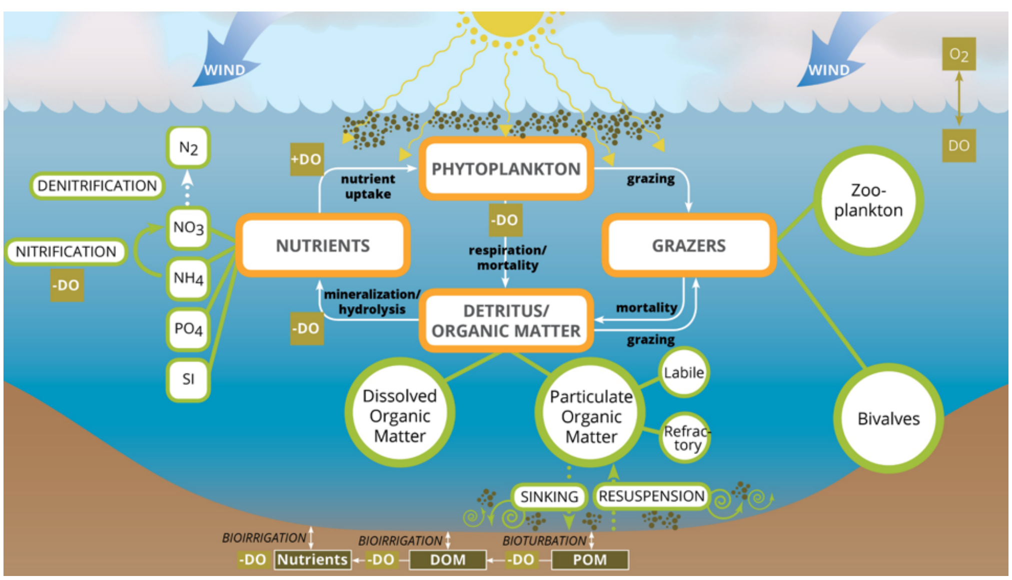


Figure 3 Variables and major processes currently in implemented in Model 1 and Model 3.

Table 1 Overview of Model Development status. Descriptions are presented in terms of (rows) regional focus area of the model (different model grids and calibrated time-periods) and by types of work (hydrodynamics, biogeochemistry, modeling studies or applications). See Figure 1 for additional information about individual models.

Regional Focus	**Model Development**		**C. Modeling Studies/Applications**
	A. Hydrodynamics & Model Setup	**B. Biogeochemistry/Sediment**	
Full Bay/ Core	1. During Yr1 used SUNTANS to drive biogeochemistry; developed translator, SUNTANS→DELWAQ 2. Refined grid to optimize model performance run-time 3. Calibrated WY2013 in DFM, extensive validation of stage, velocity, salinity 4. Developed model set-up resources and model inputs for other years (2000-2018) a. Scripts for model setup/validation b. Hydrological model, 44 watershed c. POTW flows and nutrient loads d. Developing multiyear windfield (in progress) 5. Calibration of additional water years underway (2017, 2018, 2014)	1. Stepwise testing and implementation of major biogeochemical model features a. Water column N transformations b. Sediment diagenesis / fluxes c. Oxygen cycling, respiration d. Phytoplankton production e. Zooplankton grazing 2. Testing/refinement of dynamic energy balance (DEB) model for zooplankton grazers. 3. Muliti-year (1992-2017) space/time interpolated estimates of daily light attenuation for deep channel 4. Development of tidally-corrected aggregated model (fast-running) and application to tune nutrient transformation rates 5. Work beginning in 2019 on a sediment/light model 6. Tested two approaches for simulating phytoplankton production and community	1. Conservative tracer runs of major nutrient sources to identify first-order contribution areas 2. Subembayment-scale nutrient budgets (monthly, annually) with a simplified biogeochemical model a. loads, net exchanges, losses b. Exports to the coast c. Influence of potential upgrades on ambient N concentrations 3. Full WY2013 biogeochemical simulation a. Qualitative assessment of biogeochemical model results (chl-a, N, P, DO) b. Interpretation of factors causing/destroying blooms.
2. Suisun/ Delta	1. Collaborated with CASCADE project (USGS) and Deltares a. hydrodynamic model development b. temperature model 2. Calibrated WY2011 and WY2010 (USGS) (link) 3. Physical forcing database and setup scripts for efficient model setup and validation for new water years (underway) 4. Calibration of additional hydrodynamic water years underway (WY2016)	1. Stepwise testing and implementation of major biogeochemical model features (same as above) 2. Extensive testing and refinement of DEB model for benthic grazers 3. Developing techniques for grid aggregation to allow for shorter biogeochemical run times for model tuning, exploration, sensitivity analysis, etc. (these techniques will be directly applicable to other domains or focus areas).	1. Analysis of WY2011 Delta/Suisun nutrient cycling with simplified biogeochemical model. 2. Exploring the influence of nutrient sources on ambient nutrient conditions: a. Regional San current vs. future loads b. CCCSD space/time influence 3. Full WY2011 biogeochemical simulation (phytoplankton, zooplankton, benthos)
3. Lower South Bay	1. Established high resolution grid to resolve key features, including slough channels, levees, and wetlands. 2. Combined multiple bathymetry datasets 3. Incorporated salt pond breaches/gates 4. Calibrated for some time windows 5. Undergoing further calibration	None to date	None to date

