San Francisco Bay
Nutrient Management Strategy Science Plan
Peer Review Report

SFEI ┆ **AQUATIC SCIENCE CENTER**

1. Introduction

A draft of the San Francisco Bay Nutrient Management (NMS) Strategy Science Plan was reviewed by two external experts who work on nutrient issues in estuaries: Walter Boynton (University of Maryland) and James Hagy (EPA-ORD). This document contains the following materials related to the peer:

1) Summary of feedback from peer reviewers

2) Memo sent to reviewers to initiate review (containing review instructions).

3) Peer review comments from each reviewer. Boynton's comments are contained entirely within the narrative below. Hagy's comments include both narrative and comments inserted within the science plan, and the commented version is included here.

4) Version of draft Science Plan reviewed. To avoid redundancy, the commented version from Hagy serves as the draft version here.

5) Biographies and curricula vitae of reviewers.

1. Feedback from peer review

The peer reviewer feedback was generally favorable, with some minor suggestions.

Overall feedback included:

- Science program and sequence of studies are appropriate
- Potential improvements
    - Add more effort on fish, benthos and higher trophic levels
    - Confirm the focus on HABs, because this is a challenging topic.
- Although the proposed work was considered appropriate, the current $1.4 million/yr budget was considered to be insufficient to do the work.
- Hold an annual meeting of scientists, modelers, managers
- 10-year program plan is a good start, but will likely need to be extended based on experience in other systems.

Questions to Reviewers.

We are looking for "high level" review. This plan is not intended to lay out all the detailed studies required for the next 10 years, but rather provide a "detailed-enough" framework, recognizing that the plan will be periodically revisited and updated. Also, each, specific projects will be proposed, generally guided by (but not beholden to) the Science Plan; so this is not the super-detailed roadmap, but rather the general direction.

The questions below are intended as a guide. Please feel free to also comment on issues not addressed by these questions.

1. Basic Program structure: Is there anything missing from Table 2.2 or Table 2.3?

2. Are there any major topics or issues that the Science Plan misses, based on your understanding of the system, informed by the background materials (Appendices 2-4; for the full conceptual model report from which these were borrowed, see here), or based on your own independent understanding of the system? Including,
....Does the stated Science Plan approach and topic areas (Section 2.5 and Tables 2.6 and more detailed version Table A.2) make sense and seem complete?
...Is the proposed sequencing (section 2.5 and Table 2.6) rational?
...Do the early projects look reasonable (Section 2.7, and Table 2.7 [mislabeled 5.7]) ?

3. Do the cost estimates and time estimates (in general) seem reasonable?

Review of San Francisco Bay Nutrient Management Strategy Science Plan (Draft)

W. R. Boynton

26 February, 2016

I have completed a review of the Science Plan. My review contains mainly overview comments and questions but also has more specific (and likely less important) comments.

COMMENTS:

1. The goals of the plan are very clear and include a "logical sequence" of studies, a pathway for prioritizing studies and estimates of costs. The emphasis here is a strong effort to inform major management decisions and, reading between the lines, this sort of effort is really needed because these management decisions, assuming they will include upgrades of major WWTPs and reductions in diffuse/storm water nutrient loads, will cost a great deal. So, the need to "get it right" as soon as possible is critical. In addition, it appears that the future of several current monitoring programs is uncertain. Loss of monitoring would throw important decisions into a zone of increased uncertainty and that needs to be avoided.

2. I understand why a 10 year planning schedule was adopted. But, in these dynamic and changing systems a 10 year record is very valuable but not nearly long enough. We have seen responses to strong management actions that have taken a decade to emerge…others are predicted to take longer. So, my comment here is that a 10 year program is an excellent start but needs to be extended at the appropriate time. Maybe now is the time to start thinking about this or doing the early work of alerting funders of the long-term need. I had a hell of a fight with a Maryland governor one time over this issue. His point was we had been making measurements for several years and because of that why the hell (his words) did we need to keep doing the same thing over and over. I said, well, how would he like to manage the State budget if you just got a look at it every month for a few months and then took a year or two off. He sputtered but got the point. So, long-term and regular monitoring (with sensible modifications) is the goal.

3. I think you had an exceptionally strong team putting this plan together. I know Cloern and Harding have national and international reputations of the highest order (and that ain't just smoke). Harding has completed several works that have been especially helpful in Chesapeake Bay management issues. I have also worked with Sutula and was thankful for her clear thinking and ability to work on big picture issues. A strong group with both local and global experience. I'd trust what they say.

4. The simple fact that a program such as this one is being developed (and portions implemented already) before there is serious degradation is also a very strong point. Many, including me, believe avoiding ecological disasters via early action is far more advisable (and less expensive) than trying to restore seriously damaged systems. My experience in the Chesapeake involved a decade of trying, with limited data, to convince government that there was a problem, another decade or two of developing status and trends that could be relied upon and now, finally a program designed for restoration (TMDL). Much of the delays were caused by very sparse water and habitat quality data sets. I think SFB is way ahead of other places in this regard. The deep channel information is a great start…the plan covers the missing aspects and will continue the record already available.

5. Science Plan: I support items 1 and 2 in Table 2.1. Both habitat and geography are really important. Likely there will be different impacts, different criteria, different functions associated with different zones of SFB. So, "getting to know" these habitats and different geographic regions is very useful. In items 4.a and 4.b I assume you are including climate change issues and the decadal patterns associated with adjacent ocean system. Is that correct? Given some of the changes Jim C and colleagues have found it seems like the ocean connection is very important to understand. Item 5 is a targeting issue and one where important results could be expected. I assume WWTP discharges would be important here.

6. In Table 2.2 several items jump out at me. First, item 1 has to do with loads. Our experience and experience in northern Europe, Tampa Bay, the MD and VA coastal Bays and other places all needed to "get the loads right". I think, as you have indicated, this is a top of the list item…so, be sure to get the loads right and that includes ocean exchanges. There is an emphasis on the shallow margin habitats (item 2.2) and given the little I know about SFB (and the map in this report) it still seems to me this is really an important issue. For example, in the Chesapeake we knew we had seasonal-scale hypoxia/anoxia in the deep Bay and deeper tributaries. When we began looking we also found we had a DIEL-scale hypoxia issue in shallow and productive habitats…that was a nasty surprise. The deep water and shallow water zones may well operate differently…but, you already suspect or know that. Inclusion of all the major habitats is important (they are connected) and this was recognized clearly up front in this plan. I'm confused by item 4 (Low Productivity) in Table 2.2. What does this mean? I'm really not clear on this one. Clarify.

7. A major issue I did not see well addressed in the plan has to do with access to the monitoring (and research) data that are being or will be collected. Also, what is the data QA/QC plan? My view is that quality data, ready and open access to these data are

essential for both scientists, managers and the public…everyone. The CBP stumbled with this in the early years (not in a bad way…in a getting started way) and it drove many of us nuts. Now there is a data hub and we can readily obtain data from our desks. But, all of this is not cheap and not easy. A small example, but one to make the point, we developed a coordination program for all groups doing nutrient analyses around the Bay area. Each group is provided with samples and they report back concentrations and each group gets to see the results from all groups. This sort of thing has helped keep the quality high and it sure pin-points problem areas that can be fixed. Data access, QA/QC, etc is a big issue.

8. I see a good deal of attention on nutrients, DO, HABs and phytoplankton but much less concerning upper trophic levels. From what I have read about SFB the benthos and ocean migrating communities have played a central role in Bay ecology. Keeping a close watch on this component for top-down effects on water quality seems very important. Did I miss something? Is this part of another program that will continue and thus not be part of this program?

9. Table 2.3: I really like the idea of adding rate measurements to the monitoring program. These, in my view, are worth real gold. They are the underpinnings of the concentration measurements routinely made in most monitoring programs. I strongly support monitoring primary production rates, water column respiration, nutrient and carbon burial, and denitrification rates. Currently, the CBP does not monitor phytoplankton production (the main source of labile organic matter) or water column respiration (the main DO sink in an estuary plagued by hypoxia). This is a bad omission. I urge you not to make the same mistake. In addition, having a selection of rate measurements makes calibration and verification of water quality models a better process meaning that modelers can not just "twist the rate knobs" to get the concentrations in the model to match the data.. Several investigators in our area seriously upgraded a sediment flux model because there was sufficient sediment flux data to support important model modifications, calibration and verification. With some thought and gear now available rate measurements can be a normal part of a monitoring program.

10. Adaptive management and adaptive monitoring (really adaptive science program) are good concepts. Difficult to implement but good for guidance. I recommend staying with this concept.

11. The current expected Science Program funding level ($1.38 million) seems really, really small. That will not go very far. Is there a way to set the funding bar a good deal higher? I may be missing some important things regarding funding. But, this low level of funding is just not very realistic. This needs some serious thought.

12. It appears to me that the proposed schedule of events, reports and the like (e.g., pg 9) is very tight and, for good reasons, somewhat sequential. The best of plans generally do not work out as planned….they get modified as reality intrudes. So, how to deal with this and keep the program moving forward and producing the products needed? My sense is that some strong coordination (a field or program general) will be needed. If participants do not produce reports on time and with useful interpretation I suggest dumping them and finding someone who can do it right. I'm not kidding about this.

13. Section 2.5 Rationale/Criteria: This section looks good to me. A few comments: a) do consider dropping "low return" monitoring items but DO NOT drop them too soon. CBP has made a few of these decisions and we have lived to regret it. In general we under-measure these ecosystems so be careful about dropping items that seem low-yield today because tomorrow they may become valuable b) starting the modeling work early is very good and needed. I recommend using simple models and adding complexity as needed rather than trying to make the most complex model at the start…in fact, I suggest development of mass balance computations asap using literature values or best professional judgment where data are missing and look to see where the big and small items are located. These relatively simple computations suggest where to put monitoring/research resources. This will not be news to either Cloern or Harding.

14. Item 3: This is important in general. Avoiding stove-pipe organization of the science program is essential. There needs to be effective exchange between the monitoring folks, the research people, modelers and managers. This is not easy but needed. In the past the CBP had annual meetings of all the monitoring groups as well as others in the management and modeling world. These annual meetings were a big deal and exciting. People really prepared for these presentations/discussions…hard questions were asked and participants expected reasonable answers. In a sense, we learned who was committed to the work and who was just spending some money…changes were made when necessary. With the complex and fast-moving science program proposed here there will be a serious need for cohesion of components and having the right players involved.

15. There is a strong emphasis on HABs in this work. This, I think, will be expensive work and the chance of developing a predictive model seems slim to me. I trust you have all done a "reality check" that HABs deserve the emphasis they receive in this science program. This is a tough issue…I do not have any clear advice.

16. Table 2.6: Interesting and indicates lots of thinking and planning. I did have one question. Why is the synthesis work terminated at the beginning of the program? Seems

strange. Does this plan refer to synthesis of information already at hand? Could use some clarification regarding this.

17. Appendix 2. This Background material was useful. I made a number of comments in this Appendix but I think I have mentioned all of them in previous sections of my review. But, a few comments might help: a) Table A.2.1 under Seagrass why is SAV coverage not included as a primary indicator and b) no mention of infauna in any habitat…seems like that is an omission that needs some consideration; c) Figure A.2.3. Station locations. I remember a paper by Jassby and Cloern (I think) that had an analysis of these stations and how much information was lost if fewer sites were monitored. I think they concluded that some stations could be eliminated. Perhaps portions of this effort could be re-directed to the large…very large…shoal areas in the Bay system.

I think I have captured above my main points. Main points include the following

1. Funding level looks to be much too small if I understand the information provided correctly
2. It will be a challenge to coordinate all these activities and likely will be especially challenging in the early going. Recognition that interaction among players is essential is very important and a positive aspect of the program.
3. With a few exceptions the items in the science program and the sequence of events looks solid…it is clear a lot of thought has gone into developing this program
4. Data QA/QC and system for data access needs some additional detail added. This process is not easy, fast or inexpensive…but it is critical
5. I believe the addition of key rate processes to the monitoring program is innovative and important. I have harped on this aspect of the program earlier in the review. I think this is a very strong part of the proposed program

Feel free to contact me if my comments need clarification.

From: **Hagy, Jim** <Hagy.Jim@epa.gov>
Date: Fri, Mar 4, 2016 at 2:50 PM
Subject: Evaluation of SFB science plan
To: David Senn <davids@sfei.org>

Dave –

    Attached is my CV and a draft of the Science Plan with my comments inserted throughout as PDF notes. In general, this whole plan makes a lot of sense given what I know and what we've been talking about in the group working on the SFB assessment framework. I have two or three relatively over-arching thoughts.

(1) Living Resources / Beneficial Uses. The whole plan seems to be relatively heavy on water quality processes, including biogeochemistry, phytoplankton, HABs and DO. For the most part, the biotic considerations end with phytoplankton, except for a little on benthos (especially filter feeders) and some mention of zooplankton. Dissolved Oxygen is an issue receiving attention, and the plan addresses the potential for DO effects in shallow water. I thank that more attention should be paid to fish, birds and mammals, including in the monitoring program. Is there some way to directly track and consider the biotic condition of the Bay, or will this all be inferred from DO, HABs, and phytoplankton? I am concerned that 3 times per year may offer a relatively poor measure of the benthic condition in some places. I'd suggest more frequent sampling at the expense of having to select "key index locations" or something like that to control cost. We are looking at camera approaches here to address temporal variability, which you also mentioned. Benthos can recruit, massively increase in abundance, then disappear due to predation or DO or both. Having somebody involved in the effort whose focus is on biotic condition, including fish or fisheries, is something to consider. Ultimately, the public will end up asking what the effort is trying to protect, and things with vertebrae and scales, feathers, etc. resonate.

(2) Models. The plan rightfully includes models. I would encourage SFB to be a leader in using models in an innovative way, and in my mind that means using them to "make us think" instead of using them to tell us what the answer is. We need to embrace them with a healthy skepticism. Talk of "collecting data to calibrate models" sounds like standard fare for "the whole effort is so that we can build a model to answer our questions." I don't think it's realistic to expect models to do that. Models have tremendous appeal in a policy setting because they can give an answer … straight up … about the future, about the response to something before it actually is done … etc. But, they can be wildly wrong. Often models are "calibrated" to show that they reproduce seasonal dynamics, and then we ask them to explain how the Bay might change over several decades.   San Francisco Bay is a complex place and the potential to be wildly wrong seems greater than normal. Emphasize that the models are a tool for evaluating processes and formulating and testing hypotheses and ecological relationships. But then, we need to look at all the evidence to reach decisions.

(3) Monitoring. I'm glad to see that monitoring is integral to the plan. Keep that up. The plan seems reasonable, except that I'd like some more consideration given to directly evaluating biotic condition. Those who follow us will thank us, like we thank Jim Cloern and others for sustaining the monitoring that we now can use.

-       Jim

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San Francisco Bay
Nutrient Management Strategy
Science Plan

—DRAFT—

1. Introduction

The San Francisco Bay (SFB) estuary receives large inputs of the nutrients nitrogen and phosphorous from anthropogenic sources, and has the potential to suffer negative impacts from nutrient overenrichment. Nutrient concentrations in SFB exceed those in other estuarine ecosystems where degradation is strongly expressed. To date, SFB has shown resistance to some of the classic symptoms of nutrient over-enrichment, such as excessive phytoplankton biomass as chlorophyll-*a* (*chl-a*) and low dissolved oxygen (DO). Recent observations, however, suggest that SFB's resistance to nutrient enrichment is weakening, and have generated concern that SFB may be trending toward, or may already be experiencing, adverse impacts due to its high nutrient loads. In response to these concerns, the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy (NMS).[1] The NMS lays out an overall approach for developing the underlying science to support nutrient management decisions.

This report presents a Draft Science Plan for implementing the SFB NMS. The report's main goals include:

1. Lay out a multi-year Science Plan representing a logical sequence of studies to inform major management decisions, assuming a time-line of 10+ years.

2. 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.

3. Provide realistic estimates of the time-frame and funding needed to support a Science Plan that will successfully inform management decisions.

The Draft Science Plan was developed in 2014-15 with input from science advisors (Table 1.1), the NMS Steering Committee, and the NMS Nutrient Technical Work Group (Fig. 1.1). Projects are described in more detail in the first 1-3 years, and in increasingly less detail over time, recognizing that the Science Plan will be iteratively refined based on new insights gained as work progresses.

Table 1.1 Science Advisors for NMS Science Plan

James Cloern, PhD	USGS
Lawrence Harding, PhD	UCLA
Wim Kimmerer, PhD	SFSU-RTC
Raphael Kudela, PhD	UC Santa Cruz
Mark Stacey, PhD	UC Berkeley
Martha Sutula, PhD	SCCWRP

The science advisor team was convened in December 2014 to provide initial input on the Science Plan, discuss priorities for specific studies, and recommend a sequence and time-line to address

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[1]http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarineNNE/Nutrient_Strategy%20November%202012.pdf

management questions. During two meetings (October 2014, February 2014), the NMS Steering Committee provided guidance on the approach for developing the Science Plan and science and management priorities. The Nutrient Technical Workgroup also provided input during a meeting in April 2014. Additional science advisor meeting is planned for Summer/Fall 2015 to help develop the plan's final draft, and provide input on specific projects for FY2016.

The Draft Science Plan is described in Section 2 and Appendix 1. Highly-relevant background information on nutrient issues in San Francisco Bay, and a summary of major science needs and recommended priorities are presented in Appendix 2-4 (Section 4). The background material and recommendations were originally presented in an earlier report (*Scientific Foundation for the San Francisco Bay Nutrient Management Strategy*; SFEI 2014).
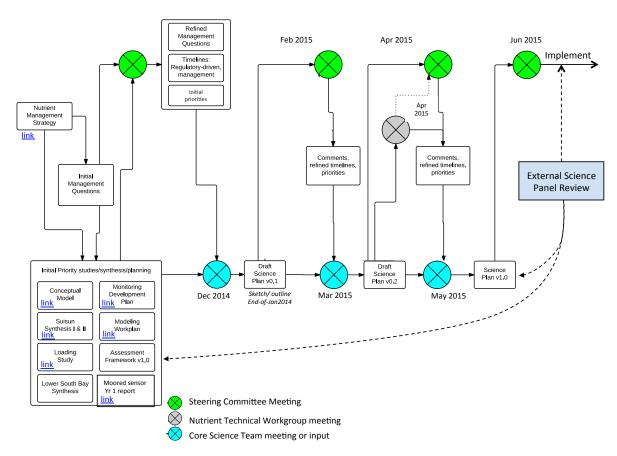

Figure 1.1 Process and timeline for Science Plan development.