3. Work Plan

The overall aims of modeling work for FY2020-FY2024 include improving NMS biogeochemical models' ability to accurately predict water quality conditions, and applying those models to answer or explore key management and science questions (Tables 2-3). The proposed approach for improving and applying the biogeochemical models includes:

1. Simulate water quality under a diverse range of physical forcings (tidal, seasonal, interannual) and observed environmental responses; evaluate model skill; and refine or 'tune' the model parameterizations or coefficients to better reproduce the full range of conditions.
2. Run the hydrodynamic model and compile other physical forcing data needed to simulate biogeochemistry for those time periods.
3. Develop needed resources or tools for exploring or interpreting model output, and optimizing run times.
4. Conduct modeling studies to address science and management questions, including through interpretation of model output and through targeted simulations using calibrated models
5. Obtain input from a team of external expert advisors: advising on the most rigorous and efficient approaches for pursuing the above work; conducting technical peer review of model results and interpretations

This section outlines the major modeling tasks, sequencing of those tasks, milestones and deliverables, and timelines. Proposed work is organized into five main task, each having multiple subtasks, including region-specific development:

Task 1: Hydrodynamic modeling and physical forcings
Task 2: Biogeochemical model development
Task 3: Modeling Studies
Task 4: Tools and Model Maintenance
Task 5: External Advising and Peer Review

Estimated timelines and milestones/deliverables are summarized in Tables 4, with budget estimates discussed in Section 4.

Task 1 Hydrodynamic Modeling

Task 1.1: Hydrodynamics for the full-Bay (core) Model A have already been calibrated for water year (WY) 2013. WY2013 was selected as the initial hydrodynamic calibration year to take advantage of the large number of stations throughout the Bay where velocities were measured (multiple weeks per station (see SFEI 2017, 2018). The hydrodynamic model will be run for an additional 3-5 water years. WY2017 is one high priority, a wet year but also one during which extensive high frequency are available (in particular in South Bay, including a ~1 month mooring deployment on the South Bay shoal). Additional years will be selected based on a few criteria, including:

1. Time periods during which Interesting or important biogeochemical phenomenon were observed
2. Availability of high-frequency biogeochemical data (increasingly available in South and Lower South Bays beginning in WY2014).
3. Perhaps somewhat counterintuitively, relatively 'boring' years, either in terms physical forcings or biogeochemistry, to contrast with other years when conditions.

Task 1.2: Hydrodynamics for up to 5 additional years will be simulated using Model A to allow for their use (after biogeochemical simulations) in estimating material fluxes to the coastal zone (water, nutrients), for integration into a collaborative project with investigators at SCCWRP and UCLA related to physical-biogeochemical simulations of conditions along the CA coast. Having 5-10 years of physical-biogeochemical simulations will allow the NMS modeling effort to serve as the terrestrial forcing model input to the coastal model. In addition to directly supporting the jointly-funded coastal project, coordination on delivering the terrestrial physical-biogeochemical forcings provides the NMS with the opportunity to obtain modeled coastal-boundary condition forcings from this model of the CA current

Task 1.3: SFB is a highly turbid estuary, and light availability in the water column is an important determinant of when and where phytoplankton blooms occur, and on the amount of nutrients utilized for primary production. Accurately predicting water column light levels (or light attenuation) is, however, extremely challenging because it typically involves simulating sediment resuspension and transport. Task 1.3 will continue on-going work, with the goal of developing and implementing a tractable approach for obtaining modeled or semi-empirical estimates of light attenuation for years in which biogeochemistry are being simulated. The exact approach that will be employed still needs to be determined, and awaits outcomes of current projecs.

Task 1.4: The LSB-focused model, Model B, was originally calibrated for time windows in 2015 and 2016 by SFEI. Additional model refinement and calibration was recently undertaken by RMA, supported by other funding. Given the system's complexity, it is expected that additional effort will be needed to further refine Model B's calibration prior to eventual use in biogeochemical simulations.

Task 1.5: The Suisun-Delta focused hydrodynamic model, Model C, has already been calibrated for WY2010 and WY2011 (funded in part by the NMS, via USGS CASCADE II project). As part of separate projects, hydrodynamic calibration for WY2016 is currently underway. Additional work will likely be needed to integrate model runs for Suisun Bay using Model C with those conducted across using Model A. Time has been allocated here, with exact work TBD.

Table 1 Nutrient Management Strategy main management questions

1. What conditions would be considered adverse impacts or impairments that require management or mitigation?		
	1.1	DO / chl in deep subtidals
	1.2	DO in shallow margin habitats
	1.3	HAB abundance, toxin abundance, Phytoplankton assemblage
	1.4	Coastal ocean
2. Monitoring and condition assessment: Are adverse impacts impacts or impairment currently occurring?		
	2.1	DO / chl in deep subtidals
	2.2	DO in shallow margin habitats
	2.3	HAB abundance, toxin abundance, Phytoplankton assemblage
	2.4	Coastal ocean
3. How do SFB habitats respond to nutrient inputs -- dose:response? Are nutrients causing or contributing to current impacts or impairment?		
	3.1	DO / chl in deep subtidals
	3.2	DO in shallow margin habitats
	3.3	HAB abundance, toxin abundance, Phytoplankton assemblage
	3.4	Coastal ocean
4. What potential future impacts or impairments warrant pre-emptive management actions?		
5. What are the contributions of individual nutrient sources to nutrient levels throughout SFB? How do these contributions vary in space and time (seasonal, under different physical forcings)?		
	5.1	Current magnitudes (± variability) of individual nutrient loads at their point of entry to SFB?
	5.2	Anticipated load changes: environmental change, flow diversion, population, land-use, management
	5.3	Magnitudes of nutrient transformations and losses within SFB, space/time variability?
	5.4	Contributions of individual nutrient sources to loads/concentrations in "subregions"?
6. What management actions or load reductions are needed to prevent or mitigate current or future impairment?		
	6.1	What "local" reductions/changes are needed within subregions to mitigate impairments?
	6.2	What load reductions or other management actions can achieve the "local" effect(s)?
	6.3	What are plausible options for achieving the local effects?