2. Science Plan

2.1 Management Questions and Knowledge / Data Gaps

The Draft Science Plan aims to build the scientific foundation needed by regulators and stakeholders to answer the six management questions in Table 2.1.

Table 2.1 Management questions targeted by the NMS Science Plan

1. What conditions in diiferent SFB habitats would indicate that beneficial uses are being protected versus experiencing nutrient-related impairment?
2. Which subembayments or habitats are supporting beneficial uses, and which may be experiencing nutrient-related impairment?
3.a To what extent is nutrient over-enrichment, versus other factors, responsible for current impairments?   3.b What management actions would be required to mitigate those impairments and protect beneficial uses?
4.a Under what future scenarios could nutrient-related impairments occur, and which of these scenarios warrant pre-emptive management actions?   4.b What management actions would be required to protect beneficial uses under those scenarios?
5. What nutrient sources contribute to elevated nutrient concentrations in SFB subembayments or habitats that are currently currently impaired or would be impaired?
6. What specific management actions, including load reductions, are needed to mitigate or prevent current or future impairment?

High priority knowledge and data gaps related to nutrient loads, nutrient cycling and ecosystem response to nutrients in SFB were identified in SFEI (2014), and are summarized here in Appendix 4.

2.2 Science Plan Structure

Activities in the Science Plan are organized by Major Program Areas and Work Categories (Table 2.3), based on the priority science needs detailed in Appendix 4 and in SFEI (2014). Program Areas 2, 3, and 4 address the five pathways for adverse impacts presented in Figure A.3.1. Program Area 1, *Nutrients*, is presented as a separate Program Area because defining the sources, fate, and transport of nutrients is essential to all elements of the Science Plan. Activities in each of the first four program areas are divided into 5 Work Categories (Table 2.3). Note that three Work Categories also appear as sub-headings under Program Area 5, *Program-wide Activities*. Monitoring, Modeling, and Protective Conditions / Asssessement Framework are essential components of Program Areas 1-4, but are also themselves major programmatic undertakings, with technical activities and coordination that are not well-placed under Program Areas 1-4.

Table 2.2 Science Plan structure

Major Program Areas	Work Categories
1. Nutrients (loads, cycling/transformations)	
2. High biomass and low dissolved oxygen	A. Synthesis
2.1 Deep subtidal	B. Monitoring
	C. Special Studies
2.2 Shallow margin habitats	D. Modeling (current conditions)
3. Phytoplankton community composition	F. Identify Protective Conditions
	F. Modeling condition under plausible future scenarios
3.1 HABs/toxins	
3.2 Food quality (due to N:P, NH4, etc.)	
4. Low productivity	
5. Program-wide Activities	
5.1 Monitoring	Future monitoring program design, including considerations of science requirements, logistics, institutional agreements, and funding
5.2 Modeling	Base model development, model documentation, model maintenance
5.3 Protective Conditions/Assessment Framework	Iteratively refine framework based on new data.
5.4 Program Management	Science communication, stakeholder engagement, coordination among projects, fundraising

Table 2.3 Work Categories within the Major Program Areas

Work Categories	Types of activities
A. Synthesis	• Analyzing/synthesizing new results from past studies, developing conceptual models, etc., to identify science needs • Analyzing/synthesizing new data from monitoring and special studies to inform next steps in science plan implementation • Workshops to identify highest priority science questions and experiments
B. Monitoring	• Current ship-based monitoring, Bay-wide…nutrients, phytoplankton biomass, phytoplankton composition, physical observations (salinity, temperature, SPM, etc.) • Moored sensors…biogeochemical data, physical data (T, salinity, stratification, velocities, etc.) • Future monitoring program design: data analysis and expert input on spatial/temporal resolution, blend of ship-based vs. fixed-station continuous monitoring, new measurements, etc.

C. Special Studies	• Field investigations to
	   o measure biogeochemical processes: e.g., primary production, nutrient transformations (water column, benthic), DO consumption (water column, benthic)
	   o collect physical observations (T, sal, velocities, light levels) to quantify mixing, transport, and stratification
	   o study processes or test hypotheses at the ecosystem-scale (e.g., factors that influence HABs or toxin production)
	• Mechanistic studies in the laboratory
	• Pilot studies related to monitoring program development, including data analysis

D. Modeling	• Biogeochemical (Water Quality) and hydrodynamic model development and application to quantitatively explore:
	   o Transport of nutrients and biomass
	   o Growth of phytoplankton, grazing by pelagic and benthic grazers, growth of different types of phytoplankton
	   o Nutrient and organic matter biogeochemical transformations and losses
	   o Hydrodynamics, effect of physics (e.g., stratification) on env'l processes

E. Identify Protective Conditions	• Levels of DO, chl, and toxins, or characteristics of phytoplankton assemblages that are protective of beneficial uses • Clarifying the organisms or beneficial uses that are being protected • Literature review to identify these levels, modeling (trophic transfer, HAB or toxin bloom size) • Nutrients, loads or concentrations that will protect beneficial uses.
F. Future scenarios	• Identify high priority environmental change scenarios to test • Identify load reduction or management scenarios. • Simulate ecosystem response under future scenarios

2.3 Timeline and Budget Assumptions

In addition to the management questions and science needs, two practical constraints strongly influence the NMS Science Plan's structure and activities. The first is the proposed timeline for answering management questions. The second is the available funding to support science activities. Currently, both the Science Plan's timeline and its funding are uncertain. It was not possible to develop the Science Plan with the timeline and budget left fluid; therefore, two major assumptions were made.

First, a 10-year time horizon was identified as the goal for reaching sufficiently-confident answers to NMS management questions (Table 2.1). This 10-year time horizon, beginning in July 201 was based on guidance from the SFBRWQCB. Tables 2.4 and 2.5 present approximate timelines for addressing the management questions in Table 1.1. Table 2.5 organizes management questions into specific questions based on the Major Work Areas in Table 2.2. The sequencing and timeline of Science Plan activities were designed to yield early provisional answers to management questions, and to refine those answers through further investigations that target major uncertainties. This iterative approach allows the Science Plan to be periodically refocused on the highest priority science needs. It would also help identify the need for any early management actions, e.g., if impairment becomes evident. The milestones and dates in Tables 2.4 and 2.5 are realistic in terms of the effort and time required to conduct investigations related to a particular line of inquiry. It is important to note, though, that the schedule assumes that all work proceeds in parallel

Second, with the timeline fixed, the Draft Science Plan budget was allowed to expand to match the proposed schedule. As with the schedule, the estimated funding needed to conduct a set of investigations are realistic. However, it became apparent early in Science Plan discussions that the current funding level ($1.38m) will be insufficient to address all the management questions (Table 2.1) for all potential adverse-impacts pathways (Figure A.3.1) at this pace, given the knowledge and data gaps that need to be addressed (Appendix 4). In addition, some amount of ramp-up time is needed to build a sustainable program. It should be noted that even with an "unlimited resources" approach, some questions remain unanswered at a final level of confidence in a 10-year period.

The Draft Science Plan in its current form is thus best considered as an idealized plan – technically feasible but unlikely to proceed as laid out because of funding constraints, and requiring either substantially increased funding or tough decisions about what lines of inquiry and types of investigations are most important to pursue. A process or structure for prioritizing science activities still needs to be developed

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
First 5 year Watershed Permit cycle.										
Second 5-year permit.										
1. What conditions would be considered a level of impairment that would require regulation/management?		Initial				Secondary				Final
2. Is impairment currently occurring?		Initial				Secondary				Final
3.a To what extent are nutrients causing or contributing to current impairment? Mechanisms/quantitative 3.b What conditions (e.g., nutrient loads or concentrations) would mitigate impairment?		Initial				Secondary			Final	
4.a What potential future impairments warrant pre-emptive management actions? 4.b What conditions (e.g., nutrient loads or concentrations) would mitigate impairment?					Initial			Secondary		
5. What are the contributions of individual nutrient sources to ambient nutrient levels throughout SFB (f(space, time))?		Initial						Secondary		
6. What management actions or load reductions are needed to prevent or mitigate current or future impairment?		Initial						Secondary		

Legend:
- Initial evaluation (yellow)
- Secondary evaluation (orange)
- Final evaluation (red)

Table 2.4 Management questions and approximate timeline for iteratively reaching answers. The 10-year timeline is based on a Regional Water Board goal of establishing nutrient objectives for SFB by the end of the second Bay-wide nutrient permit (2024). See Table 2.5 for more detailed version

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
First 5 year Watershed Permit cycle. All information needed to inform next permit required by 4.5 year mark										
Second 5-year permit. All information needed to inform next steps beyond the 10 years needed by 9 year mark										
1. What conditions would be considered a level of impairment that would require regulation/management?										
1.1 DO in deep subtidal, and chl-a leading to that DO										
1.2 DO: shallow margin habitats										
1.3 HAB abundance, toxin abundance (concentration, area, duration, frequency), community/food shifts										
2. Is impairment currently occurring?										
2.1 DO in deep subtidal, and chl-a leading to that DO										
2.2 DO: shallow margin habitats										
2.3 HAB abundance, toxin abundance (concentration, area, duration, frequency), community/food shifts										
3.a To what extent are nutrients causing or contributing to current impairment? Mechanisms/quantitative										
3.b What conditions (e.g., nutrient loads or nutrient concentrations) would mitigate impairment?										
3.1 DO in deep subtidal, and chl-a leading to that DO										
3.2 DO: shallow margin habitats										
3.3 HAB abundance, toxin abundance (concentration, area, duration, frequency), community/food shifts										
4.a What potential future impairments warrant pre-emptive management actions?										
4.b What conditions (e.g., nutrient loads or nutrient concentrations) would mitigate impairment?										
4.1 Effects of plausible physical and biological drivers on ecosystem dose:response (3.1-3.6)?										
4.2 Scenarios with sufficiently high probability of occurring and large impact?										
4.3 What conditions would mitigate or prevent impairment?										
5. What are the contributions of individual nutrient sources to nutrient levels throughout SFB (f(space, time))?										
5.1 Current magnitudes (f(t)) 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" (f(t))?										
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 in subregions to mitigate current impairments (3.1-3.6)?										
6.2 What external load reductions or other management actions can achieve the desired "local" effect(s)?										
6.3 What are the optimal approaches for achieving the local effects?										

Legend:
- Initial evaluation
- Secondary evaluation
- Final evaluation

Table 2.5 Expanded version of Table 2.5 depicting schedule of iteratively answering management questions for the range of potential adverse impact pathways and nutrient loads/transformations.

2.4 Regulator and Stakeholder Priorities

Input was solicited from regulators and stakeholders at several points during the Science Plan development process to identify priorities and time-sensitive issues. Several themes emerged during these discussions:

1. The Science Plan must consider, and help define, the specific beneficial uses that are targeted for protection, including identifying the organisms and ecosystem services that management actions would aim to protect from nutrient-related adverse impacts.

2. The conditions that would be considered protective of those beneficial uses should be identified quantitatively: e.g., protective DO concentrations for specific fish species; protective algal toxins concentrations for chronically-exposed marine biota. Although decisions about what beneficial uses and protective conditions will drive any management actions will ultimately be made by regulators, specific and quantitative guidance is needed from scientific studies.

3. Provisional answers to some questions are needed by June 2018 to inform permit renewal discussions:
   a. Identify sources that contribute to nutrients in SFB as a function of space and time;
   b. Define regional demarcations / boundaries in SFB based on retrospective data analysis of relevant water-quality properties and modeling of sources;
   c. Evaluate evidence of adverse impacts in SFB, such as low DO and algal toxins, and examine the extent to which nutrients cause or contribute to those water-quality problems.

4. The Science Plan's implementation needs a process for prioritizing among science activities (Figure A.3.1) and assessing timeline/schedules, in order to achieve to achieve an appropriate balance between program cost, program duration, and the level of confidence in the answers to management questions.

Input from regulators and stakeholders will continue to be sought as the Science Plan is developed into a final draft, and periodically during its implementation.

2.5 Rationale/Criteria for Establishing Workflow and Priorities

This section provides an overview of several criteria used to guide the development of the Science Plan using the structural elements defined in Tables 2.2 and 2.3.

1. Adopt an approach that produces preliminary answers early, and allows them to be refined by iteration as results are obtained.
- Goal: Provide timely answers to managers and stakeholders to guide subsequent investigations and inform any early decisions.
- Periodically refine answers to science and management questions (e.g., every 3 years), seeking increased confidence with each iteration.
- Revise the Science Plan as new data are obtained, recognizing that a long-term plan is needed to guide the program, and building in flexibility for the program to identify and pursue new priorities as they emerge.

2. Use a tiered approach to develop a sequence of projects.
- The management questions (Table 2.1) provide some guidance on how projects would be sequenced in an ideal case, if all work could proceed in series.
    1. First, examine whether beneficial uses are being protected, or adverse impacts appear to be occurring, using existing data and "no regrets" new projects;
    2. If necessary, assess condition more thoroughly to provide increasing levels of certainty about the occurrence of nutrient-related impacts;
    3. Study mechanistic links between adverse impacts and nutrients using existing data and then through new investigations;
    4. Identify protective conditions with respect to nutrients

- As an example, Table A.1 details a logical sequence of studies for exploring issues related to HABs/toxins. From an efficiency standpoint, it makes sense to determine the likelihood that SFB has or may develop a HAB/toxin problem before directing resources at expensive mechanistic or toxicity studies. Other Program Areas were examined in a similar way.
- In reality, work can not always follow a strict tiered sequence, because, in some cases, this approach would prove inefficient with respect to cost or cause major delays. For example, biogeochemical models will be essential tools for exploring linkages between nutrient loads and cycling, phytoplankton biomass, and DO in SFB. These models will take considerable time to develop, calibrate, and validate. Model development therefore needs to start earlier than would be suggested by a purely-efficient project sequence that would invest in model development only after "nutrient impacts" were confidently identified.

3. When possible, pursue projects that benefit more than one Program Area, and look for opportunities to leverage efforts in one program area to advance others.

- HABs exemplify an undesirable shift of phytoplankton species composition to a community including toxic forms. Data collection using microscopy, pigments, and ancillary data that will advance our understanding of HABs will also shed light on factors that shape phytoplankton community composition and food quality.
- Many projects identified below have direct and indirect benefits for other program areas.

4. Organize field investigations spatially to ensure integrated and efficient collection of necessary data

- A diverse array of environmental data will be needed to advance our understanding of SFB's responses to nutrient over-enrichment:phytoplankton growth rates, grazing rates, nutrient concentrations and transformation rates, light levels, turbulent mixing energy, etc.
- These data are best collected simultaneously both to ensure accurate interpretations and to maximize studies' cost-effectiveness (i.e., smaller incremental cost of adding measurements to a field program than launching a new study):

biological

chemical ← physical

5. Target high-priority conceptual and data gaps through specific projects in FY2016-FY2018.

- Since nutrients have only emerged as a concerning issue in SFB within the past several years, there are major nutrient-related gaps in the areas of modeling, monitoring, and process rates due to few targeted investigations to date (Appendix 4).
    - Despite an urgent need for biogeochemical models to support many components of the NMS, biogeochemical modeling for SFB is early in its development. Accordingly, we identify the development of biogeochemical models as an early major need in the Science Plan.
    - Moored sensors for continuous monitoring of nutrient-related parameters are needed to complement ship-based monitoring to assess condition and calibrate models.
    - Nutrient transformations have not been carefully studied in SFB, and rates of biogeochemical processes, such as denitrification deserve attention as they likely play a major role in regulating ambient nutrient concentrations.
    - Few investigations have focused on HABs and algal toxins in SFB. Available data indicate that both HAB-forming species and some algal toxins are frequently detected. Investigations to will help better characterize risks from

HABs and toxins and examine linkages to nutrients emerge as an early priority in the Science Plan.

- DO-related conditions in SFB's margin habitats have received little investigation until recently. The available data strongly suggest the need for further investigation in the early stages of Science Plan implementation.

- Other nutrient-related adverse impact pathways have received substantial investigation over the past several years. A number of ecosystem-scale studies and controlled experiments focused on NH_4^+ inhibition of phytoplankton growth rates and N:P or NH_4^+ impacts on phytoplankton food quality have proceeded during the past several years. Some of these studies are still underway but nearing conclusion. Therefore new studies related to NH_4^+ and N:P adverse impact pathways were not identified for the years FY2016-2018. As on-going studies are completed, the state of that science needs to be assessed, and at that point gaps can be identified and relevant studies prioritized.

6. While the Science Plan should identify the full breadth of science needs, its implementation will undoubtedly be constrained by the realities of time and funding and require decisions among competing priorities.

- The Science Plan reflects a recommended 10-year time frame, when possible, for answering management questions.
- The current funding level was not used to constrain the Science Plan. As a result, more work is proposed to occur in parallel than can be accomplished with current funding.
- Thus, the Science Plan can be thought of as a comprehensive science-needs road map. As such, it can be used to concretely identify funding needs and thus serve as a fundraising tool and help focus NMS fundraising efforts (e.g., national and regional RFPs).
- Some degree of prioritization will still be necessary, independent of fundraising. A prioritization effort could be a next step in the Science Plan development or update. External review of the Science Plan would also be helpful step for recruiting additional expert input on science priorities.

2.6 10-year Science Plan

This section presents a 10-year Science Plan at several resolutions. Figure 2.6 depicts the approximate timing of major activities within the main Work Categories across all Program Areas. Table 2.6 provides more detail, breaking down work into Program Areas, Work Categories, and major activities. A more granular version of Table 2.6 is presented in Table A.2, which aims to illustrate the full breadth of science needs. Despite what may look like a very detailed portrayal of activities in Table A.2, the project descriptions are still quite general, and specific data needs remain to be identified and prioritized as the program progresses.