Table 2 Modeling-related Science Questions, translating management questions into testable scientific questions that will shape model development or specific projects to address those questions. Shaded boxes indicate NMS Management Questions (Table 1) addressed by each Science Question.

	Modeling Science Questions	**Management Questions**																			
		1				**2**				**3**				**4**	**5**				**6**		
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4		5.1	5.2	5.3	5.4	6.1	6.2	6.3
A	How do individual nutrient sources contribute to specific habitats, regions, and subembayments, and how do relative contributions vary as a function of physical forcings?									■	■	■					■	■		■	■
B	What are reasonable regional or subembayment boundaries for nutrient management considerations (contiguous areas having similar relative nutrient sources)?									■	■	■					■	■		■	■
C	Subembayment-level nutrient budgets: What are the magnitudes of loads, losses, transformations, and transport? What are the assimilative capacities for N and P?									■	■	■					■	■	■	■	
D	How do fluxes of N and P to the coast vary seasonally/interannually, and what are the primary controlling factors?												■	■					■		
E	What factors regulate phytoplankton blooms/productivity? Under what conditions do large blooms occur?					■	■	■		■	■	■		■					■	■	
F	Under what conditions could low DO develop in deep subtidal habitats?	■				■				■				■					■	■	
G	How do salt pond restoration and management influence nutrients, chl, DO in LSB? (current and future openings)						■			■	■			■			■	■	■	■	
H	To what extent do exchange with salt ponds, combined with high nutrient loads, contribute to DO deficits in LSB sloughs in creeks?						■			■	■			■			■		■	■	
I	What factors contribute most strongly influence, or best explain, long-term trends in chl-a over time?									■		■	■	■					■		
J	How will the Bay respond to changing N inputs? Increases due to population growth; Decreases resulting from load reduction scenarios									■	■	■	■	■			■	■	■		
K	What confidence intervals or levels of certainty are associated with management-relevant model interpretations?									■	■	■	■	■			■	■	■	■	■

Table 4. Timeline of major subtasks

TASK #	DESCRIPTION	FY 2020				FY 2021				FY 2022				FY 2023				FY 2024			
Task 1	**Hydrodynamic Modeling**																				
1.1	Simulate ~5 additional years				2																
1.2	Simulate ~5 additional years, coastal										6										
1.3	Light field				2						6										
1.4	LSB focus						4a				6										
1.5	Suisun/Delta focus						4a														
Task 2	**Biogeochemical model refinement**																				
2.1	Full-bay, chl-a/DO, ~5 yrs				2						6										
2.2	Full-bay, nutrients, ~5 yrs				2						6										
2.3	LSB-focus						4a				,4b,6						,4c,10				
2.4	Suisun-focus										7a,6						7b,10				7c,14
2.5	Coastal exchange, integration										8a,6						8b,10				8c,14
2.6	Sensitivity analysis		1a		1b,2				1c												
Task 3	**Modeling Studies (analyses, interpretations)**																				
3.1	Nutrient source attribution, subembayments				3a,2						3b,6						3c,10				3d,14
3.2	Effects of load increases				11a,2						11b,6						11c,10				11d,14
3.3	Effects of Load reductions																12a,10				12b,14
3.4	Potential bloom/DO effects							5a			5b,6		5c								
3.5	Long-term changes in chl-a, GPP, etc.										9a,6						9b,10				
3.6	Quantifying uncertainty																13a,10				13b,14
Task 4	**Tools & Model Maintenance**																				
4.1	Grid aggregation				3a,2				3b												
4.2	Particle/tracer tests				2																
4.3	Maintaining model input, new physical forcings																				
4.4	Troubleshooting, refining code																				
4.5	Computing resources																				
4.6	Model management (documentation, etc.)				2						6						10				14
Task 5	**Modeling program review**																				
5.1	Staff prep, report out		*		*,2						*,6						*,10				
5.2	Honoraria/travel																				

Task 2 Biogeochemical Model Development/Refinement

The primary focus of Task 2 is on-going calibration, testing, and refinement of biogeochemical models. Although the Modeling Studies and Applications are called out separately within Task 3, some of the initial work related to those applications will also be carried out within Task 2: when relevant, model runs will be set up such that they yield output that can be directly used in Task 3; since the applications and science/management questions targeted in Task 3 address many of the key motivations for the modeling work, we will be evaluating model performance and interpreting output from Task 2 runs with an eye toward the focused interpretations in Task 3.