The Science Plan project timelines (Tables 2.6 and A.2) and milestone timing (Table 2.4-2.5) present realistic estimates of the time required to conduct investigations and reach confident answers to management questions. As noted in Section 2.4, the plan is not constrained by the current budget, and pursuing all of these topics in parallel would require an effort that would substantially outstrip the current program budget.
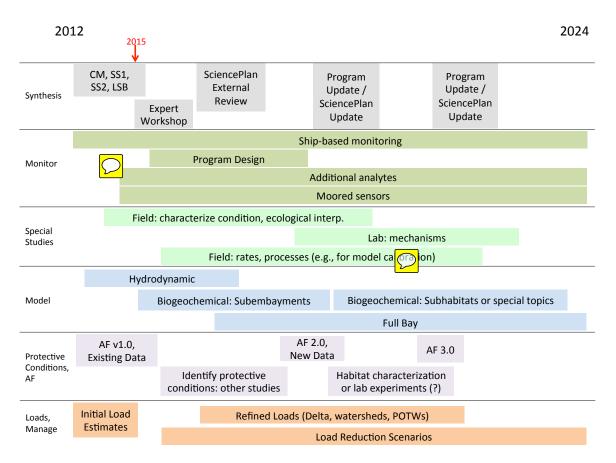

Figure 2.6 Approximate timing of major work categories over a 10 year Science Plan.

While Figure 2.6 and Table 2.6 present the timing of work, and when answers to management questions would be reached, they do not convey the workflow and iterative nature of activities. Sidebar A provides three examples to better illustrate the Science Plan's workflow and iterative structure.

Table 2.6 Overview of the 10-yr Science Plan. Dark Grey indicates a deliverable or end of project. Red/Yellow/Orange signify answers reached with similar confidence levels as in Tables 2.4 and 2.5

Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1 Nutrient: loads, transformations,													
Synthesis													
Monitoring — Ship-based monitoring													
Monitoring — Continuous, moored stations													
Special Studies													
Modeling — Load estimates													
Modeling — transport, transformation													
Protective Conditions													
Future Scenarios													
2.1 High chl, low DO - Deep Subtidal													
Synthesis													
Monitoring — Ship-based monitoring													
Monitoring — Continuous, moored stations													
Special Studies — Field investigations: biogeo, physics													
Special Studies — Habitat assess (e.g., fish, benthos)					TBD								
Modeling													
Protective Conditions													
Future Scenarios													
2.2 High chl, low DO - Shallow Margin													
Synthesis													
Monitoring									TBD				
Special Studies — DO in shallow margin habitats									TBD				
Special Studies — Field investigations: biogeo, physics													
Special Studies — Habitat assess (e.g., fish, benthos)					TBD								
Modeling													
Protective Conditions													
Future Scenarios													
3.1 Phytoplankton community: HABs/Toxins													
Synthesis													
Monitoring — Ship-based monitoring													
Monitoring — Continuous, moored stations													
Special Studies — Field investigations, data analysis													
Special Studies — Experiments: HABs, toxin production													
Special Studies — Experiments: biota toxicity								TBD					
Modeling													
Protective Conditions													
Future Scenarios											TBD		
3.2 Phytoplankton community: Food Quality													
synthesis — Suisun Synthesis II													
synthesis — Additional Synthesis, External Review													
Monitoring — Ship-based monitoring													
Monitoring — Continuous, moored stations													
Special Studies — Complete funded projects, other funds													
Special Studies — Field study, data analysis (w/ HABs)													
Special Studies — Experiments:comm. comp. (w/ HABs)													
Special Studies — Experiments: measure food quality								TBD					
Modeling													
Protective Conditions — expert input, lit. review: food quality													
Future Scenarios											TBD		
4 Low Biomass													
Synthesis — Suisun Synthesis I, II													
Synthesis — Additional Synthesis, External Review													
Monitoring — Ship-based monitoring													
Monitoring — Continuous, moored stations													
Special Studies — Complete funded projects, other funds													
Special Studies — New field studies or experiments					TBD								
Modeling													
Protective Conditions													
Future Scenarios									TBD				

Table 2.6 cont'd

Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
5 Nutrient Program Coordination													
Synthesis: Bi-annual program updates, Science Plan updates													
Monitoring: develop program, basic monitoring, infrastructure													
Modeling: base model development, refinement, maintenance													
Assessment Framework Development													
Program Management													

2.7 Projects identified for FY2016-2018

Table 2.7 summarizes projects that were identified within the 10-year plan (Figure A.2) as beginning in FY2016-2018. Table 2.7 also notes the geographic focus of each investigations and the target Program Areas, as well as estimated costs.

A next important step is to prioritize among these projects to identify those projects that should go forward in FY2016, recognizing that their estimated total cost exceeds current funding.

Table 5.7 Projects Identified for FY2016-2018. Note, prioritization among projects has not been done. Costs are approximate. Symbols indicate the level of alignment between the project and each Program Area and Subembayment. ● Directly aligned; ◉ Moderately aligned; ○ Limited alignment (e.g, knowledge transfer from one subembayments or project to another, but no data)

	Project	Cost/yr ($1000s)	Start Date	Length (yr)	Program Area Focus						Subembayment Focus				
					1	2.1	2.2	3.1	3.2	4	LSB	SB	CB	SPB	SUI
1	On-going ship-based monitoring. Costs for basic nutrient-related analytes (nutrients, phytoplankton community, ancillary)	100	Jul 2015	3+	●	●	●	●	●	●	●	●	●	●	●
2	Measure new analytes, core monitoring; pigments, toxins (filters, SPATT, biota/benthos)	150	Jul 2015	3+	●	●	●	●	●	◉	●	●	●	●	●
3	Moored sensor monitoring: Field work/ maintenance, data interpretation, system-scale interpretations for DO, nutrients, biomass	200	Jul 2015	3+	●	●	●	◉	◉	○	●	●	◉	○	○
4	DO in margin habitats: Field work/ maintenance, data interpretation, system-scale interpretations for DO, nutrients, biomass	200	Jul 2015	3	●	●	●	◉	◉		●	●		○	○
5	Biogeochemical modeling - LSB, South, Suisun focus in Year 1-3. - Bay-wide nutrient transport/cycling to identify zones of influence of nutrient sources	400	Jul 2015	3+	●	●	●	◉	◉	●	●	●	●	●	●
6	Monitoring Program Development: historical data analysis, specify types of analytes and spatial/temporal frequency	150	Sep 2015	3	●	●	●	●	●	●	●	●	●	●	●
7	Data analysis/interpretation of -phytoplankton community composition and physical/chemical factors (microscopy: 1992-2017) - pigment and toxin data and physical/chemical factors (2011-2017), and pigment, toxin, nutrient, and physical/chemical condition in LSB	150	Sep 2015	3	●			●	●		●	●	●	●	●
8	Integrated investigation in subembayments (start LSB/South Bay): Grazing, hydrodynamic data, phytoplankton production, sediments or light, MPB production, community/HABs/toxins, nutrient transformations, DO	400	Sep 2015	3	●	●	●	●	●	○	●	●	○	○	○

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		Cost/yr ($1000s)	Start Date	Length (yr)	Program Area Focus						Subembayment Focus				
	Project				1	2.1	2.2	3.1	3.2	4	LSB	SB	CB	SPB	SUI
9	Intensive Bay-wide investigation: toxins/HABs, e.g., phytoplankton community, HABs, toxins, and/or toxins in bivalves	200	Jan 2016	3		●	●	●			●	●	●	●	●
10	Identifying protective DO levels for deep water and shallow margin habitats (desktop study: species to protect, DO tolerance (time, duration), expert input, comparison with ambient condition, monitoring gaps	150	Sep 2015	2		●	●				●	●	●	●	●
11	Identifying protective toxin levels for SFB habitats (desktop study: species to protect, food web, expert input, bioaccumulation and plume modeling, comparison with ambient condition, monitoring gaps	100	Sep 2015	2				●	●		●	●	●	●	●
12	Identifying protective food quality for SFB (desktop study: species to protect, feeding practices and requirements, consideration of potential past food quality, expert input), comparison with ambient condition, monitoring gaps, science gaps	50	Jan 2016	2				●	●		●	●	●	●	●
13	External review or workshop: N:P, NH4 inhibition	25	Sep 2015	1	●			●	●	●	○	○	○	●	●
14	AF data analysis: Update/analyze probability of HABs and toxins vs. chl-a, and low DO, new data	100	Jul 2017	2				●		●	●	●	●	●	●
15	Load estimates: Hydrological modeling to estimate inputs from local watersheds; Refined estimates of Delta Loads; updated loads from POTWs	150	Sep 20155	3	◉	◉	◉	◉	◉	◉	●	●	●	●	●
16	Science coordination and oversight across projects; Reporting; NMS Program Management: stakeholder coordination, project management	350	Jul 2015	3	●	●	●	●	●	●	●	●	●	●	●
	Estimated Total ($mill/yr)	~2800													

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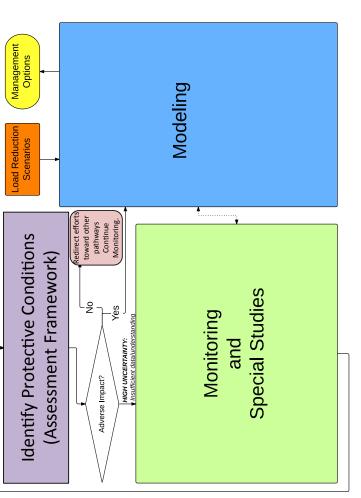
Sidebar A
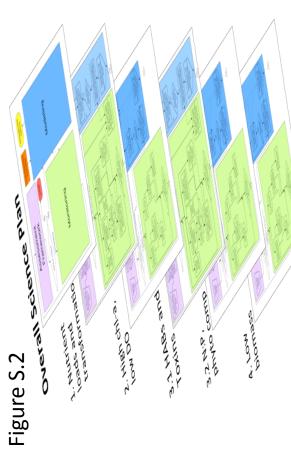
Each major Program Area could be thought of as having its own sub-plan (Figure S.1 and S.2). Some projects or activities may be distinct to one program area, and others may contribute to multiple program areas (vertically).

Figure S.3 is a general example, while Figure S.4 and Figure S.5 present the cases for HABs/toxins and Low DO in sloughs/creeks, respectively. Enter the diagram in the purple "Identify Protective Conditions" box, and proceed to the "Adverse Impact?" decision. For most of the Program Areas, there remains considerable uncertainty about whether adverse impacts are occurring and the dose:response with nutrients, which leads into the Monitoring and Special Studies box. The smaller rectangles illustrate the types of studies or activities that would be pursued during a pass through the Monitoring and Special Studies box. One pass through this box, carrying out multiple activities in parallel (e.g., monitoring, field investigations) to generate new data or test hypotheses, would take ~3 years. That new information would be used to provide provisional answers to management questions (Tables 2.4-2.5) and refine the Assessment Framework (AF).

The process repeats until the ambient condition data and AF have developed to the point where "Adverse Impact?" can be answered with sufficient confidence. Exactly what constitutes sufficient confidence is a regulatory decision or management decision. If there is an adverse impact, work moves to revising conceptual models, developing and implementing numerical models, investigating the quantitative importance of nutrients, and exploring load reduction scenarios that would mitigate impairment. As noted above, work would likely proceed on multiple fronts in parallel, not in series – for example, work will have been moving forward with model development, and when modeling is needed to answer a specific question, the Base Model will ready for use and customization for the specific questions being explored.

Figure S.1

Figure S.2

Figure S.3 General Case

Figure S.3 General Case

Management Options

Load Reduction Scenarios

What management actions will

Base Model Development: nutrients, phytoplankton response, hydrodynamics

Nutrients Important?

Yes

No

Pathway-specific modeling

Iterative Assessment Framework v1.0, v2.0...

Redirect efforts toward other pathways. Continue Monitoring.

Starting objectives

Adverse Impact?

HIGH UNCERTAINTY: Insufficient data/understanding

No

Yes

Identify protective conditions for beneficial use
- existing data
- expert input
- field surveys
- experiments

Mechanistic Studies

Monitoring

Synthesis

Revised conceptual model

Monitoring Program Design, Pilot Studies

Enough confidence to iterate Framework?

No

Yes

Figure S.4 HABs/toxins

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Figure S.5 Low DO: sloughs, creeks

Appendix 1 Additional Science Plan Tables

Table A.1 Tiered ordering of HABs/toxins questions and estimated effort associated with work. Note: In general the costs included here do not include the costs associated with routine monitoring (field work) to collect samples, or cost of ancillary data (nutrients, T, sal, light, etc.).

Tier	Question	Current level of completion	Confidence if answer given today	Cost and activity	Time to complete	Total Cost ($1000s)	Feasible to answer by 2024?
1	Are HABs/NABs/toxins present? If so which ones, how abundant?	20% Existing data show presence common detection of HAB species Toxins are ubiquitous but effect is unknown	High	$150/yr 1 more year of sample collection	1.5 yr	$225	Yes
2	Are HABs causing impairment, based on existing data on what causes adverse impacts elsewhere, and based on toxin concentrations in biota and water?	10% Toxins are ubiquitous in water. Toxins have also been detected in most bivalve samples analyzed to date, but are generally low relative to existing guidance levels.	Low	$200/yr Bivalve sampling, water column sampling. Additional 2-3 years of data.	4 yr	$800	Yes
3	What are the ecological drivers at a large scale, in particular the role of nutrients (alongside other physical/biological factors)?	10% Some data available, more needed. 3-5 additional years of data.	Low	$150/yr Additional sample analysis, data analysis and interpretation	3 yr	$450	Yes
4	What are the physiological drivers? In particular what roles do nutrients play, and what would be protective concentrations?	5% Based on studies in other systems	Low	$150-200/yr Substantial undertaking	6+ years e.g., 3 yr for each class of organisms	>$1000	Yes
5	Is acute or chronic impairment evident in resident organisms?	0% No data	Low	$100-200/yr Lab experiments or tissue from Bay animals	5+ yrs	>$1000	Yes
6	Predictive/statistical models: Is there a nutrient-related high risk? What levels of nutrients would be protective?	0% Need ecological and physiological results from 3 and 4, and data from 1 and 2.	Low	$150/yr	3 yrs	$450	Yes, but #2-4 would need to start early
7	Numerical simulation models: Is there a nutrient-related high risk? What levels of nutrients would be protective?	0% Need much data on growth conditions	Low	$200 Semi-quantitatively improved understanding of nutrient role and risk	5 years of model development	$1000	Not to completion

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Table A.2 10-year Science Plan

o - - - - - - - x   Indicates a project that was/is funded and is completed or still underway

Dark grey squares indicate a deliverable or report (there are more deliverables than noted in table; just a subset here)

The yellow, orange and red cells indicate a milestone for answers being iteratively reached to questions that are closely tied to management questions (initial, medium, and final, respectively), corresponding to Tables 2.4 and 2.5.

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	First 5 year Watershed Permit cycle.	▓	▓	▓	▓	▓	▓	▓	█					
	Second 5-year permit.									▓	▓	▓	▓	█
1.	**Nutrient: loads, fate, transport**													
1.A	*Synthesis_Nutrients*													
1	conceptual model	o -	- - - - x											
2	LSB synthesis		o -	- - - - x										
3	Suisun Synthesis I	o -	- - - x											
1.B	*Monitoring_Nutrients*													
1	Baseline Nutrient monitoring: monthly, bi-weekly, Bay-wide	- -	- - - - -	- - -		▓	▓	▓	▓	▓	▓	▓	▓	▓
2	Additional new parameters, shifting toward new nutrient program			o - - x	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
3	Continuous, moored stations, LSB and South Bay focus, nutrients			o - - x	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
4	Continuous, moored stations, other subembayments, nutrients					▓	▓	▓	▓	▓	▓	▓	▓	▓
1.C	*Special investigations: rates, physics, state variables_Nutrients*													
1	Biogeochemical Mapping, LSB focus				o - - x									
2	Physical data collection, interpretation, LSB and South Bay focus				o - - - x									
3	N and P transformations and uptake, field investigations, physical data, LSB and South Bay focus				▓	▓	▓	▓	▓	▓				
4	N/P transformations, field investigations, physical data, other subembayments						▓	▓	▓	▓	▓			
1.D	*Modeling*													
	Load estimates													
1	Overall Loading estimates, v1.0, v2.0, ...	o -	- - - x						▓		▓			
2	Delta loads to Suisun, v1.0, v2.0	▓	o -	- - - - x				▓	▓	▓	▓			
3	Refined point source load estimates, v1.0, v2.0, ...	▓	▓			▓	▓	▓						
4	Local watershed load estimates	▓	▓				▓	▓						
	transport, transformation													
5	Subsystem: LSB and South Bay, including sensitivity analysis				o - - x	▓								
6	Subsystem: Suisun Bay, including sensitivity analysis						▓	▓	▓					
7	Bay-wide nutrient transformations + transport; source tracking/attribution						▓	▓	▓	▓	▓	▓	▓	
8	Exchange with coastal ocean, fate of exported nutrients						▓	▓	▓	▓	▓	▓	▓	
1.E	*Protective Conditions: nutrients*													
1	Based on protective levels for DO, HABs, etc, determine protective nutrient concentrations or loads										▓	▓	▓	▓
1.F	*Future Scenarios: Nutrients*													
1	Nutrient cycling/concentrations under future land uses										▓	▓	▓	▓
2	Future scenarios for nutrient inputs (e.g., load reductions)									▓	▓	▓	▓	▓
2	**High chl, low DO**													
2.1	**2.1 DO: deep subtidal**													
2.1.A	*Synthesis*													
1	conceptual model	o -	- - - - x											
2	LSB synthesis		o -	- - - - x										
2.1.B	*Monitoring: state variables/concentrations*													
1	Baseline biomass monitoring: monthly, bi-weekly, Bay-wide	- -	- - - - -	- - -		▓	▓	▓	▓	▓	▓	▓	▓	▓
2	Additional new parameters, shifting toward new nutrient program			o - - x		▓	▓	▓	▓	▓	▓	▓	▓	▓
3	Continuous, moored stations, LSB and South Bay focus, biomass/DO		- -	- - - - x		▓	▓	▓	▓	▓	▓	▓	▓	▓
4	Continuous, moored stations, other subembayments, bioimass/DO					▓	▓	▓	▓	▓	▓	▓	▓	▓
2.1.C	*Special investigations: rates, physics, state variables, chl-DO deep*													
1	Biogeochemical Mapping, LSB				o - - x									
2	Physical data collection, interpretation, LSB				o - - - x									
3	LSB and South Bay focused field investigations: Biomass, productivity, respiration/oxygen demand in water column and sediments, grazing, physical observations (stratification, velocities, etc.)					▓	▓	▓	▓					
4	field investigations, other embayments: Biomass, productivity, respiration/oxygen demand in water column and sediments, grazing, physical observations (stratification, velocities, etc.)						▓	▓	▓	▓	▓			
5	Habitat/condition assessments (e.g., fish surveys, benthos)					▓	▓	▓	▓	▓	▓			
6	Controlled studies on DO/T tolerance for target species									TBD				
2.1.D	*Modeling_chl-DO_deep*													

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#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Subsystem: LSB and South Bay, focus on explaining recent changes, including sensitivity analysis, relative imporanance of regulating factors (clams, light, etc.)				o - - x		▮(yellow)							
2	Subsystem: Suisun, focus on explaining past changes, relative importance of factors (light, NH4, clams, flushing), including sensitivity analysis		░	░	░	░	░	▮(yellow)						
3	Bay-wide biomass/production/DO								░	░	░▮(orange)	░	░▮(red)	
4	Exchange with coastal ocean, fate of exported biomass, importance of imported biomass						░	░	░	░	░	▮(orange)	▮(red)	

2.1.E Protective Conditions: DO, chl_deep

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Assessment Framework Development, v1.0, v2.0, v3.0; Based on newly collected data, model simulations, habitat assessments, and any refinements to DO standards		o - - - - - - x					▮(yellow)		▮(orange)	▮(red)			
2	Evaluating DO standards: literature review, desktop studies				o - - x		▮(yellow)			▮(orange)	▮(red)			

2.1.F Modeling Future Scenarios: DO, deep subtidal

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	DO, productivity, biomass, etc., under environmental change scenarios										░	░	░▮(yellow)	░▮(orange)
2	Future scenarios for management actions (e.g., load reductions)										░	░	░▮(yellow)	░▮(orange)

2.2 DO: shallow margin

2.2.A Synthesis

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	conceptual model	o - - - - - - x												
2	LSB synthesis (including Analysis of existing DO data in Lower South Bay)		o - - - - - x											
3	Suisun Marsh TMDL work (separate effort)	░	░											

2.2.B Monitoring: state variables/concentrations

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	On-going monitoring in sloughs, or special studies?									TBD				

2.2.C Special investigations: rate measurements, physics, state variables

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	DO in shallow margin habitats, LSB focus				o - - - x	░	░	░▮(yellow)		TBD				
2	Biogeochemical Mapping, LSB				o - - x									
3	Physical data collection, interpretation, LSB				o - - - x									
4	LSB and South Bay focused field investigations: Biomass, productivity, respiration/oxygen demand in water column and sediments, grazing, physical observations (stratification, velocities, etc.)					░	░	░	░					
5	field investigations, other embayments: Biomass, productivity, respiration/oxygen demand in water column and sediments, grazing, physical observations (stratification, velocities, etc.)								░	░	░			
6	Habitat/condition assessments (e.g., fish surveys, benthos)					░	░	░▮(yellow)	░	░▮(orange)	░▮(red)			
7	Controlled studies on DO/T tolerance for target species									TBD				

2.2.D Modeling_chl-DO_shallow

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Slough modeling: focus on one representative sloughs in LSB or South Bay, biomass/DO, nutrients; starting basic, adding complexity as needed					░	░	░						
2	Expand to other sloughs/creeks, as needed and feasible							░	░	░				

2.2.E Protective Conditions: DO_shallow

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Assessment Framework Development, v1.0, v2.0, v3.0; Based on newly collected data, model simulations, habitat assessments, and any refinements to DO standards					░	░	░▮(yellow)	░	░▮(orange)	▮(red)			
2	Evaluating DO standards: literature, desktop studies				o - - x		▮(yellow)			▮(orange)	▮(red)			

2.2.F Modeling Future Scenarios: DO, deep shallow

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	DO, productivity, biomass, etc., under environmental change scenarios										░	░	░▮(yellow)	░▮(orange)
2	Future scenarios for management actions (e.g., load reductions)										░	░	░▮(yellow)	░▮(orange)

3 Phytoplankton community

3.1 HABs/toxins

3.1.A Synthesis: HABs/toxins

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	conceptual model	o - - - - - - x												
2	Suisun Synthesis 2		o - - - - - - x											

3.1.B Monitoring: state variables/concentrations

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	baseline USGS program	- -												
2	integrative measurements (SPATT on Polaris, or at fixed sites)	- - - - - - - - - - - x												
3	additional measurements (consistent set of stations under all conditions)				o - - x	░	░	░	░	░	░	░	░	░
4	On-going water column sampling for toxins								░	░	░	░	░	░
5	Benthos monitoring (natural organisms or e.g., mussel watch)								░	░	░	░	░	░

3.1.C Special investigations

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	analysis of archived pigment samples; on-going analysis of samples collected during monitoring		o - - x	░	░	░	░							
2	analysis of archived toxin samples (11/2011-12/2014); on-going analysis of samples collected during monitoring			o - - x										

#	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
3	Biogeochemical Mapping, LSB, in particular interpretation of pigments and toxins				o - -									
4	Physical data collection, interpretation				o - - - x									
5	data analysis/interpretation of historical HAB and community composition data, and recent data: statistical analysis, mechanistic interpretation				▓	▓								
6	data analysis/interpretation of pigment and toxin data (2012-2017): statistical analysis, mechanistic interpretation					▓	▓							
7	targeted/intensive field investigations to characterize spatial/temporal distribution of HABs/toxins and physical/chemical conditions: LSB, South					▓	▓	▓						
8	targeted/intensive field investigations to characterize spatial/temporal distribution of HABs/toxins and physical/chemical conditions; Bay-wide and/or other embayments								▓	▓				
9	Controlled experiments: factors influencing HABs and toxin production							▓	▓	▓	▓	▓		
10	Controlled experiments: toxicity to biota									TBD				
3.1.D	***Modeling_HABs***													
	simplified domain models for exploring factors that could favor HAB blooms or toxin production, HAB-promoting/toxin-promoting					▓	▓							
	predicting HAB occurrence								▓	▓	▓	▓		
3.1.E	***Protective Conditions: HABs/toxins***													
1	Assessment Framework Development, v1.0, v2.0, v3.0; Based on newly collected data, habitat assessments, etc.: HABs/toxins.		o - - - - - - x					y		▓	▓			
2	Evaluating toxicity and HAB thresholds: which organisms to protect, existing data from other studies, lit review				▓	▓	▓	y		▓	▓			
3	based on toxicity criteria, estimate size/concentration bloom or toxin plumes(bioaccumulation/exposure)				▓	▓	▓	y		▓	▓			
3.1.F	***Modeling Future Scenarios: toxins/HABs***													
	simulations under future drivers									TBD				
3.2	**Food Quality**													
3.2.A	***synthesis***													
1	Suisun Synthesis II		o - - - - - x											
2	Additional synthesis, External Review				▓									
3.2.B	***Monitoring: state variables/concentrations***													
1	baseline USGS program	- - - - - - - - - - - -			▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
2	additional measurements (consistent set of stations under all conditions)			o - - x		▓	▓	▓	▓	▓	▓	▓	▓	▓
3	On-going water column sampling for appropriate measures of phytoplankton community				▓	▓	▓	▓	▓	▓	▓	▓	▓	
3.2.C	***Special Studies***													
1	analysis of archived pigment samples (11/2011-6/2014)		o - - x										
2	analysis of additional archived pigment samples (through 6/2015) (along with HAB study)			o - - x									
3	Biogeochemical Mapping, LSB, jointly with HABs				o - -									
4	Physical data collection, interpretation				o - - - x									
5	data analysis/interpretation of historical community composition data, and recent data: statistical analysis, mechanistic interpretation; Jointly with HABs				▓	▓	▓							
6	data analysis/interpretation of pigment and toxin data (2012-2017): statistical analysis, mechanistic interpretation; Jointly with HABs					▓	▓							
7	targeted/intensive field investigations to characterize spatial/temporal distribution of communities: LSB, South; jointly with HABs					▓	▓	▓						
8	targeted/intensive field investigations to characterize spatial/temporal distribution of communities; Bay-wide and/or other embayments; Jointly with HABs							▓	▓	▓				
9	Controlled experiments: factors influencing community composition, some overlap with HABs studies							TBD						
10	Controlled experiments: factors influencing cellular composition or effects at higher trophic levels (ecological stoichiometry)								TBD					
3.2.D	***Modeling***													
1	simplified domain models for exploring factors that shape community composition; some overlap with HAB modeling					▓	TBD							
2	predicting phytoplankton composition and food quality, some overlap with HAB modeling								▓	TBD				
3.2.E	***Protective Conditions: Food Quality***													
	literature review, healthy phtoplankton community					▓	▓							
	experimental work to identify optimal food quality					▓	TBD							
3.2.F	***Modeling Future Scenarios: food quality***													
	simulations under future drivers									TBD				
4	**NH4 inhibition of primary production**													
4.A	***Synthesis***													
1	Suisun Synthesis I		o - - - - - x											

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	Topic	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
2	Suisun Synthesis II		o - - - - - - x											
3	Additional synthesis, External Review					▓								
4.B	***Monitoring: state variables/concentrations***													
1	baseline USGS sampling	- - - - - - - - - - - -				▓	▓	▓	▓	▓	▓	▓	▓	▓
4.C	***Special investigations***													
1	Complete recent and current projects: Dugdale et al., Glibert et al.; Berg/Kudela et al; Kraus et al. (other funding)	▓	▓											
2	analysis/interpretation of existing data, alongside physical/chemical measurements					▓								
3	New targeted/intensive field investigations						TBD							
4	New controlled experiments:						TBD							
4.D	***Modeling***													
1	Simplified domain, mechanistic model, NH4, light, clams, flow					▓	▓							
2	Further refined model for NH4 considerations								▓	▓				
4.E	***Protective Conditions:***													
1	Interpretation of experimental, field, modeling results, protective levels						▓ (yellow/orange)				(red)			
4.F	***Modeling Future Scenarios***													
1	simulations under future drivers									TBD				
5	**Nutrient Program Development and Maintenance**													
5.A	A. Synthesis: Bi-annual program updates, periodic updates of Science Plan, etc.		o - - - - - ▓			▓	▓	▓	▓	▓	▓	▓	▓	▓
5.B	B. Monitoring: program development, basic monitoring, infrastructure		o - - - x			▓	▓	▓			▓		▓	
5.C	C. Special Studies													
5.D	D. Modeling: base model development, refinement, maintenance		o - - - - - x											
5.E	E. Assessment Framework: data assimilation, refinement		o - - - - - - - x				▓				▓		▓	
5.F	F. Program Management				▓	▓	▓	▓	▓	▓	▓	▓	▓	▓

Appendix 2. Background

A.2.1 San Francisco Bay and the Bay Area

San Francisco Bay (SFB) encompasses several subembayments of the San Francisco Estuary, the largest estuary in California (Figure A.2.1). SFB is surrounded by remnant tidal marshes, intertidal and subtidal habitats, tributary rivers, the freshwater "Delta" portion of the estuary, and the large mixed-land-use area known as the San Francisco Bay Area (Figure A.2.2.A). San Francisco Bay hosts an array of habitat types (Figure A.2.1), many of which have undergone substantial changes in their size or quality due to human activities. Urban residential and commercial land uses comprise a large portion of Bay Area watersheds, in particular those adjacent to Central Bay, South Bay and Lower South Bay (Figure A.2.2.A). Open space and agricultural land uses occupy larger proportions of the watersheds draining to Suisun Bay and San Pablo Bay. The San Joaquin and Sacramento Rivers drain 40% of California, including agricultural-intensive land use areas in the Central Valley. Flows from several urban centers also enter these rivers, most notably Sacramento which is ~100 km upstream of Suisun Bay along the Sacramento River.

SFB receives high nutrient loads from 42 public owned wastewater treatment works (POTWs) servicing the Bay Area's 7.2 million people (Figure A.2.2.B). Several POTWs carry out nutrient removal before effluent discharge; however the majority perform only secondary treatment without additional N or P removal. Nutrients also enter SFB via stormwater runoff from the densely populated watersheds that surround SFB (Figure A.2.2.A). Flows from the Sacramento and San Joaquin Rivers deliver large nutrient loads, and enter the northern estuary through the Sacramento/San Joaquin Delta (not shown, immediately east of the maps in Figure A.2.1 and A.2.2).

Figure A.2.1 Habitat types of SFB and surrounding Baylands. Water Board subembayments boundaries are shown in black. Habitat data from CA State Lands Commission, USGS, UFWS, US NASA and local experts were compiled by SFEI.

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A.2.1 San Francisco Bay Nutrient Strategy

Dissolved inorganic nitrogen (DIN) and phosphorus (DIP) are essential nutrients for primary production that supports SFB food webs. However DIN and DIP concentrations in SFB greatly exceed those in other US estuaries where water quality has been impaired by nutrient pollution (Cloern and Jassby, 2012). SFB has long been considered relatively immune to its high nutrient loads. For example, the original San Francisco Bay Regional Basin Plan from 1975 stated that only limited treatment for nutrients was necessary because the system was considered to be light limited (SFBRWQCB, 1975). Research and monitoring over the last 40 years have identified several factors that impart SFB with its resistance to high nutrient loads (e.g., see Cloern and Jassby 2012; Cloern et al., 2007; Kimmerer and Thompson, 2014): high turbidity (low light), strong tidal mixing (breaks down stratification and fully mixes the water column, resulting in low light availability), and abundant filter-feeding clam populations (remove phytoplankton from the water column).

However, recent studies indicate that the response to nutrients in SFB is changing, indicate that the system is poised to potentially experience future impacts, or suggest that current nutrient levels are already causing adverse impacts. These observations include: a 3-fold increase in summer-fall phytoplankton biomass in South Bay since the late 1990s; frequent detections in SFB of algal species that have been shown in other nutrient-rich estuaries to form harmful blooms; detection of algal toxins Bay-wide; an unprecedented red tide bloom in Fall 2004; and studies suggesting that the chemical forms of nitrogen can influence phytoplankton productivity and composition. To address growing concerns that SFB's response to nutrients is changing and that conditions may be trending toward adverse impacts due to elevated nutrient loads, the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) worked collaboratively with stakeholders to develop the San Francisco Bay Nutrient Management Strategy[1], which lays out an approach for gathering and applying information to inform management decisions. Overall, the Nutrient Management Strategy aims to answer four fundamental questions:

1. Is SFB experiencing nutrient-related impairment, or is it likely to in the future?
2. What are the major nutrient sources?
3. What nutrient loads or concentrations are protective of ecosystem health?
4. What are efficacious and cost-efficient nutrient management options for ensuring that Bay beneficial uses are protected?

The indications of changing SFB response to nutrients have come to the fore at a time when the availability of resources to continue assessing the Bay's condition is uncertain. Since 1969, a USGS research program has supported water-quality sampling in the San Francisco Bay. This USGS program collects monthly samples between the South Bay and the lower Sacramento River to measure salinity, temperature, turbidity, suspended sediments, nutrients, dissolved oxygen and chlorophyll a. The USGS data, along with sampling conducted by the Interagency Ecological Program (IEP), provide coverage for the entire Bay–Delta system (Figure A.2.3). The San Francisco Bay Regional Monitoring Program (RMP) has no independent nutrient-related monitoring program, but instead contributes approximately 20% of the USGS data collection cost. The Nutrient Strategy highlights the need for a regionally-supported, long-term monitoring program that provides the information that is most needed to support management decisions in the Bay.

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[1]http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarineNNE/Nutrient_Strategy%20November%202012.pdf

The timing also coincides with a major state-wide initiative, led by the California State Water Resources Control Board (State Water Board), for developing nutrient water quality objectives for the State's surface waters, using an approach known as the Nutrient Numeric Endpoint (NNE) framework. The NNE framework establishes a suite of numeric endpoints based on the ecological response of a waterbody to nutrient over-enrichment and eutrophication (e.g. excessive algal blooms, decreased dissolved oxygen). In addition to numeric endpoints for response indicators, the NNE approach includes models that link the response indicators to nutrient loads and other management controls. The NNE framework is intended to serve as numeric guidance to translate narrative water quality objectives.
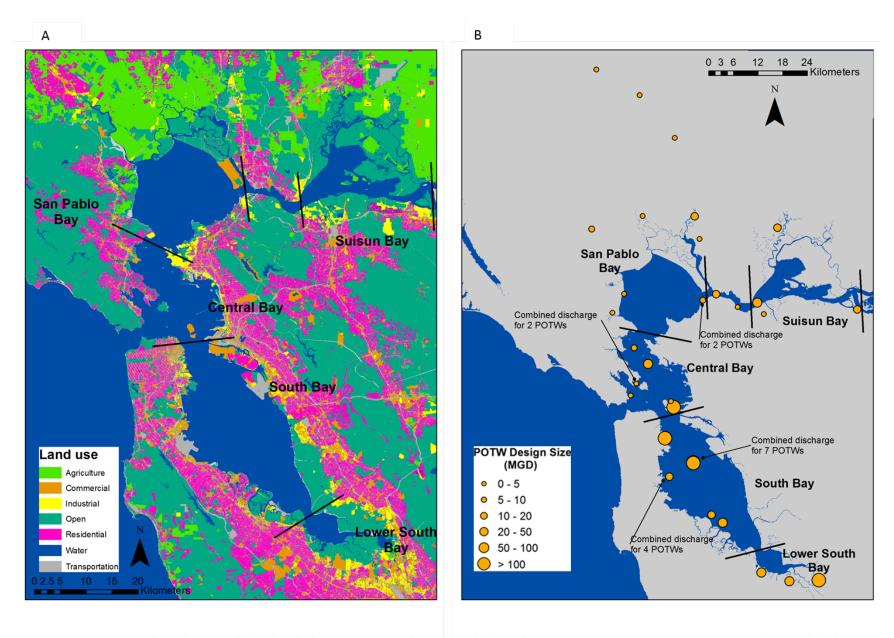
Figure A.2.2 A. Land use in watersheds that drain to SFB (Data from Association of Bay Area Governments, 2000). **B.** Location and design size (in million gallons per day) for POTWs that discharge directly in SFB or in watersheds directly adjacent to subembayments. In both figures, Water Board subembayment boundaries are shown in black.