<u>Tasks 2.1 and 2.2 Full-Bay (Model 1) Biogeochemical Calibration</u>: The full-Bay, Model 1, biogeochemical model will undergo further calibration for phytoplankton production, dissolved oxygen, and nutrients, by simulating additional time periods (up to ~5 additional years), and tuning the model to achieve the best 'global' calibration for predicting the range of conditions observed. The full-Bay biogeochemical model has already been provisionally-calibrated for WY2013. That model setup will be used as the starting point for simulating subsequent years, with hydrodynamic output from Task 1.1 used to drive the biogeochemical model. As noted above, additional simulation years will be selected based on a few criteria, including:

1. Time periods during which Interesting or important biogeochemical phenomenon were observed
2. Availability of high-frequency biogeochemical data (increasingly available in South and Lower South Bays beginning in WY2014).
3. Perhaps somewhat counterintuitively, relatively 'boring' years, either in terms physical forcings or biogeochemistry, to contrast with other years when conditions.

WY2017 is one high priority year, because of its distinct set of physical forcings (wet year), noteworthy biogeochemical responses, and the availability of high frequency biogeochemical data (Figure 3). Other potential years include: WY2006 or WY1998 (large blooms); one or more from WY2014-WY2016, WY2018, or WY2019 (abundant high frequency data); and some historic years during which extensive discrete data collection and some rate measurements were performed (e.g., 1980).

Major activities will include: i. Incorporating a time-space varying light field; ii. Refining sediment diagenesis model; iii. Further testing of pelagic and benthic grazing; iv. Utilizing high-frequency observational data to guide model tuning and improve mechanistic accuracy of simulated processes; v. For all of the above, tuning the numerous (and interconnected) processes; and vi. Detailed mechanistic interpretation and write-up of biogeochemical model results (including for WY2013; spatial and temporal variations of important processes, mass balances, etc.).

Although phytoplankton (chl-a), DO, and nutrients will generally all be included across model runs, they are binned into two distinct tasks in Table 4, in recognition that effort (and progress) may focus more on one than the other at times, because of differences in the targets of some of the motivating management or science questions, or to test differences in modeling approaches. For example, D-WAQ has the option of simulating phytoplankton using two very distinct approaches, BLOOM [potentially more informative or mechanistically-accurate (multiple phytoplankton classes) if working correctly, but much more complex, requiring further testing and consideration] vs. DYNAMO [a more straightforward approach, consistent with many other estuary models]. Although the WY2013 model employs DYNAMO, pilot work is already underway, in collaboration with Deltares modelers, on testing and refining BLOOM for application in SFB, and that work will continue in Task 2.1.

Model calibration and the related activities above will greatly aided by two tools that require require some development:

- *Grid aggregation*: [Note: Described here, but budgeted for as Task 4.1] Converting hydrodynamic data from the high-resolution output yielded by Task 1 to a lower-resolution 'working-version' for model testing and tuning. High-res hydrodynamic output is needed to ensure transport and mixing are simulated properly; and high-res biogeochemical runs will the gold-standard used for most final interpretations and analyses. However, because of the extremely long run times for high-res biogeochemical simulations (10-14 days to run 1-yr on a multi-processor machine), faster-running approximations are needed to test model refinements, and to efficiently tune numerous processes to yield a optimized calibration. Although work has already begun on developing grid aggregation code for the Suisun-Delta (Model C), that approach needs to be refined and tested for other regions (Model 1). In addition, multiple test runs and analysis must be carried out to identify the appropriate resolution and structure for the aggregated runs, to achieve an acceptable balance between model fidelity and run-time (e.g., target ~1 day to simulate 1 yr).
- *Tracers and Particle Tracking:* [Note: Described here, but budgeted for as Task 4.2] Numerical tracers and particle tracking are important modeling tools used to help interpret model output. Added to the model at user-selected locations (e.g., as a continuous inflow, or as point source or cloud), the transport and spreading over time of conservative (non-reactive) or reactive tracers (e.g., like a dye) or a cluster of particles can be used to understand or quantify mixing rates, flushing rates, or residence times, and can also track or record conditions that a water parcel experiences during transit. The Deltares models do not currently have 3D particle tracking capabilities; however, through a collaborator, the NMS has access to a powerful particle-tracking code that has been used extensively in other Bay-Delta 3D-unstructured grid models. In addition, while D-WAQ does have tracer capability, some work is needed to develop capacity at SFEI to efficiently setup, run, and interpret tracer output. Therefore, work will go forward to adapt the particle tracking model for use with DFM; and to develop utilities for running, visualizing, and interpreting tracer results.

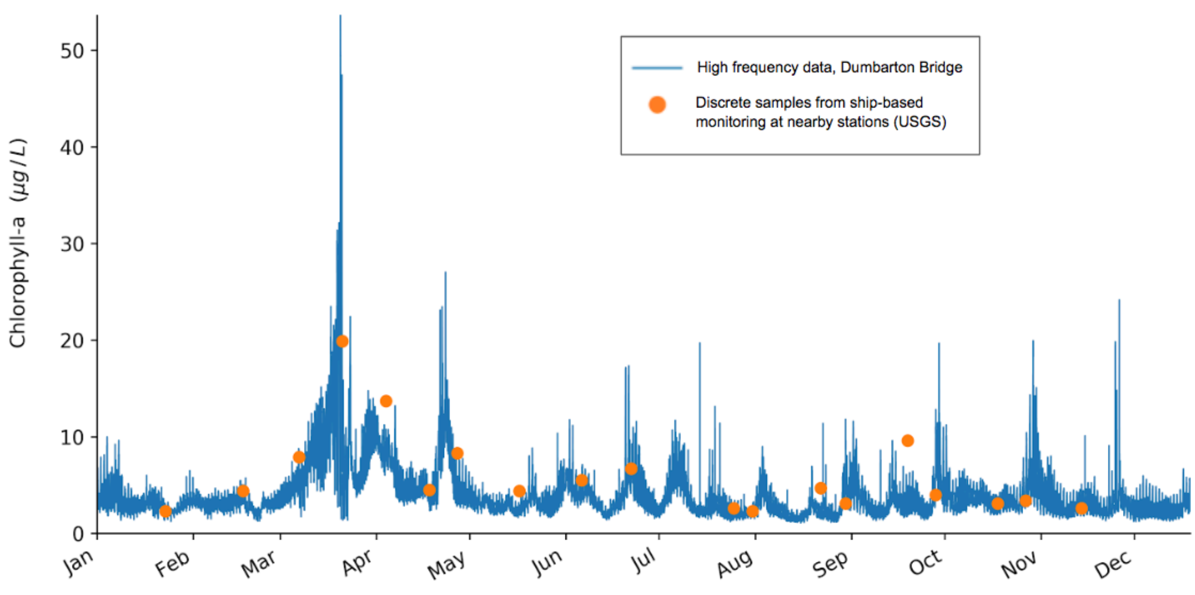


Figure 3 Chlorophyll-a data near the Dumbarton Bridge during 2017, from a high-frequency moored instrument (15 min; blue line) and biweekly-monthly discrete samples from ship-based monitoring.

<u>Task 2.3 Lower South Bay focused Biogeochemical Model Development (Model 2)</u>**:** The goal of this task is to model exchange between, and transformations within, salt ponds, sloughs, and the open Bay, with a particular emphasis on quantifying processes not currently captured by Model 1. The tidal sloughs in the South and Lower South Bay are small features compared to the open bay; however, because of recently-restored hydraulic connections with salt ponds, the pond-slough-exchange influence on nutrient cycling, phytoplankton production, and DO appears to be locally-important within margin habitats (SFEI, 2014a, MacVean et al, 2018), and may also substantially influence biogeochemistry in open Bay areas south of the Dumbarton Bridge.

LSB is a complex environment, with numerous small features that are nonetheless important -- e.g., small narrow sloughs connected with even narrower salt pond breaches or gates. Explicitly simulating those small features leads to a high-resolution grid (Figure 2), which in turn leads to long run times.

LSB biogeochemical modeling work will follow a somewhat different approach than our approach for full-Bay modeling work (Model 1). Because of the long-run times, we will focus on shorter simulation time periods, in particular those with dense observational data. We will also explore questions related to pond-slough effects on open-Bay biogeochemistry through approaches that emphasize the use of high frequency observational data combined with transport modeling and tracers or particles. Lastly, a key aim of initial LSB biogeochemical work will be to assess the relative importance of pond-slough interactions in terms of influence open-Bay conditions (i.e., must they be included?), and whether they need to be explicitly modeled or could be approximated in other less computationally intensive ways. The exact approaches for conducting biogeochemical model simulations in LSB remain under development, and is among the topics that we will explore extensively with external advisors.

<u>Task 2.4 Suisun-Delta focus (Model 3):</u> The goal of this task is to develop a subembayment-scale water quality/ phytoplankton/ grazing model, aimed at mechanistically modeling biogeochemical processes in north SF Bay (Suisun, San Pablo) and the Delta, to help address multiple nutrient management questions that are somewhat unique to this region. Details of, and rationale for this project are described fully in a June 2018 Progress Report (SFEI, 2018b). Work in this region has gone forward thus far using Model 3.

Suisun-Delta biogeochemical model development work has thus far been supported by a range of Delta and Bay funders, including: Central Valley Regional Water Quality Control Board, Delta Science Program Council, Regional San, Delta Regional Monitoring Program, and indirectly the NMS (via direct funding from Central Contra Costa Sanitary District). Although on-going work has a strong Delta focus, it has a strong nexus to NMS management questions given the large, seasonally-varying nutrient flux that enters Suisun Bay from the Delta.

Biogeochemistry for Model 3 has been provisionally calibrated for WY2011. On-going work includes undertaking biogeochemical model calibration for WY2016, a data-rich year with very different phytoplankton productivity. Although a different grid is being used currently for simulating Suisun-Delta than the full-Bay, there is strong cross-fertilization between efforts in terms of model set-up, parameterizations, tuning, etc. For example, the considerable effort put toward zooplankton grazing in Model 1 was directly transferable to Model 3. In addition, we are using many of the same code/tools for visualizing and interpreting data. For Suisun-Delta modeling, simulating benthic grazers is of paramount importance, and has been a major focus over the past several months. Experience gained on that front, within Model 3, will be largely transferable to Model 1 and Model 2.

Work on Model 3 (largely funded by non-NMS sources) over the next several years includes:

1) Work towards resolving drastically different modeling responses of phytoplankton dynamics during two different water years (WY2011 and WY2016), as a starting point to assess the robustness of the model structure and parameters.
2) Focus on resolving the timing, amplitude, and duration of the bloom events in WY2016. Bloom condition provides a better opportunity to tune the model parameters compared to non-bloom conditions, as modeled phytoplankton biomass tend to show greater sensitive to parameter tuning when the amplitude of the biomass is high. We will also use the opportunity to tune rates and parameters related to dissolved oxygen (DO), where greater fluctuations in DO is also expected when system production and respiration activities are strong. This step is expected to result in a set of optimized system-wide parameters, which will improve our confidence about the ability of the model to quantify the linkages between the drivers and modeling targets or management needs.
3) Reconcile the spatial discrepancy between the model results and observations. Spatial variability in drivers will first be interpolated from the best-available measurement data across the Delta to each computational cell. The drivers may include, solar radiation, wind, turbidity, initial clam biomass, and sediment properties. Significant effort will be made to merge the observed data from various sources, check their compatibility and quality, and setting up the initial or forcing conditions for the biogeochemical model.
4) Final revisions to model structure and parameters, as needed. We may find, by this point, that the major spatial or temporal difference in the modeled key variables can only be resolved by using a model with higher complexity (e.g., resolving phytoplankton community structure rather than a single group). We will then need to revise the model structure and make suggestions on the new data needed to constrain the model. Without knowing the outcome from the first four steps, it is hard to estimate what modifications are required to improve the model, as well as the associated schedule.