Since San Francisco Bay is California's largest estuary, it is a primary focus of the state-wide effort to develop NNEs for estuaries. Through the Nutrient Strategy, the SFBRWQCB is working with regional stakeholders and with the State Water Board to develop an NNE framework specific to SFB. That effort was initiated by a literature review and data gaps analysis that recommends indicators to assess eutrophication and other adverse effects of nutrient overenrichment in San Francisco Bay McKee et al., 2011)[2]. McKee et al. (2011) evaluated a number of potential indicators of ecological condition for several habitat types based on the following criteria:

- Indicators should have well-documented links to estuarine beneficial uses
- Indicators should have a predictive relationship with nutrient and hydrodynamic drivers that can be easily observed with empirical data or a model
- Indicators should have a scientifically sound and practical measurement process that is reliable in a variety of habitats and at a variety of timescales
- Indicators must be able to show a trend towards increasing or/and decreasing benefical use impairment due to nutrients

The report recommended focusing on subtidal habitats initially, and proposed the following primary indicators of beneficial use impairment by nutrients: i. phytoplankton biomass; ii. phytoplankton composition; iii. dissolved oxygen; and; iv. algal toxin concentrations. In addition, 'supporting indicators' and 'co-factors' were identified, and are summarized in Table A.2.1. Supporting indicators provide additional lines of evidence to complement observations based on primary indicators, and co-factors are essential information to help interpret and analyze trends in primary or supporting indicators.

Table A.2.1 Recommended indicators within the context of the SFB NNE. Excerpted from McKee et al 2011

Habitat	Primary Indicators	Supporting Indicators	Co-Factors
All Subtidal Habitat	Phytoplankton biomass, productivity and assemblage Cyanobacteria cell counts and toxin concentration Dissolved oxygen	Water column nutrient concentrations and forms[1] (C,N,P,Si) HAB species cell counts and toxin concentration	Water column turbidity, pH, conductivity, temperature, light attenuation Macrobenthos taxonomic composition, abundance and biomass Sediment oxygen demand Zooplankton
Seagrass Habitat	Phytoplankton biomass Macroalgal biomass & cover Dissolved oxygen	Light attenuation, suspended sediment concentration Seagrass areal distribution and cover Epiphyte load	Water column pH, temperature, conductivity Water column nutrients
Intertidal flats	Macroalgal biomass and cover	Sediment % OC, N, P and particle size Microphytobenthos biomass (benthic chl-a)	Microphytobenthos taxonomic composition
Muted Intertidal and Subtidal	Macroalgal biomass & cover Phytoplankton biomass Cyanobacteria toxin concentration	Sediment % OC, N, P and particle size Phytoplankton assemblage Harmful algal bloom toxin concentration	Water column pH, turbidity, temperature, conductivity Water column nutrients

[2]http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarineNNE/644_SFBayNNE_LitReview%20Final.pdf

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Regions of SFB behave quite differently with respect to nutrient cycling and ecosystem response due to a combination physical, chemical, and biological factors. To facilitate the discussion of spatial trends in this report, SFB was divided into 5 subembayments, as depicted in Figure A.2.1: Suisun Bay, San Pablo Bay, Central Bay, South Bay and Lower South Bay (LSB). These subembayment boundaries were chosen based on geographic features and not necessarily hydrodynamic features, represent one of several sets of boundaries that could be used. The boundaries illustrated in Figure A.2.1 are similar to those defined by the SFBRWQCB in the San Francisco Bay Basin Plan, although we use different names for the subembayments south of the Bay Bridge.
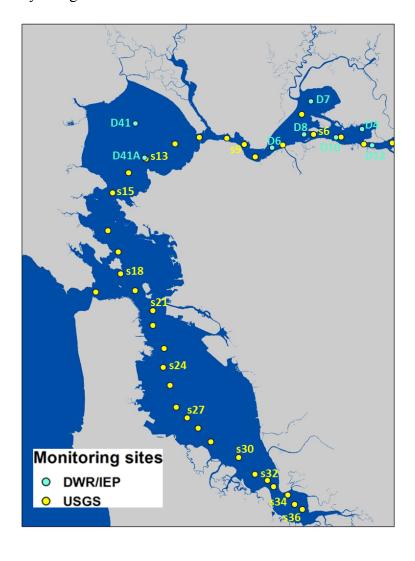
Figure A.2.3 Location of DWR/IEP and USGS monthly sampling stations. Data from labeled USGS Stations (s6, s15, s18, s21, s27, s36) are used in Figures 5.7, 6.3-6.7 and 7.11.

Appendix 3 Problem Statement

A.3.1 Recent observations in SFB

In estuarine ecosystems in the US and worldwide, high nutrient loads and elevated nutrient concentrations are associated with multiple adverse impacts (Bricker et al. 2007). N and P are essential nutrients for the primary production that supports food webs in SFB and other estuaries. However, when nutrient loads reach excessive levels they can adversely impact ecosystem health. Individual estuaries vary in their response or sensitivity to nutrient loads, with physical and biological characteristics modulating estuarine response (e.g., Cloern 2001). As a result, some estuaries experience limited or no impairment at loads that have been shown to have substantial impacts elsewhere.

Figure A.3.1 illustrates several potential pathways along which excessive nutrient loads could adversely impact ecosystem health in SFB. Each pathway is comprised of multiple linked physical, chemical, and biological processes. Some of those processes are well-understood and data are abundant data to interpret and assess condition; others are poorly understood or data are scarce. A recent conceptual model report (SFEI 2014a) describes the processes creating the pathways between loads and adverse response, and describes the current state of knowledge and data availability.
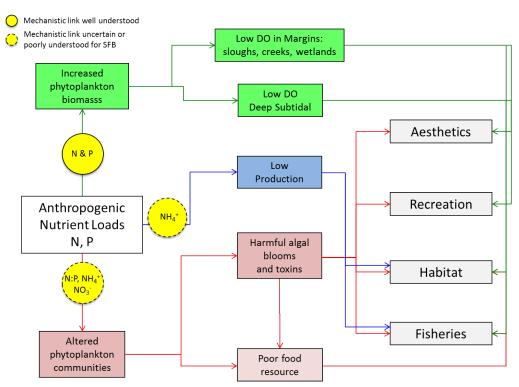
Figure A.3.1 Potential adverse impact pathways: linkages between anthropogenic nutrient loads and adverse impacts on uses or attributes of SFB. The shaded rectangles represent indicators that could actual be measured along each pathway to assess condition. Grey rectangles to the right represent uses or attributes of SFB for which water quality is commonly managed. Yellow circles indicate the forms of nutrients that are relevant for each pathway

Current nutrient loads to some SFB subembayments are comparable to or much greater than those in a number of other major estuaries that experience impairment from nutrient overenrichment (SFEI 2014). Consistent with its high loads, SFB has elevated levels of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorous (DIP) relative to other estuaries (Figure A.3.2). Yet SFB does not commonly experience classic symptoms of nutrient overenrichment, such as massive and sustained phytoplankton blooms, or low dissolved oxygen over large areas in the subtidal zone. SFB has been spared the most obvious adverse impacts of high nutrient loads along these pathways due to a combination of factors (high turbidity; strong tidal mixing; large populations of benthic filter feeders) that have imparted SFB with some inherent resistance to these effects (Cloern and Jassby, 2012; SFEI 2014). However, several recent sets of observations indicate that nutrient-related problems may already be occurring in some areas of SFB, or serve as early warnings of problems on the horizon.
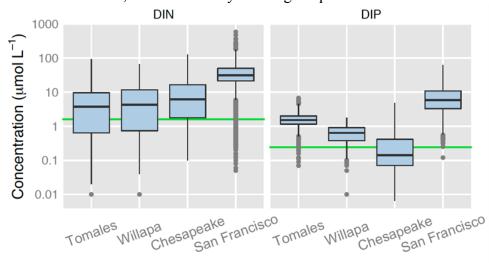
Figure A.3.2 Nutrient concentrations in South Bay compared to other estuaries. Source: Cloern and Jassby (2012)

Over the past 15 years, statistically significant increases in phytoplankton biomass have been observed throughout SFB. Most notably summer/fall phytoplankton biomass tripled between the mid-1990s and the mid-2000s (Figure A.3.3; Cloern et al., 2007) in South Bay and LSB, representing a shift in trophic status from oligo-mesotrophic (low to moderate productivity system) to meso-eutrophic (moderate to high productivity system) (Cloern and Jassby, 2012).
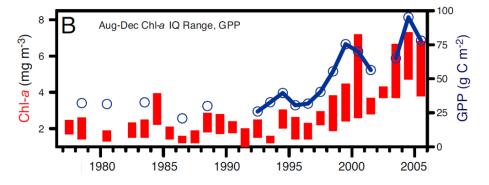
Figure A.3.3 Interquartile range of Aug-Dec chl-a concentrations averaged across all USGS stations between Dumbarton Bridge and Bay Bridge, 1977-2005. Source: Cloern et al., 2007

More recent data from South Bay suggest that, at least presently, biomass concentrations have plateaued at a new level instead of continuing to rise (Figure A.3.4). While the greatest magnitudes of biomass increase (i.e., in ug/L chl-a) have been observed in South Bay, other SFB subembayments have also experienced statistically significant increases in phytoplankton biomass (J Cloern, personal communication).
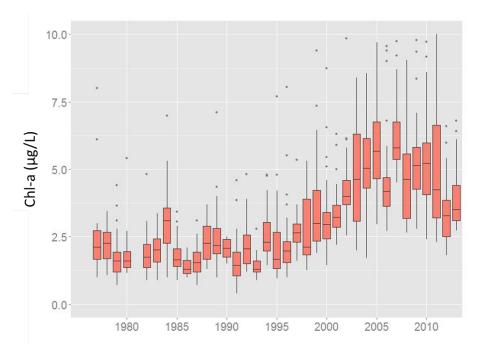
Figure A.3.4 Same stations as and data as presented Figure A.3.5, with data extended through 2013 (Interquartile range of Aug-Dec chl-a concentrations averaged across all USGS stations between Dumbarton Bridge and Bay Bridge, 1977-2013). Source: SFEI 2014c

In Suisun Bay, extremely low phytoplankton biomass has defined the system since 1987 (Figure A.3.8), coincident in time with the invasive clam, *Potamocorubula amurensis,* becoming widely established. The extended period of low phytoplankton biomass and low rates of primary production are considered to be among the factors contributing to long-term declines in upper trophic level production in Suisun Bay and the Delta by limiting food supply (Baxter et al., 2010; NRC 2012). While the low phytoplankton biomass and productivity in Suisun Bay have frequently been attributed to the impacts of *Potamocorbula* and low light levels due to high suspended sediments (e.g., Kimmerer and Thompson, 2014), recent studies have argued that elevated ammonium (NH_4^+) concentrations in Suisun Bay also limit primary production rates and play an important role in both creating the low biomass conditions and exacerbating food limitation (Dugdale et al., 2007; Dugdale et al., 2012; Parker et al. 2012a,b). Other studies have proposed that high ambient concentrations of nitrate (NO_3^-) and NH_4^+, and altered ratios of N:P cause shifts phytoplankton community composition toward

Figure A.3.5 Phytoplankton biomass in Suisun Bay, 1975-2010. Source: J Cloern, USGS; Data: USGS, DWR-EMP

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species having poor food quality, adversely impacting Delta food webs (Glibert 2010; Glibert et al., 2011).

Harmful phytoplankton species also represent a growing concern. The harmful algae, *Microcystis spp.*, and the toxin they produce, microcystin, have been detected with increasing frequency in the Delta and Suisun Bay since ~2000 (Lehman et al., 2008). In addition, the HAB toxins microcystin and domoic acid have been detected Bay-wide (Figure A.3.6). The ecological
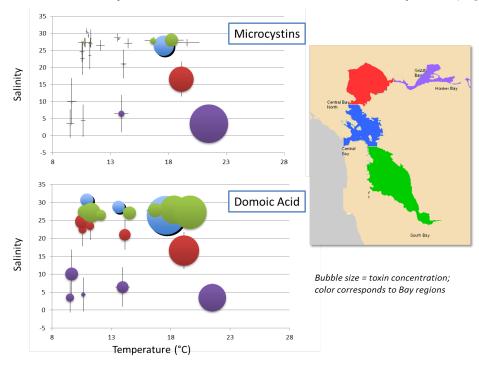
Figure A.3.6 HAB toxins detected in SFB during 2011. Bars represent 1 SD for salinity and temperature Source: R. Kudela

Bubble size = toxin concentration; color corresponds to Bay regions

significance of observed toxin levels in the Bay are not yet known. A number of phytoplankton species that have formed harmful algal blooms (HABs) in other systems have been detected throughout SFB (Figure A.3.7 and Table A.3.1). Although the abundances of HAB-forming organisms in SFB have not generally reached levels that would constitute a major bloom, they do periodically exceed thresholds established for other systems (Sutula et al., in prep), and major *Microcystis spp* blooms and elevated microcystin levels have been observed with some regularity in the Delta (Lehman et al., 2008). Moreover, since HAB-forming species are present in SFB and nutrients are abundant, HABs could readily develop should appropriate physical conditions create opportunities that HABs can exploit. In fact, an unprecedented large red tide bloom occurred in Fall 2004 following a rare series of clear calm days during which the water column was able to stratify, and chl-a levels reached nearly 100 times their typical values (Figure A.3.8; Cloern et al. 2005). In addition, harmful-bloom forming species have been detected at elevated abundances in salt ponds in LSB undergoing restoration (Thebault et al., 2008), raising concerns that salt ponds could serve as incubators for harmful species that could then proliferate when introduced into the open bay

Legend: ◆ Heterosigma akashiwo ▲ Karenia mikimotoi ● Karlodinium veneficum ◆ Chattonella marina

San Pablo Bay

Central Bay

South Bay

1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
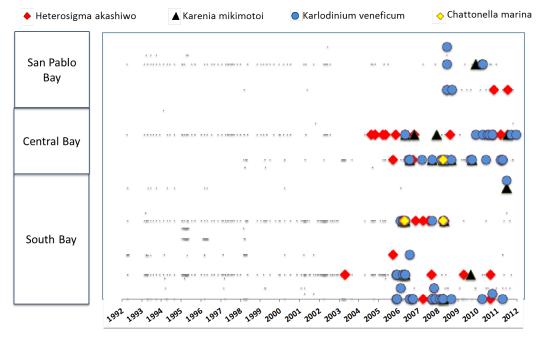
Figure A.3.7 Several potentially harmful algal species detected in South Bay, Central Bay, and San Pablo Bay over the past 20 years. Y-axis represents distance to USGS stations from Lower South Bay. Grey dots represent sample collection/analysis, colored dots represent one of the 4 species detected in a collected sample. Source: T Schraga, USGS
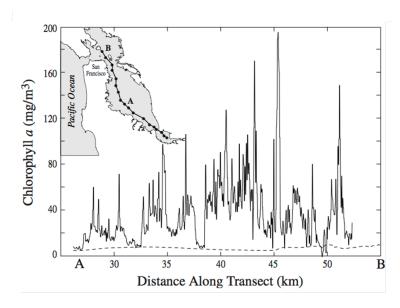
Figure A.3.8 Phytoplankton biomass South and Central Bays. Measurements taken during a red tide on 8 September 2004 (solid curve). Phytoplankton biomass returned to typical seasonal levels on 14 September (dashed curve). Inset map shows location of the sampling transect A-B. Source: Cloern et al. 2005

Table A.3.1 Potentially harmful algal species detected through USGS science program in SFB: 1992-2012. Source: T Schraga, USGS

Genus/Species	Division/ Phyla	1st observed	Most recent observed	# of times observed	Toxin**	Impact	Location and timing of observations
Alexandrium	Dinoflagellate	1992	2011	247	saxitoxin	neurotoxin, fish kills	South, Central, and San Pablo Bays - Spri and Fall
Amphidinium	Dinoflagellate	1996	2008	36	compounds with haemolytic and antifungal properties	fish kills	South Bay - spring bloom (March-April) a occasionally fall bloom (September-Octob
Dinophysis	Dinoflagellate	1993	2011	51	okadaic acid		Central bay
Heterocapsa	Dinoflagellate	1992	2012	394		food web hab, kills shellfish	Found throughout year, but mostly seen in spring and summer, South and Central Bay occasionally up to San Pablo Bay
Karenia mikimotoi *	Dinoflagellate	2006	2011	22	gymnocins, compounds similar to brevetoxin	kills benthic organisms, fish, birds, + mammals	South bay + Central Bay
Karlodinium veneficum *	Dinoflagellate	2005	2012	63	compounds with hemolytic, ichthyotoxic, and cytotoxic effects	kills fish, birds + mammals	South bay + Central Bay
Heterosigma akashiwo *	Raphidophyte	2003	2011	39	neurotoxin	fish kills	South bay + Central Bay
Pseudo-nitzschia	Diatom	1992	2011	132	domoic acid		Large blooms occurred in central and soutl Bay (stn 27) in 1990s
Anabaena	Cyanobacteria	1993	2011	24	PSTs		Sacramento River and confluence.
Aphanizomenon flos-aquae	Cyanobacteria	1995	2011	13	PSTs		Sacramento River and confluence. Low #s South Bay

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Genus/Species	Division/Phyla	1st observed	Most recent observed	# of times observed	Toxin**	Impact	Location and timing of observations
Aphanocapsa	Cyanobacteria	1993	2011	22			South Bay 2005+6, 2011 Delta confluence (San Joaquin source most likely)
Aphanothece sp.	Cyanobacteria	1992	2011	32			South Bay 2005+6, 1990s and 2010-11 Suis and Sac River
Cyanobium sp.	Cyanobacteria	1999	2008	79	microcystin		South and Central Bay
Lyngbya aestuarii	Cyanobacteria	2011	2011	1	saxitoxin	human health impacts (skin, digestion, respiratory, tumors) and paralytic shellfish poisoning	September 2011 - large bloom in Suisuin are (stn 3)
Planktothrix	Cyanobacteria	1992	2011	23	PSTs		South Bay 2005-2007, 1990s, 2010-11 Suis and Sac River
Synechococcus sp.	Cyanobacteria	1992	2011	66			South Bay spring (March/April)
Synechocystis	Cyanobacteria	1997	2011	224	microcystin		South Bay and San Pablo Bay, mostly in fall

All of these species have had high biomass in SFBAY. Multiple species are grouped within a genera. If it's a single species, it is listed as such

*Known as exceptionally harmful in temperate estuaries such as in Japan and Atlantic coast estuaries. All were detected for the first time in SFb in the past 10 years and have persisted

** Not all toxins are known. Genera with PST have two or more Paralytic Shellfish Toxins = microsystin, cylindrospermopsin, anatoxin, saxitoxin. All cause Paralytic Shellfish Poisoning. PSTs microcystin and cylindrospermopsin cause liver damage in mammals, anatoxin and saxitoxin damage nerve tissues in mammals (humans, dogs, etc.)
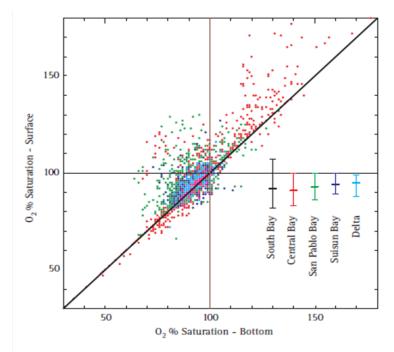
Figure A.3.9 DO in deep subtidal areas of SFB. Source: Kimmerer 2004

Figure 32. Oxygen concentration as percent saturation in near-surface and near-bottom samples. Color indicates region, and error bars give medians and 10th and 90th percentiles of the data. Data from USGS monitoring program, which focuses on channel stations and the portion of the Delta in the lower Sacramento River.