Task 2.5 Integrate with coastal modeling work: For this task, Model 1 will be used to simulate full-Bay biogeochemistry for up to 5 years (in addition to Task 2.1), with the goal of developing a multi-year time-series of predicted nutrient exports to the coast. Unlike the intensive analysis/tuning conducted within Task 2.1, these runs are primarily focused on what leaves the system. While considerably less effort (compared to Task 2.1) will therefore be invested toward interior Bay interpretations, the simulations will take advantage of the best current full-Bay calibration available when work commences, which at that point should be based on refinements and 'global-tuning' for 2-3 one-year simulations. The coastal export simulations simulations can be updated, as-needed, if major model refinements occur.

Work in Task 2.5 will be directed toward:

- Coordinating, or integrating, with the coastal biogeochemistry project
- Working with that group of modelers to implement the best approaches for
    - generating material efflux time-series (freshwater, nutrients) to the coastal ocean at appropriate locations (location/2D surface across which flux computed; time resolution; data format, etc.)
    - extracting model output from the UCLA coastal CA Current model (e.g,, nitrate, T, sal), for use as boundary condition inputs to Model 1, for those or other relevant years.

Task 2.6 Sensitivity Analyses: Limited data exist for direct rate measurements of nutrient-related processes in SFB, especially data collected during the past 25+ years. The NMS model includes numerous biogeochemical processes whose rates can be adjusted according to characteristics of the system being modeled. While it is not practicable to gather observations for all these processes, having empirical data for some of the most important processes (or measurements that capture the cumulative effect of multiple processes included in the model) is important for improving the quantitative accuracy (i.e., getting the 'right' number) and mechanistic accuracy (i.e., the correct contributions of multiple processes to deliver that number) of the model

– with greater mechanistic accuracy leading to more robust calibrations that yield higher quantitative accuracy when the model is run for a new set of conditions.

In FY2020, the NMS plans to undertake an intensive 2-3 year set of field studies to address this important data. Given limited funds and the short study time-window, that work must target high priority data needs

Task 2.6 will undertake a sensitivity analysis to evaluate the relative importance of current modeling-related data gaps by assessing their quantitative influence on model results. The outcomes of this work will be used to identify priority data needs and inform fieldwork prioritization . Work will begin with a literature review and gathering expert input on the relative quantitative importance of processes or rates, based on both field studies and modeling studies. Based on that background, we will design a set of modeling simulations and data analysis tasks to quantify the importance of processes that could be measured in the field. Getting the most out of this project requires thoughtful framing of the goals or questions: simulations and analyses need to target a set of 'potentially influential' model results, i.e., outcomes that could lead to different management decisions depending on what answer is obtained within a plausible range range of outputs (with that range determined through the sensitivity analysis).

Task 3 Modeling Studies: Analyses and Interpretations

Task 3 consists of modeling projects, including simulations and interpretation, designed to target key Modeling-Related Science Questions (Table 3) and their related management questions. The work plans for Tasks 1 and 2 were developed with the goal of building the necessary foundation to carry out Task 3 work. For most aspects of the Task 3 projects, much of the intensive model-development work needed to pursue the project be undertaken in Tasks 1 or 2. In addition to conducting additional model runs, the Task 3 projects include the interpretations and the technical write-ups that are needed to inform decisions.

Each Task has a deliverable specific to the project, with one or more draft reports or report-outs prior to a final report. Some of those report-outs will be in the form of progress updates or early and/or early results included in periodic overall modeling program updates (FY20 Q4; FY22 Q2; FY23 Q4)

Task 3.1 Nutrient Source Attribution, Subembayment Delineation: In this task, biogeochemical simulations will be interpreted to: i) Quantify the contributions of individual POTWs to nutrient delivery (mass fluxes to a region) and nutrient concentrations within specific regions or habitats; and ii) Subdivide the SFB into 'management units', by identifying contiguous areas that can be considered biogeochemically-similar from a management standpoint. The Management Units[1] will be determined based on i) Similar nutrient source profile (same major sources contributing in similar proportions); and ii) Comparable responses in terms of nutrient-related management indicators. The aim is to subdivide SFB into a practical yet scientifically defensible number of regions. – enough Units to ensure appropriate management and effective management strategies can be considered, but no more than is necessary. Multiple water years and seasons will be explored as part of identifying appropriate Management Unit designations. Work will proceed in phases, obtaining provisional estimates early using the best available calibration (end of FY20), and refined thereafter, as needed, after major model refinements (FY22, final FY24).