DO concentrations in deep subtidal habitats throughout the Bay typically remain at levels above 5 mg L^{-1}, (Figure A.3.12), the San Francisco Bay Basin Plan standard. However, in LSB, open-Bay sampling has most frequently occurred at slack high tide. Recent continuous measurements at the Dumbarton Bridge indicate that DO levels at low tide are commonly 1-2 mg/L lower than at high tide during summer months (e.g., Figure A.3.10.A), and can occasionally dip below, 5 mg L^{-1} (SFEI, unpublished data). During Summer 2014, USGS sampling cruises detected DO < 5 mg/L at other deep subtidal stations south of the Dumbarton Bridge during two cruises[3].

Low DO commonly occurs in some shallower margin habitats (Figure A.3.10B and Figure A.3.11). For example, studies of salt ponds undergoing restoration in LSB show that they experience large diurnal DO fluctuations (Topping et al., 2009) and occasionally experience sustained periods of anoxia (Thebault et al., 2008). In some slough habitats of LSB, DO regularly dips below 5 mg L^{-1}, frequently approaches 2 mg L^{-1} (Shellenberger et al., 2008). At a site in Alviso Slough, DO remained near or below 2 mg L^{-1} for sustained periods (up to 10-12 hours) during Summer 2013 (Figure A.3.10.B) and Summer 2014 (SFEI, 2015). Low DO has also been observed in Suisun Marsh, although whether that low DO is linked to nutrient issues in SFB is still being investigated (effluent from managed duck ponds is presumed to be a major cause; Tetra Tech 2013). Under natural conditions, shallow subtidal and tidal wetland habitats commonly experience low DO, and plants and animals native to these habitats are often well-adapted to these DO swings. However, there is a paucity of DO data in margin habitats, and the

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[3] http://sfbay.wr.usgs.gov/access/wqdata/query/easy.html

severity of low DO (frequency, duration, spatial extent, concentration), whether it is impacting biota, and the extent to which excess nutrients cause or contribute to the low DO conditions are all poorly known.

A. Dumbarton   **B. Alviso**
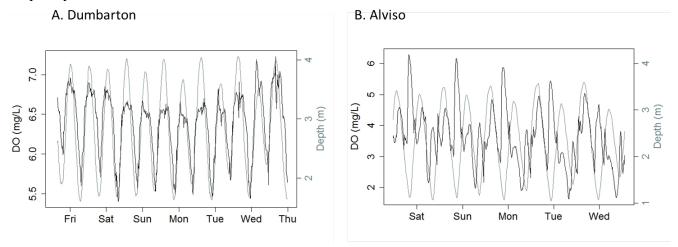
Figure A.3.10 Time series of DO (mg/L) and depth at **A.** Dumbarton Bridge and **B.** Alviso Slough, Sep 5-12 2013.

In addition to characterizing and addressing any current nutrient-related problems in SFB, there is a need to anticipate potential future adverse impacts. The highly elevated DIN and DIP concentrations Bay-wide provide the potential for impairment to occur in the future if the physical and biological factors that provide SFB with resistance to high nutrient loads continue to change. Any major reductions in nutrient loads to SFB will take years-to-decades to implement. Thus, if future problems are to be averted, potential impairment scenarios need to be anticipated, evaluated, and, if deemed necessary, managed in advance of their onset. A proactive approach to characterizing and managing potential problems – while they are on the somewhat-distant horizon, as opposed to imminent – will allow greater flexibility in the management options that can be pursued.

% Time below 5 mg L^{-1}

Sloughs   Former Salt Ponds
n=10   n=14
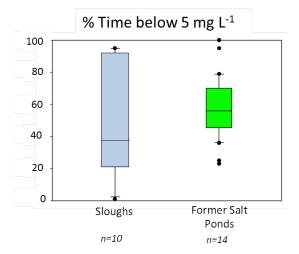
Figure A.3.11 Percentage of time DO less than 5 mg/L in sloughs and salt ponds rimming Lower South Bay, based on a review of all available multi-program continuous sensor measurements. Source: SFEI 2014c

Appendix 4 Key Observations and Recommendations

The following observations and recommendations are excerpted from *"Scientific Foundation for the San Francisco Bay Nutrient Management Strategy"* (SFEI 2014), and serve as the starting set of recommendations for the Science Plan.

A.4.1 Key observations

1. Changes in SFB's response to nutrient loads over the past decade, combined with the Bay's high nutrient loads and concentrations, justify growing concerns about elevated nutrients.

2. The future trajectory of SFB's response to nutrients is uncertain. One plausible trajectory is that SFB maintains its current level of resistance to the classic effects of high nutrient loads and no further degradation occurs. A second, equally plausible scenario is that SFB's resistance to nutrients continues to decline until adverse impacts become evident. The highly elevated DIN and DIP concentrations Bay-wide provide the potential for future impairment. Any major reductions in loads to SFB will take years-to-decades to implement. Thus, if future problems are to be averted, potential impairment scenarios need to be anticipated, evaluated, and, if deemed necessary, managed in advance of their onset.

3. By considering current conditions in SFB, trends of changing ecosystem response, and a conceptual model for SFB's response to nutrients, we identified the following highest priority issues:
    a. Determine whether increasing biomass signals future impairment. This issue is most pertinent for Lower South Bay and South Bay.
    b. Determine if low DO in shallow habitats causes adverse impacts, and quantify the contribution of excess nutrients to that condition.
    c. Characterize/quantify the extent to which excess nutrients contribute now, or may contribute in the future, to the occurrence of HABs/NABs and phycotoxins.
    d. Further evaluate other hypotheses for nutrient-related adverse impacts to ecosystem health, including nutrient-induced changes in phytoplankton community composition and ammonium inhibition of primary production. That evaluation – to include expert workshops, data analysis/synthesis, or modeling – should aim to identify high priority investigations that are needed to help determine protective nutrient levels, and assess their potential quantitative importance.
    e. Test future scenarios that may lead to worsening conditions through the use of numerical models.
    f. Quantify the contributions of individual nutrient sources to ambient concentrations in different areas of the Bay, considering both their transport and in situ transformations and losses.
    g. Evaluate the potential effectiveness of various nutrient management strategies at mitigating or preventing adverse impacts.

4. Although concern related to changing ecosystem response in SFB is warranted, widespread and severe nutrient-related impacts do not currently appear to be occurring, based on existing sampling locations and parameters commonly measured. This apparent lack of current severe impacts translates into time for conducting investigations to improve understanding of SFB's response to nutrients and allows for sound, science-based management plans to be developed

and implemented. That said, the considerable amount of time required to implement any management strategy raises the level of urgency such that work should move forward expeditiously.

5. Given the stakes of no action - and the time required for data collection, analysis, and modeling tools to reach a useable state - work needs to move forward in parallel on implementing multiple aspects of the Nutrient Strategy. A well-coordinated program is needed to maximize the effectiveness and efficiency of this effort. That program needs to integrate seamlessly across what might otherwise be (or become) semi-independent program areas. Specifically, we recommend the following set of highly-integrated program areas:
    a. Monitoring: Develop and implement a sustainably-funded and regionally administered monitoring program that continues routine monitoring, and fills newly-identified data gaps relevant to nutrients;
    b. Modeling: Develop and apply linked hydrodynamic and water quality models to integrate observations, identify critical data gaps (to be addressed through monitoring or experimental studies), quantify processes at the ecosystem scale, and evaluate future scenarios (including management alternatives);
    c. Observational and Experimental Studies: Undertake special studies (field investigations, controlled experiments) to address the highest priority knowledge and data gaps identified in #3; and
    d. Data Synthesis and Interpretation: Analysis of existing and newly collected data (from monitoring and experimental studies), incorporatingmodels, to improve understanding of linkages between nutrients and ecosystem response and to inform the development of an assessment framework.

6. The Delta/Suisun boundary, while an important regulatory boundary, is not meaningful from ecological and loading standpoints. Nutrient loads to and transformations within the Delta exert considerable influence over nutrient loads to and ambient concentrations within Suisun, San Pablo, and Central Bays. Furthermore, the ecology and habitat quality of the Delta and Suisun Bay are tightly coupled. A unified approach – one that spans the Bay-Delta continuum - for evaluating the impacts of nutrients on beneficial uses will best serve both ecosystem health in the Bay-Delta and the information needs of environmental managers.

A.4.2 Recommendations for Addressing Priority Knowledge Gaps

Section A.4.2.1 provides an overview of the recommended highest priority work efforts over the next 1-5 years to address knowledge and data gaps to, in a targeted way, inform nutrient management decisions in SFB. The process consisted of (see SFEI 2014)

- Identifying the highest priority scenarios for potential impairment along one or more pathways, and high priority science questions that need to be addressed related to those scenarios (Tables A.4.1 and A.4.2);
- Prioritizing data or knowledge gaps related to the key processes that control ecosystem response to nutrients along the pathways of the near-term highest priority scenarios (Tables A.4.3-A.4.6.

Recommendations presented in Section A.4.2.1 are organized around several major themes or types of work. Not all high priority data gaps are discussed in the text below, and the reader is also referred to Tables A.4.1-A.4.6. Section A.4.2.2 takes a broader view, and describes

knowledge gaps and data needs in terms of a set of ecological and management challenges that lie ahead.

A.4.2.1 Recommendations

R.1 Develop a regionally-administered and sustainably-funded nutrient monitoring program

Major research and monitoring efforts in San Francisco Bay and the Delta include the USGS research program[4] and the IEP Environmental Monitoring Program.[5] The data generated through these programs, and the related interpretations, form much of the foundation for current understanding of SFB's response to nutrients. However, the focus and mandates of these programs are not necessarily aligned with those of a program designed program to inform nutrient management decisions. Furthermore, future funding of the USGS program is uncertain.

Developing a regionally-administered and sustainably-funded nutrient monitoring program needs to be a major priority. Effort needs to be directed toward developing the institutional and funding frameworks for the program, and developing its primary science goals and activities. Several initial recommendations are presented below.

R.1.1 Program development

R.1.1.1 Develop institutional and funding agreements

Developing and implementing a regional nutrient monitoring program will be a major undertaking in terms of logistics and cost, and long-term institutional support will be needed. There are several entities currently involved in ship-based and continuous (moored sensors) monitoring (e.g., USGS, IEP, CA Department of Water Resources, CA Department of Fish and Game). To avoid unnecessary duplication of effort and maximize resources, there may considerable advantage to achieving some monitoring program goals through fostering close coordination among on-going programs, and augmenting those efforts with additional monitoring. Activities distributed across independent programs need to be well-coordinated, especially in terms of methods, QA/QC, data management and data sharing, synthesis, and reporting.

R.1.1.2 Develop the monitoring program science plan: management questions, goals, priorities, and approaches

A nutrient monitoring program science plan needs to be developed that lays out the management questions, and the program's goals and priorities relative to those management questions. Detailed plans for achieving those goals also need to be developed. A number of the goals and data needs may differ considerably from those of the current research and monitoring activities (i.e., USGS, IEP). When evaluating the future program's needs relative to current efforts, particular attention needs to be given to the following issues:

- The optimal distribution of effort and resources among broad monitoring categories (water column vs. benthos, shoals vs. channel, open bay vs. margins, physical/hydrodynamic vs. biological vs. chemical)
- Key parameters or processes to be measured within these categories;
- Spatial and temporal resolution of sampling; and

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[4] http://sfbay.wr.usgs.gov/access/wqdata/
[5] http://www.water.ca.gov/iep/activities/emp.cfm

- The distribution of monitoring effort between ship-based sampling and moored sensors for continuous monitoring.

For some of these issues, considerable data resources already exist from long-term monitoring in SFB. A major component of the monitoring program design effort should include analyzing this data to inform decisions (e.g., about the necessary spatial and temporal density of sampling). Pilot studies should also be part of planning, to inform which parameters provide important additional information, test methods that provide less expensive approaches for essential data collection, and select moored sensor sites and parameters.

R.1.2. Initial monitoring program science recommendations
Several clear monitoring program recommendations emerged through developing the conceptual model (SFEI 2014), and identifying data/knowledge gaps related to priority scenarios (Tables 6.3-6.6).

R.1.2.1 Continue shipped-based monitoring along SFB's deep channel
The long-term record provided by the USGS research program has yielded important insights into the mechanisms that shape SFB'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. New parameters may be needed informative, such as size-fractionated chl-a and C:chl-a, organic forms of N and P, as well as others noted below.

R.1.2.2 Develop a moored sensor sub-program for high temporal resolution data
Data collection at higher temporal resolution for chl-a, DO, nutrients, turbidity, and other parameters is needed at multiple locations to assess condition and to improve our quantitative understanding of ecosystem response to nutrients, including the processes that influence phytoplankton blooms, influence oxygen budgets, and regulate nutrient fate. High temporal resolution data will be essential for accurately calibrating water quality models. Continuous monitoring with moored sensor systems is feasible for a wide range of water quality parameters. Techniques for some parameters are becoming increasingly well-established and reliable (e.g., salinity, T, turbidity, chl-a, DO), while others are advancing (e.g., nitrate, phosphate, ammonium, phytoplankton counts and identification). Moored sensor systems can telemeter data, allowing for near real-time assessment of conditions. The data from moored sensors are not a substitute for ship-based sampling, but rather provide strongly complementary information about physical and biological processes that influence key water quality parameters (chlorophyll, DO, T, SpC) over time-scales (hours) that are too short to effectively monitor or study through ship-based sampling. While there are currently multiple stations in Suisun Bay and the Delta that measure some nutrient-related parameters, there are only 3 newly-added stations south of the Bay Bridge for measuring chl-a or nutrients (added in September 2013), and few that measure DO and other parameters (T, SpC, turbidity).

R.1.2.3 In addition to monitoring along the channel, monitoring is needed in shoal environments, including lateral transects
Sampling along the shoals is needed for improved understanding of phytoplankton and nutrient processes, and for model calibration. Most of the water quality data available in SFB is from stations along the deep channel. The shoals are important areas for phytoplankton and MPB production, and large lateral heterogeneities in phytoplankton biomass (and SPM, which influences light availability and growth rates) are common in SFB (Thompson et al., 2008;

Cloern, 1995). In addition, a substantial proportion of nutrient transformations likely take place along the shoals (benthic nitrification and denitrification). Shoal monitoring can be accomplished both through boat/ship-based transects or with moored sensors, and the best approach will vary depending on the questions being addressed. Using autonomous underwater vehicles (AUVs) outfitted with sensors may also be a possibility. AUVs are commonly employed in research studies, and some AUV-sensor systems are already commercially-available. Pilot studies that test AUVs in SFB would be useful for assessing the feasibility and cost effectiveness of this approach, and to inform planning.

R.1.2.4 Coordinated monitoring in shallow subtidal habitats.
Some agencies (e.g., stormwater, wastewater) carry out periodic monitoring in shallow habitats, and several focused studies have been conducted in Lower South Bay systems (Thebault et al., 2008; Shellenbarger et al. 2008; Topping et al., 2009). However, there is currently no systematic monitoring in shallow margin habitats either at the subembayments scale or Bay-wide. Data collection on productivity (e.g., chl-a, light levels) and DO concentrations in select systems would help inform whether adverse impacts are occurring in these systems due to low DO, and help ascertain the causes of low DO. Before embarking on this effort, it would be worthwhile to examine existing data from current or recent studies (e.g., studies in LSB) to assess the need for monitoring and identify the best approaches to pursue.

R.1.2.5 Increased focus HAB/NAB-forming species, phycotoxins, and phytoplankton community composition in general
Given the prevalence of HAB-forming organisms in the Bay and the frequent detection of phycotoxins Bay-wide, it would be prudent to more closely monitor phytoplankton composition, the occurrence of HAB-forming organisms and phycotoxins within San Francisco Bay. Composition and biovolume 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 nutrient are two among many factors that can influence phytoplankton community composition and the occurrence of HABs. The relative contributions of those factors toward causing adverse shifts in composition or HAB occurrences are poorly understood. More frequent (in space and time) analysis of phytoplankton composition and phycotoxins, in combination with special studies, (see Recommendation 4.1) will be needed to better understand these mechanisms and assess potential linkages to nutrients.

Determining taxonomy and biomass by microscopy is expensive and time consuming, which limits the amount of data that can be collected. Some amount of manual microscopy ground-truthing will always be needed. However, other techniques, in combination with microscopy, may allow for increased data collection of at lower costs. Carrying out pilot studies will help inform which techniques provide valuable and cost-effective information. Measuring phytoplankton-derived pigments is one such approach. Different classes of phytoplankton have distinct pigment fingerprints. It is possible, with sufficient calibration (relative to microscopy) and training of software to quantify phytoplankton biomass within specific classes. Flow cytometers and digital imaging tools are also available. These systems - which measure optical properties and capture images of individual cells, and employ image-recognizing software to identify and count phytoplankton down to the species level - can be deployed at moored stations for continuous monitoring, used on a monitoring vessel as it cruises along a transect, or used in the laboratory. Moored applications can telemeter data, allowing for near real-time information.

One such system provided early warning of a toxic algal bloom in the Gulf of Mexico.[6] An additional advantage of digital imaging approaches is that an archive of phytoplankton image data would be developed: if a phytoplankton species eventually becomes important, the digital archive could be mined to determine when that species first appeared.

Pilot projects have been initiated recently that are measuring phycotoxins in SFB, and an algal pigment pilot study is underway. Continuation of similar pilot studies, and testing a variety of methods, will help identify the most informative and cost-effective options, all the while establishing baseline concentration data against which future data can be compared. The feasibility of measuring algal toxins in archived benthos samples should also be considered in order to generate longer time series of algal toxins and look for changes over the past decade or more (if well preserved samples exist).

R.1.2.6 Benthos monitoring to quantify spatial, seasonal, and interannual variability in grazer abundance

Grazing by benthic filter feeders is considered to be one of the main controls on phytoplankton biomass accumulation in several subembayments. To estimate the influence of the benthic grazing, and track its changes in space and time, benthos surveys are needed on a regular basis in some subembayments, most importantly Lower South Bay, South Bay, San Pablo Bay, and Suisun Bay. In recent years there has been ample benthos monitoring in Suisun Bay and the Delta (and some in San Pablo Bay), although the fate of this program is not known. There are currently no sustained programs in the other subembayments. However, there are some years during which intensive benthic sampling has taken place (e.g., Thompson et al. 2008), and along with opportunistic sampling efforts (in some cases, samples have been archived but not yet analyzed for biomass; J Thompson, personal communication). Benthos monitoring could occur less frequent than water quality monitoring, e.g., three times per year (spring, summer, fall). Sorting, counting, and weighing benthos samples is time consuming and costly. A pilot study to test the feasibility of using benthic cameras may also be worth considering (alongside traditional sample collection for calibration/validation), since its use could potentially allow for more cost-effective benthos surveys.

R.1.2. 7 Zooplankton abundance/composition

Monitoring data on zooplankton are needed to quantify pelagic grazing rates. Zooplankton abundance and composition may also serve as an important indicator of food supply and quality for higher trophic levels. Long term zooplankton monitoring has been carried out in Suisun Bay and the Delta. However, zooplankton abundance and composition are not currently measured in other subembayments.

R.1.2.8 Allocate sufficient funding for data interpretation and synthesis

Data analysis and data synthesis are essential components of a monitoring program. Allocating sufficient funds for these activities will allow field results to be efficiently translated into management-relevant observations that inform decisions, and allow the monitoring program to nimbly evolve to address emerging data requirements. Annual reports will be needed that not only compile and present data, but that also evaluate and interpret trends. More detailed special studies will also be needed periodically to generate scientific synthesis reports on complex data sets (e.g., spatial and seasonal trends in phytoplankton community composition).

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[6] http://www.whoi.edu/oceanus/viewArticle.do?id=46486

R.2. Develop and implement a science plan for SFB that targets the highest priority management and science questions

The size of SFB, and the complexity and diversity of its nutrient-response issues, create a situation in which there are numerous science questions that need to be addressed to improve our understanding of the system. Addressing the management and science questions will require a combination of field studies, controlled experiments, monitoring, and modeling across the topics of nutrient cycling, phytoplankton response (biomass and community composition), and hydrodynamics. It will not be feasible to explore all the relevant science questions – that would take longer than management decisions can wait, and would outstrip any reasonable budget. To best target science efforts, there would be considerable benefit to developing and implementing a science plan that: identifies the highest priority management issues, and associated science questions; and identifies the sets of studies and data collection/monitoring needs that efficiently target those questions. In some cases, the management issues, science questions, data gaps, and studies may be similar Bay-wide. In other cases, the science questions or data gaps may be subembayment- or habitat-specific. The science questions listed in Tables A.4.1-A.4.2 and the recommendations in this section could serve as a starting point in what would be an iterative Science Plan development process.

Analysis of existing data from SFB, combined with broader critical literature review, would be useful early steps in science plan development, to articulate what is well-understood - in other estuaries and SFB - and focus scientific studies and monitoring on addressing the most critical knowledge and data gaps.

R.3. Develop hydrodynamic, nutrient cycling, and ecosystem response models

Tables A.4.1-A.4.2 illustrate that modeling will play a central role in addressing a wide range of science questions. Models can also be used to prioritize data collection needs. While there are multiple hydrodynamic models available for SFB, there are currently no integrated hydrodynamic-phytoplankton-nutrient models. Considerable progress could be made toward addressing several important science questions through using "simplified-domain" models that are built upon simplified (spatially-aggregated), but still accurate, hydrodynamics. Potential applications of these simplified domain models include (not an exhaustive list):

R.3.1 Quantitative analysis of nutrient budgets (including losses/transformations of nutrients);

R.3.2 Quantifying the relative importance of major processes that control primary production in Suisun Bay (light, clams, flushing, NH_4^+ inhibition), and explore which factors may explain the changes in phytoplankton biomass in South Bay over the past ~20 years.

R.3.3 Performing sensitivity/uncertainty analysis, and identifying highest priority monitoring activities, process level studies, or rate measurements to minimize model uncertainty.

R.3.4 Forecasting ecosystem response under future scenarios, and narrowing the list of high priority scenarios;

In developing such models, there is a benefit to "starting simple", and adding complexity as needed. LSB/South Bay and South Bay could serve as good initial focus areas for basic model development and application, because of the abundance of data for those systems and since these two subembayments are where concerns about adverse impacts from nutrients are greatest. Lessons learned through applying basic models will be useful for informing larger-scale or more complex model development.

Higher spatial resolution models, or larger spatial scale models (e.g., full Bay as opposed to individual subembayments) will be needed to explore several important issues, including:

R.3.5 Determine the zones of influence of individual POTWs under a range of hydrodynamic forcings and estimated transformations/losses

R.3.6 Test future scenarios under which adverse impacts may develop Bay-wide or in individual subembayments

R.3.7 Evaluate the effectiveness of different nutrient control strategies for achieving desired reductions in ambient concentrations as a function of space and time.

R.3.8 Quantify loads from the Delta to Suisun Bay under seasonally- and interannually-varying hydrological conditions, and the influence of these loads in Suisun and down-estuary subembayments under a range of forcings.

R.3.9 Quantify the importance of net nutrient loads from the coastal ocean to SFB under a range of commonly-occurring forcing scenarios, and explore the fate of the nutrient-rich SFB plume leaving the Golden Gate, and the potential influence of those nutrients on coastal ecosystems.

R.4. Carry out special studies to address key knowledge gaps about mechanisms that regulate ecosystem response, and inform whether or not impairment is occurring

The draft list of priority science questions in Tables A.4.1-A.4.2, viewed alongside the data/knowledge gap priorities in Tables A.4.3-A.4.6, present an initial picture of the types of data collection and studies that are the most important in the near term. A number of priorities have been discussed above in the context of monitoring program development (*R.1.2.1-1.2.8*) and modeling (*R.3.1-R.3.9*). An overview of special study priorities is provided below; however, the reader is also referred to the Tables A.4.1-A.4.6.

Nutrient cycling

R.4.1 Controlled field/lab experiments to measure pelagic nutrient transformations (pelagic nitrification, nutrient uptake rates)

R.4.2 Controlled field/lab experiments to measure benthic nutrient transformations (benthic nitrification, denitrification, mineralization and N and P fluxes from sediments)

R.4.3 Quantify the importance of internal nutrient transformations using models.

Productivity of phytoplankton and MPB

R.4.4 Controlled experiments that further test the proposed "NH_4^+-paradox" mechanism of lower productivity when NH_4^+ is elevated, determine relevant thresholds, and allow its effect to be better parameterized and compared to other regulating factors in models (*R.3.2*).

R.4.5 Through analysis of existing data or through field studies, assess the variability or uncertainty in the Cole and Cloern (1987) productivity relationship due to factors such as different phytoplankton assemblages, temperature, light levels, etc.

R.4.6 Field measurements to quantify MPB primary production rates and biomass.

R.4.7 Compare MPB production and biomass with phytoplankton production and biomass, consider how MPB's relative importance would change (or already has changed) due to ecosystem change (lower suspended sediments, benthic grazers), and explore how those changes influence nutrient cycling, oxygen budgets, and food webs.

Dissolved O₂

R.4.8   Controlled field experiments to quantify sediment oxygen demand in a range of depositional environments. These can be carried out in conjunction with the benthic nutrient transformation special studies as part of the same experimental protocol (*R.4.2*).

R.4.9   Monitoring and targeted mechanistic studies of DO in shallow margin habitats to assess the severity of low DO (concentration, spatial extent, frequency, duration).

R.4.9   In cooperation with other efforts or as special nutrient-related studies, determine the degree to which low DO in margin habitats (or in open water areas of some areas of the Bay, specifically LSB) adversely impact biota. To a certain degree, this work could be carried out based on existing data from other studies on DO tolerances of key organisms. Field surveys of fish or benthos abundance may also be warranted.

R.4.10 Through field experiments and modeling, quantify the degree to which anthropogenic nutrients contribute to occurrences of low DO.

HABs, toxins, and phytoplankton community composition

R.4.12 Rigorous analysis of existing phytoplankton community composition data – for HAB-forming species and composition more broadly – to test qualitative and quantitative agreement with various conceptual models, and refine those conceptual models as needed.

R.4.13 Field studies (collecting phytoplankton composition data at higher temporal or spatial resolution) to test mechanisms of HAB development and phytoplankton community succession in response to physical, chemical, and biological drivers.

R.4.14 Field studies to evaluate the potential importance of salt ponds as incubators of HAB-forming species.

R.4.15 Controlled experiments, using mixed cultures and monocultures from SFB, that mechanistically explore the interactive effects of nutrient availability (including variability in concentrations and forms), light, and temperature on HAB/NAB development and phycotoxins production, or other shifts toward assemblages that poorly support food webs. The goals of such studies would be to identify conditions that favor some classes or species of phytoplankton over others under the prevailing conditions in SFB (light limitation, excess nutrients), and enable predictions about assemblage response. Such information is also essential for identifying nutrient concentrations or loads that would decrease the risk of HAB occurrences or other adverse assemblage shifts.

R.4.16 Apply the information from R.4.1.5 within models to, among other issues, evaluate the magnitude of the nutrient component of stress, and explore potential composition responses to changing conditions, including those due to potential management actions (e.g., nutrient load reductions).

A.4.2.2 Grand Challenges

During the conceptual model development and identification of knowledge gaps, data gaps, and monitoring needs, four so-called "Grand Challenges" emerged related to understanding and managing SFB ecosystem health. While there is overlap between the underlying management issues that motivated the more specific recommendations above and those that motivated the Grand Challenges, the Grand Challenges represent a somewhat different, more holistic perspective or framework for considering science and data collection needs. In so doing they

highlight connections between nutrient issues and other ecosystem health concerns, and provide an additional impetus for addressing those data collection needs.

Grand Challenge 1: What do we need to know in 10-20 yrs to make improved decisions related to water quality management or ecosystem health, including those related to nutrients? 1-2 decades is approximately the time scale over which large capital improvement projects are planned and implemented. 10-20 years is also a long enough time period for trends to become evident, e.g, the changes in phytoplankton biomass in South Bay and LSB since the late 1990s. What information needs to be collected now, to serve as baseline condition data, so that changes in important indicators can be confidently identified and attributed to the correct causal agent(s), whether those changes lead to improved or worsened condition?

Grand Challenge #2: The northern estuary is poised to experience major changes due to management actions and environmental change. Anticipated changes include: nitrification and nutrient load reductions at Sac Regional wastewater treatment plant; numerous large scale restoration projects and changes in water management in the Delta; changing climate patterns altering the timing, residence time, and amount of water passing through the Delta. What do we need to be measuring now in order to determine if these changes have positive, negative, or no impacts on ecological health in SFB and the Delta? How will phytoplankton respond to changes in nutrient loads/speciation? How will the food web respond?

Grand Challenge #3: Large areas along the margins of South Bay and LSB are slated to undergo restoration. Given the size of these areas compared to the adjacent water surface area, it is reasonable to expect that proposed restorations along the margins will have measurable impacts on water quality and ecological health in the open Bay. Some of these effects may be positive, including increased habitat for fish, birds and other organisms. It will be desirable to document those changes; in order to do so, baseline data is needed for these higher trophic level indicators of ecosystem health. Those changes could also encourage more denitrification and decreased N within the Bay, which could be considered within integrated nutrient management plans. As discussed earlier, there may also be unintended and undesirable consequences, including: restored/reconnected salt ponds acting as incubators for HAB-forming phytoplankton species; exceedingly high primary production rates and high biomass, causing periodic low DO in wetlands and sloughs; and increased duration of stratification due to dampening of tidal mixing energy. What hypotheses of adverse impacts need to be tested, as part of restoration planning, so that the risks of severe unintended consequences can be minimized?

Grand Challenge #4: Similar to Grand Challenges 1-3, what baseline observational data is needed to detect climate-related changes in habitat quality in SFB and to disentangle them from other anthropogenic drivers? What types of modeling simulations should be done to anticipate effects? The CASCaDE II[7] project is exploring these issues, largely focused in the Delta. Similar studies may be warranted in the Bay.

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[7] http://cascade.wr.usgs.gov/

Table A.4.1 Highest priority adverse impact scenarios, science questions, and types of studies needed to address those questions

	Literature Review	Analysis of existing data and synthesis	Data collection and monitoring	Field or laboratory experiments	Bay Modeling: Basic	Bay Modeling: Complex or full bay	Watershed Modeling	Assessment Framework	Technology, cost-benefit analysis
1 High phytoplankton biomass and low DO in LSB and South Bay									
a. What level of phytoplankton biomass (and over what area, for what period of time) would result in adverse impacts in LSB and South Bay habitats?	x	x			x	x		x	
b. What are the relative importances of the fundamental drivers that underlie recent changes in phytoplankton biomass in LSB (decreased SPM, loss of benthic grazers, other)?		x	x		x	x			
c. What is the importance of organic matter produced in margin habitats to biomass and DO budgets in LSB and South Bay deep subtidal habitats?			x		x	x			
d. What will be the response of phytoplankton biomass and DO if suspended sediments continue decreasing at rates similar to the past 20 years? Do adverse impacts become increasingly likely at environmentally-relevant SPM values? Or are adverse impacts unlikely along this pathway under this scenario?			x		x	x			
e. What scenarios could lead to worsened conditions and adverse impacts? - Longer periods of stratification due to salt pond and wetland restoration efforts, higher production/biomass? - Changes in climate patterns, longer periods of stratification, higher T, higher production/biomass? - Salt pond and wetland restoration, greater biomass production in margin habitats that is transported to deep subtidal habitats? - Multiple changes in parallel (lower SPM, longer stratification, biomass from margins, low grazing rates)?		x	x	x	x	x			
f. Based on this analysis, what are likely future trajectories in LSB and South Bay? Will biomass concentrations level off or continue increasing? What will be the response of DO?		x	x		x	x			
g. What reductions in nutrient loads are necessary to prevent adverse impacts?			x		x	x			
2 High phytoplankton biomass and low DO in margin habitats									
a. What low DO 'severity' would cause adverse impacts: spatial extent within individual sub-habitats (e.g., %age of slough), DO deficit, frequency, duration? Individual sub-habitats vs. overall condition (e.g., individual slough(s) impacted vs. percentage of total slough kilometers impacted)?	x	x						x	
b. How common (spatially) are low DO occurrences in these habitats? What is the severity of the low DO in each sub-habitat and collectively (within individual sloughs/creeks/salt-ponds, and collectively, what is the spatial extent (e.g., small stretch vs. entire slough), frequency, duration, DO deficit, bottom layer or full water column)?		x	x						

	Literature Review	Analysis of existing data and synthesis	Data collection and monitoring	Field or laboratory experiments	Bay Modeling: Basic	Bay Modeling: Complex or full bay	Watershed Modeling	Assessment Framework	Technology, cost-benefit analysis
c. Are relevant biota adversely impacted by low DO? Field surveys, potentially controlled studies. Avoidance, stress/toxicity, death	x	x	x	x					
d. What mechanisms act to cause the periodicity of low DO, including causing it to develop and dissipate? New organic matter sources (e.g., *in situ* production within sloughs or inputs from adjacent habitats, microphytobenthos vs. phytoplankton), on-going sediment oxygen demand, residence time, stratification, freshwater inputs, tidal exchange		x	x	x	x	x			
e. To what extent do anthropogenic nutrient loads contribute to or cause increased severity of low DO (spatial extent, DO deficit, frequency, duration)?		x		x	x				
f. Based on observed (or modeled) conditions relative to conditions that have adverse impacts, are these habitats (subset or as a whole) adversely impacted by low DO?		x	x		x	x		x	
3. HABs/NABs and phycotoxins									
a. What frequency or magnitude of HABs/NABs or HAB-toxins would cause adverse impacts?	x	x			x			x	
b. How do the abundances of phycotoxins and the HAB-forming species vary in space and time within the Bay? Have there been detectable changes over time, based on existing data? What are the sources of phycotoxins (in situ production vs. transport into SFB or subembayments)?		x	x	x					
c. What causes/contributes to increased frequency or elevated abundances of HAB/NAB-forming organisms? To what extent do nutrients cause, contribute to, or enable increased abundance/blooms? Seeding rates from the coast, seeding rates from adjacent habitats (including salt ponds), role of physical drivers (T, light, mixing/stratification) and chemical conditions (nutrients) favoring higher *in situ* production specifically of HAB/NAB forming organisms	x		x	x	x	x			
d. What causes/contributes to production of *in situ* phycotoxins production? To what extent do nutrients cause, contribute to, or enable increased phycotoxins production? role of physical drivers (T, light, mixing/stratification) and chemical conditions (nutrients) favoring higher *in situ* production	x		x	x					
e. What future scenarios could increase the frequency or severity of HAB/NAB events or increase phycotoxin abundance? - restoration and reconnection of salt ponds/wetlands? high-light, warm, nutrient-replete incubators? - future water management practices in the Delta (withdrawals, longer residence times) ? - changes in climate patterns? How likely are those changes in the 20-30 yr time horizon?		x	x	x	x				