Task 3.2 Effects of load increases: In this task we will investigate how SFB responds under different increasing load scenarios. Recent analysis of data from the 5 largest POTWs indicates that their combined loads have

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[1] Management Units is essentially the same as 'subembayments'; but we opted to use Management Unit instead, to distinguish the specific meaning here (and the currently undetermined boundaries) from the multiple formal and informal designations for SFB subembayments that are already in use.

increased by 25% from 2000-2017. To provide early guidance to inform potential management decisions and timelines, we will simulate 2-4 future loading scenarios under a range of physical forcings (2-3 water years) and characterize how important indicators of ecosystem health respond to these increases (phytoplankton blooms, gross primary production, dissolved oxygen).

Funds for Task 3.2 are specifically allocated in FY23-24. However, during Tasks 2.1-2.2 model development work we will conduct a limited set of simulations and interpretation to deliver early estimates (end of FY20, mid-FY22), using the best available model at the time. In FY23-24, we will return to this question, using the updated model(s) and a broader range of simulated water years.

<u>Task 3.3 Effects of load reductions:</u> This project will evaluate the effectiveness of a set of proposed load reduction scenarios for mitigating water quality impacts, including over a range of physical forcings (3-5 water years). The set of load reduction scenarios to be simulated will be determined through discussions with regulators, dischargers, and other stakeholders, including the NMS Steering Committee. In the current draft plan, the majority of work on Task 3.3 will occur in FY23-24; if warranted, some initial work and provisional results could be moved earlier, similar to Task 3.2.

<u>Task 3.4 What conditions could lead to low DO in deep subtidal habitats?</u> Over the 25+ year record when DO data were consistently measured Bay-wide, near-surface and near-bottom DO levels almost always exceeded the 5 mg/L Basin Plan standard. Establishing nutrient loading limits based on protecting DO levels requires us to explore the question - under what conditions could unacceptable DO conditions develop? To explore this question, we will use hydrodynamic+biogeochemical models to identify conditions under which low DO could develop in deep subtidal habitats. For one of the initial projects, we will 'force' the biogeochemical model by adding varying magnitude blooms (up to extreme) to simulations (concentration*area*depth), and assess the effects on DO levels. Through this approach we can identify the organic matter loading rate required (as a function of space and time) to draw down DO levels low enough to have a pronounced impact, in a system like SFB that has strong mixing and ventilation of its bottom waters. Based on the results of this analysis, we may also explore the influence of stratification duration in combination with organic matter loading.

<u>Task 3.5 Factors causing long-term changes in phytoplankton biomass and GPP:</u> Phytoplankton biomass and productivity have exhibited substantial changes in SFB over the past 20-30 years, with sharp increases in fall chl-a in South Bay being the most well-documented (Cloern et al. (2007, 2010). Cloern et al (2007,2010) proposed that these changes were due to top-down influence of decreased grazing pressure, caused by a shift in grazer abundance related to the Pacific Decadal Oscillation. Suspended particulate matter levels also dropped by as much as a factor of 2 in some areas of SFB during this time, leading to increased light levels which could also contribute to greater phytoplankton production. In this task we will use the NMS biogeochemical model(s), simulating a range of physical and biological forcings, to quantitatively examine the potential causes of recent changes in phytoplankton biomass, with the aim of understanding or predicting how much further production could change, and potential influences on dissolved oxygen and other indicators.

<u>Task 3.6 Quantifying uncertainty in model predictions:</u> Since NMS numerical models will be used to help identify nutrient management actions, there is clear need to quantitatively understand how much confidence can be placed in model results, or much uncertainty there is model predictions. Task 3.6 will develop a framework for quantifying uncertainty, and apply that framework to estimate uncertainties in model predictions. Initial effort on quantifying uncertainty will be carried out through the natural course of work in Task 2. This project will build upon those efforts, and undertake a set of analyses and interpretations targeted toward evaluating uncertainties as they relate to management relevant model results (or decisions related to results). Initial formal steps on this project will involve: gathering input from stakeholders on the types of

endpoints for which uncertainty estimates would be most informative; and working with external experts to develop a study design that targets those endpoints.

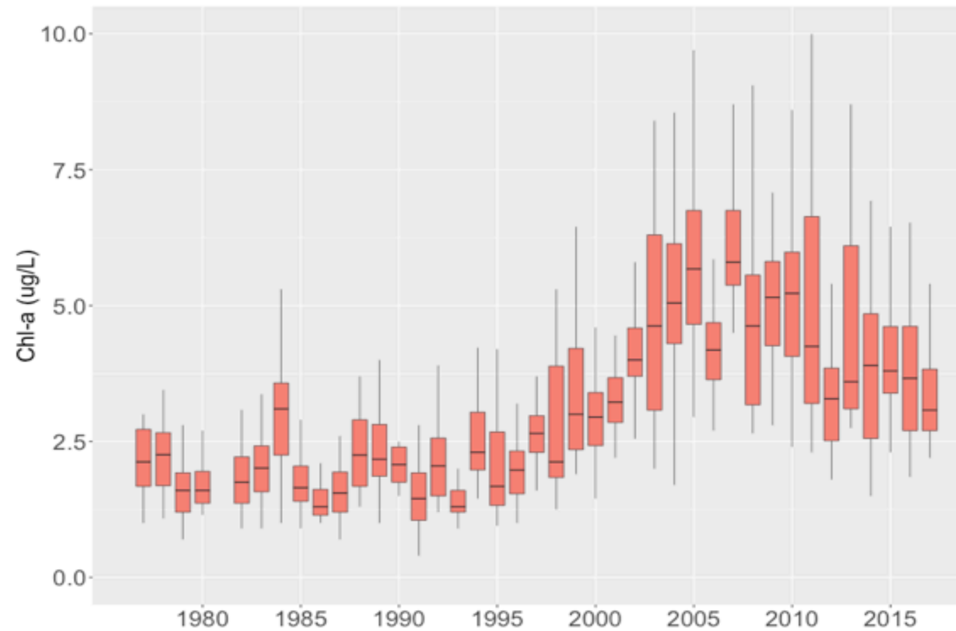

Figure 4 Chl-a concentrations in South Bay late summer and fall (Aug-Dec). Red bars: interquartile range; horizontal black line: median; vertical black lines: ±2 s.d. Observations through 2005 and 2008 first published by Cloern et al (2007,2010), with subsequent data presented in SFEI (2015,2017).

Task 4 Tools and Model Maintenance

Several activities related to tool development, model maintenance, and model aggregation are captured under Task 4. While thorough model documentation and maintenance would be needed in any case, there are some additional needs that arise from our goals of having this model be used as community resource during the project – including the need to pass the model to and receive it back from collaborators during the project -- and thereafter that place further emphasis on documentation, versioning, and maintenance. Tasks 4.1 (grid aggregation) and 4 (tracers, particles). Additional subtasks include

Task 4.3 Developing (and documenting) additional physical forcing data and biogeochemical boundary conditions to drive models

Task 4.4 Troubleshooting and refining code

Task 4.5 Computing resources (access to supercomputer time, and/or purchasing in-house hardware as needed)

Task 4.6 Model Management: documentation, versioning, sharing.

Task 5 Modeling Program Review

The NMS modeling program process and products will benefit from advising by external experts and by external peer-review of work plans, and peer-review of early-stage, intermediate, and final products. For this purpose, a Modeling Advisory Team (MAT) will be convened, consisting of 3-5 national experts in relevant disciplines. MAT members will not be involved with the modeling work directly, but will be involved with the project over multiple years, and can serve as a resources both in terms of advising and reviewing.

Beginning in late FY2019 or early FY2020, NMS-SFEI-staff will initiate the MAT process and convene the first MAT meeting. The primary focus for the first MAT meeting will be on reviewing and advising on this modeling work plan; and reviewing the current state of NMS models. Thereafter the MAT will be reconvened every 1-1.5 years, with the potential for smaller topic-specific subgroups to be convened more frequently.

The timing of comprehensive progress report deliverables from other tasks (Table 4) are timed to coincide with convening the MAT, and those reports will serve as some of the main materials for MAT review. As output from each MAT meeting, the MAT prepare a report-out document, prepared by the chair or point-person with assistance from SFEI staff (as needed).

Budget and Deliverables

The estimated budget to complete this work is summarized in Table 6. The timing and sequencing of projects was informed by program needs and by the goal of distributing effort and funding consistently over the 5-year period. This cost does not include the cost of nutrient monitoring and special studies that will contribute towards modeling activities represented throughout this Work Plan.

The timing of deliverables is presented within Table 4 (red numbers).

Table 6. Estimated budget (thousands of dollars)

TASK	TITLE	TOTAL	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Task 1 Hydrodynamic Modeling		**600**					
1.1	Simulate ~5 additional years	100	50	50			
1.2	Simulate ~5 additional years, coastal	100		50	50		
1.3	Light field	150	50	50	50		
1.4	LSB focus	150	50	50	50		
1.5	Suisun/Delta focus	100	50	50			
Task 2 Biogeochemical calibration		**1,360**					
2.1	Full-Bay, chla+DO	300	100	100	100		
2.2	Full-Bay, nutrient cycling	300	100	100	100		
2.3	LSB-focus	300	50	100	100	50	
2.4	Suisun-focus	200			100	50	50
2.5	Coastal exchange	150		50	50		50
2.6	Sensitivity Analysis	110	60	50			
Task 3 Modeling Studies (analyses, interpretations)		**700**					
3.1	Nitrogen sources, source attributions, subembayments	150	50			50	50
3.2	Effects of load increases on chl-a / DO / exports	100				50	50
3.3	Evaluating the efffects of load reduction scenarios					50	50
3.4	Can big blooms ever become a problem for DO in SouthBay?	100	25	25	50		
3.5	Explore potential causes of increasing chl-a, GPP, etc.	150		25	25	100	
3.5	Assessing/Quantifying uncertainty	200				100	100
Task 4 Tools & Model Maintenance		**550**					
4.1	Grid aggregation - testing, refining, technical report/publication	75	50	25			
4.2	Refining/testing particle and tracer applications	50	50				
4.3	New hydrological forcings or nutrient inputs	75	15	15	15	15	15
4.4	Troubleshooting / refining code	100	20	20	20	20	20
4.5	Computing resources - internal or supercomputer time	50	25			25	
4.6	Model management: documentation, versioning, sharing	200	20	40	20	60	60
Task 5 Modeling program review		**125**					
5.1	staff time, prepping	75	25		25	25	
5.2	travel, honoraria	50			25	25	
	Total	**$3,435**	**790**	**800**	**780**	**620**	**445**

Budget Assumptions: SFEI staff: 1 new FTE modeler @ $210,000/yr plus contributions from existing SFEI staff; Contractors: SFEI will contract with collaborators having specialized expertise to advise on model development and application, and carry out some aspects of model development. These contractors will be part of the Core Team; MAT Honoraria: MAT members will be paid an annual honorarium and will have travel expenses reimbursed.

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