	Literature Review	Analysis of existing data and synthesis	Data collection and monitoring	Field or laboratory experiments	Bay Modeling: Basic	Bay Modeling: Complex or full bay	Watershed Modeling	Assessment Framework	Technology, cost-benefit analysis
h. Based on a comparison of observed conditions and conditions considered to induce adverse impacts, are regions/subembayments/habitats of SFB experiencing HAB/NAB related adverse impacts, or will they in the future?			x					x	
i. What decreases in nutrient loads or ambient nutrient concentrations would decrease adverse impacts, or the risk of adverse impacts, from HABs/NABs?					x	x			
4. Other Nutrient Impact Pathways: Low phytoplankton biomass (NH$_4^+$ inhibition), Suboptimal phytoplankton community composition									
a. What is the underlying mechanism by which NH$_4^+$ slows or inhibits primary production? Characterize NH$_4^+$ concentrations and magnitude of effect. At what NH$_4^+$ concentrations are primary production rates substantially impacted?	x	x		x					
b. What is the relative contribution of elevated NH$_4^+$ compared to other factors that maintain low phytoplankton biomass in Suisun Bay (clam grazing, light limitation, flushing)?					x	x			
c. Are current NH$_4^+$ loads or concentrations adversely impacting biomass levels in Suisun Bay?		x	x		x	x		x	
d. What nutrient load reductions would prevent or mitigate adverse impacts due to NH$_4^+$ inhibition of primary production?					x	x			
e. What constitute optimal, or healthy, phytoplankton assemblages in SFB's subembayments? Conversely, what assemblages would be considered to poorly support desirable food webs?	x	x						x	
f. How have phytoplankton community compositions changed within SFB subembayments over recent years?		x	x						
g. Based on what is known from other systems or from prior experimental/field work (Bay-Delta or elsewhere), what hypothesized mechanisms are most likely to influence phytoplankton community composition in the Bay-Delta, based on ambient conditions (nutrient concentrations, light, temperature, stratification, etc.)? What controlled experiments or observations in SFB are needed to further evaluate these proposed mechanisms in SFB?	x	x							
h. What is the magnitude (or relative importance) of the role that current ambient nutrient concentrations play in shaping phytoplankton community composition?	x	x		x	x	x			
i. What changes to nutrient availability would mitigate or prevent adverse impacts of nutrients on phytoplankton community composition?	x	x		x	x	x			
i. What other adverse impact pathways may require further attention in SFB (aquatic macrophytes, macroalgae, SAV habitat)?	x	x							

Table A.4.2 Highest priority mitigation scenarios, science questions, and types of studies needed to address those questions

	Literature Review	Analysis of existing data and synthesis	Data collection and monitoring	Field or laboratory experiments	Bay Modeling: Basic	Bay Modeling: Complex or full bay/Delta	Watershed Modeling:	Assessment Framework	Technology, cost-benefit analysis
5. Reductions in nutrient loads from POTWs and nutrient loads from the Delta									
a. What are the magnitudes of loads from individual POTWs?		x	x						
c. How do internal processes shape nutrient concentration within SFB, how do they vary in space/time: mixing/flushing, nitrification, denitrification, uptake/assimilation, regeneration from sediments, etc.				x	x	x			
b. What are the zones of influence and magnitude of contributions of individual POTWs and Delta loads, and how do these vary seasonally and interannually?					x	x			
d. How do Delta loads to Suisun Bay vary seasonally and interannually? What portions of the loads that enter Suisun Bay from the Delta originate from Regional San, others POTWs? What portions of the loads come from Central Valley agriculture? What are the load contributions from agriculture within the Delta?		x	x		x	x	x		
f. What will Delta loads to Suisun Bay be under future scenarios: restoration, changes to water management practices, changes in agricultural practices?					x	x			
i. Considering areas of influence, zones where impairment may be occurring, and internal processes, what combination of load reductions are needed to mitigate or prevent impairment?					x	x			
g. What is the range of options for achieving various levels of nutrient load reductions from POTWs? What are the costs and multiple benefits (nutrients + other benefits, e.g., recycled water) of individual POTW efforts, and of longer-term integrated sub-regional plans?									x
h. Given the necessary load reductions and cost-benefits, what are the best options for achieving load reductions?									x
6. Reductions in stormwater nutrient loads									
a. Are stormwater nutrient loads potentially important sources to some margin habitats in some subembayments, or at the subembayments scale, and do they warrant further consideration?		x	x		x	x	x		
b. If yes, what are the loads from priority watersheds? What is their contribution to nutrient loads, or organic matter/BOD loads, to margin habitats?		x	x				x		
c. What are the magnitudes of stormwater nutrient contributions to deep subtidal habitats in other subembayments?					x	x			

	Literature Review	Analysis of existing data and synthesis	Data collection and monitoring	Field or laboratory experiments	Bay Modeling: Basic	Bay Modeling: Complex or full bay/Delta	Watershed Modeling:	Assessment Framework	Technology, cost-benefit analysis
7. Other mitigation strategies: wetland restoration/treatment and shellfish beds									
a. What is the potential for wetland restoration/treatment to mitigate adverse impacts of nutrients?	x				x	x			
b. What is the potential for managed shellfish beds to mitigate adverse impacts of nutrients?	x				x	x			
b. If wetlands or managed shellfish beds appear to be promising nutrient management options – what do pilot studies, advanced modeling, and economic considerations suggest about their potential to be part of an integrated management program?					x	x			x
8. Influence of nitrification at Regional San and Suisun direct POTWs on NH_4^+ inhibition of primary production or other adverse impacts									
a. What is NH_4^+ fate within the Delta and how does this change as a function of season, flow, etc.?					x	x			
b. What load reductions are necessary to reduce NH_4^+ to ambient concentrations that would not inhibit production or have other adverse impacts?					x	x			

Table A.4.3 N and P loads and cycling: current state of knowledge for key processes and parameters

Process or Parameters	Importance for quantitative understanding	Current Level of Knowledge about magnitude, composition, or controls	Need for additional or continued data collection, process studies, modeling	Priority for study in next 1-5 years
Loads				
POTWs	High	**Moderate: C**omprehensive effluent monitoring is currently underway. Prior to 2012, data availability varies by POTW and in general is fairly sparse for several nutrient forms (NO$_3^-$, o-PO4, TN, TP)	Very High	Very High
Stormwater runoff	Uncertain	**Low**: Limited stormwater data and limited modeling effort	High	High
Delta	High	**Low:** Initial estimates suggest Delta loads may be a large source but they need to be validated, and time-series of loads are needed.	Very High	Very High
Groundwater	Low	**Low:** Poorly quantified but not expected to be major source because of relatively high loads from other sources	Low	Low
Direct atmospheric deposition	Low	**Low:** Poorly quantified but not expected to be major source because of relatively high loads from other sources, including from the large Central Valley watershed	Low	Low
Exchange through GG	Uncertain	**Low:** Has the potential to be large, but highly uncertain	High	High
Processes				
Benthic denitrification	High	**Low**: see OM mineralization and NH4 and PO4 release below	Very High	Very High
Pelagic denitrication	Low	**Low**: not expected to be important because of oxic water column	Low	Low
Benthic nitrification	High	**Low**: see OM mineralization and NH4 and PO4 release below. Potentially large, but limited field measurements, and need for both field and model-based estimates.	Very High	Very High
Pelagic nitrification	High	**Low**: Potentially large, but limited field measurements, and need for both field and model-based estimates.	Very High	Very High
N fixation	Low/Uncertain	**Low**	Moderate	Low

Process or Parameters	Importance for quantitative understanding	Current Level of Knowledge about magnitude, composition, or controls	Need for additional or continued data collection, process studies, modeling	Priority for study in next 1-5 years
OM mineralization and release of NH4 and o-PO4 from sediments, and in the water column	High	**Low**: Potentially a substantial source from the sediments to the water column. Limited data from two studies in SFB, but well-studied in other systems and at least initially may be able to use that information. Field studies aimed at exploring this issue will also inform sediment oxygen demand, benthic primary production, benthic denitrification, and benthic nitrification.	**Very High**	**Very High**
Settling/burial of N and P	High	**Low/Moderate**: limited field estimates to date, although could be estimated based on other sedimentation data.	**Moderate**	**Low**
Rates of NH4, NO3, and o-PO4 uptake by phytoplankton	High	**Moderate**: field measurements exist for NH4 and NO3 in northern estuary, limited data in South Bay and LSB. Uptake rates for P are not well-studied. Both N and P uptake rates can be partially constrained by knowing phytoplankton C:N:P and productivity	**Moderate**	**Moderate**
Other processes: DNRA, ANAMOX	Low	**Low**: but expected to be relatively small	**Low**	**Low**
N and P budgets for subembayments: loads, transformations, sources/sinks, export	High	**Low**: The ability to quantify these will provide important information on the subembayments' ability to process/assimilate N and P. Basic modeling work needed.	**Very High**	**Very High**
Ambient concentration data				
Phytoplankton C:N:P	High	**Low**: Currently not routinely measured during monitoring	**Very High**	**Very High**
Concentration of NO3, NH4, and PO4	High	**Moderate**: monthly data available at ~15 stations Bay-wide but finer spatial and temporal resolution needed to inform process level understanding and modeling	**Very High**	**Very High**
Concentrations of NO_2^- and N_2O	Low/Moderate	**Moderate**: not needed for nutrient budgets, but informative as diagnostic of processes	**Moderate**	**Moderate**
Concentration of DON, PON, DOP, POP within and loaded to the system	Moderate/ uncertain	**Low:** Little current data, and information is needed. Given the high DIN and DIP concentrations, abundance organic forms may be relatively low.	**High**	**High**

Table A.4.4 Phytoplankton and MPB productivity / biomass accumulation: current state of knowledge for key processes and parameters

Process or Parameters	Importance for quantitative understanding	Current Level of confidence about magnitude or mechanistic controls	Need for <u>additional or continued</u> data collection, process studies, modeling	Priority for study in next 1-5 years
PHYTOPLANKTON - Processes				
Primary production rates	**High**	**Low/Moderate**: Basic understanding about light limited production is well modeled. Recent studies suggest that the relationship may have shifted, and revisiting this may be important for estimating system productivity.	**Very High**	**High**
Pelagic grazing	**High**	**Low**: Long-term program in Suisun Bay/Delta for macrozooplankton, but limited micro-zooplankton data, which may be more quantitatively important in terms of overall grazing rate. No systematic zooplankton sampling in LSB, South Bay, Central Bay.	**Very High**	**High**
Benthic grazing	**High**	**Low**: good data to support estimates in Suisun Bay. Limited data in LSB South Bay. Monitoring of benthos abundance would inform this.	**Very HIgh**	**Very High**
Sinking, respiration, burial	**High**	**Moderate**: Discussed within context of Dissolved Oxygen	**Low**	**Low**
Inhibition of primary production rates by elevated NH_4^+	**High/ Uncertain**	**Low**: Several studies have been completed and others are underway. Uncertainty remains about mechanism and relative importance of the process. Field/lab studies and modeling work can be done in parallel, with the former designed to further elucidate the mechanism and thresholds and the latter to quantify its role relative to other factors.	**Very High**	**Very High**
Production in the shoals vs. channels (during stratification), and physical or biological controls on bloom growth/propagation	**High**	**Low**: Considered to be an important process but limited data available. Data needed to better predict bloom magnitudes.	**Very High**	**Very High**
Germination of resting stages	**Low**	**Low:** Not considered among the highest priority processes to study	**Low**	**Low**
PHYTOPLANKTON – Ambient concentration data				
High frequency data in channel	**High**	**Low**: Very limited high temporal resolution (continuous) phytoplankton biomass data beyond of Suisun Bay. Needed to better predict blooms.	**Very High**	**Very High**
High temporal resolution data in shoals	**High**	**Low:** Very limited high temporal resolution (continuous) phytoplankton biomass data beyond of Suisun Bay. Needed to better predict blooms.	**Very High**	**Very High**
d	**High**	**Moderate/High**: USGS program has been collecting monthly data at along the channel for the past 35 years, and needs to be continued.	**Very High**	**Very High**
Phytoplankton C:N ,C:chl-a,	**High**	**Low:** Valuable information to inform understanding of processes and for	**Very High**	**Very High**

Process or Parameters	Importance for quantitative understanding	Current Level of confidence about magnitude or mechanistic controls	Need for <u>additional or continued</u> data collection, process studies, modeling	Priority for study in next 1-5 years
and size-fractionated chl-a		modeling		
Microphytobenthos - Processes				
Primary production rates	**Moderate**	**Low:** may be able to predict productivity based on light levels and chl-a, although needs to be confirmed	**Moderate**	**Moderate**
Grazing	**Moderate/ Unknown**	**Low:** Potentially important as a sink, but difficult to study.	**Low**	**Low**
Microphytobenthos – Ambient abundance data				
Basic biomass information, seasonal, spatial	**High**	**Low:** Very limited data on MPB abundance and productivity, despite the fact that MPB productivity may be comparable in magnitude to phytoplankton productivity.	**High**	**High**

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Table A.4.5 Dissolved Oxygen: current state of knowledge for key processes and parameters

Process or Parameters	Importance for quantitative understanding	Current Level of confidence about magnitude or mechanistic controls	Need for <u>additional or continued</u> data collection, process studies, modeling	Priority for study in next 1-5 years
Processes or loads				
Atmospheric exchange	**High**	**Moderate**: Difficult to measure but readily modeled (albeit with substantial uncertainty)	**Low**	**Low**
Pelagic and benthic nitrification (for O2 budget)	**Low/Moderate**	**Moderate**: NH4 loads/concentrations provide an upper bound on this oxygen sink. It is not expected to be a major DO sink, or	**Low**	**Low**
Sediment oxygen demand (Benthic respiration + oxidation of reduced compounds).	**High**	**Low**: This set of processes is particularly important for understanding O_2 budget in shallow margin environments. The mechanisms are well understood but rates are poorly constrained and likely are highly variable in space/time. Field experiments are possible. Increased (high spatial/temporal resolution) monitoring of DO will also allow "average" demand to be quantified by difference/modeling.	**Very High**	**Very High**
Pelagic and benthic primary production rates	**High**	**Low**: Benthic production rates, in particular are particularly poorly constrained and would require field surveys. Pelagic rates can be reasonably well-estimated based on phytoplankton biomass and light. As noted above, high spatial/temporal resolution monitoring of chl-a will help refine estimates	**Very High**	**Very High**
Pelagic respiration	**Moderate**	**Moderate**: In shallow areas, sediment oxygen demand will be of much greater importance than pelagic respiration. Pelagic respiration rates by viable phytoplankton can be reasonably well-estimated based on biomass. Respiration of dead OM is a function of OM abundance and quality, and water temperature.. In deep channel areas of the Bay, where pelagic respiration will be more important than sediment oxygen demand, low DO does not appear to be a major issue, and thus constraining these rates are not among the highest priorities.	**Low**	**Low**
DO – Ambient concentration data				
High spatial resolution DO data in deep channel	High	**Low**: USGS research program provides an excellent long-term record along the Bay's spine. This work needs to be continued.	**Very High**	**Very High**
High temporal resolution DO data in deep channel	High	**Low**: Limited DO data available from continuous sensors, in particular in South Bay and LSB. A network of sensors is installed in Suisun Bay and the Delta.	**Very High**	**Very High**

Process or Parameters	Importance for quantitative understanding	Current Level of confidence about magnitude or mechanistic controls	Need for **additional or continued** data collection, process studies, modeling	Priority for study in next 1-5 years
High temporal resolution data in shoals and shallow margin habitats	High	**Low**: Some special studies have been performed, and some on-going monitoring by POTWs and others (e.g., USGS studies in salt ponds). While these individual efforts have valuable information and some reports are available, a meta-analysis of this data has not been completed, and there is currently no overarching regional program.	**Very High**	**Very High**

Table A.4.6 Phytoplankton community composition and HABs: current state of knowledge for key processes and parameters

Process or Parameters	Importance for quantitative understanding	Current Level of Certainty about magnitude, composition, or controls	Need for additional or on-going data collection or process studies	Priority for study in next 1-5 years
Processes				
Pelagic grazing rates (size-selective)	High	**Low**: No systematic zooplankton sampling in LSB, South Bay, Central Bay. Only 1 station in San Pablo.	Moderate	Moderate
Size-selective benthic grazing rates	High	**Low**: Good data to support estimates in Suisun Bay. Limited data in LSB South Bay. Monitoring of benthos abundance would inform this.	Very High	Very High
Temperature, light, and nutrient (concentration, N:P, form of N) preferences of phytoplankton PFTs specific to SFB subembayments	High	**Low**: Limited understanding of how these factors/preferences may shape phytoplankton community composition, in particular in a light-limited nutrient-replete system.	Very High	Very High
Effects of trace metals, organics or pesticides	Moderate/ Uncertain	**Low:** Limited information on vitamins, trace-metals, and the influence of anthropogenic contaminants such as pesticides that may be influencing community composition. competition with diatoms.	Moderate	Moderate
Effect of physical forcings, including exchange between subembayments, oceanic and terrestrial (including wetlands, salt ponds) end-member inputs, large scale climate forcings	High	**Moderate:** Data on community composition over the past 20 years (Bay wide) and up to 40 years (Suisun and Delta) to explore different explanations.	Very High	Very High
NH4 inhibition: diatom productivity	High/ Uncertain	**Low:** Several studies completed, others underway.	Very high	Very high
Ambient composition data				
Size-fractionated chl-a	High	**Low:** Provides a coarse measure of in which classes phytoplankton biomass resides, which is a useful albeit coarse surrogate for food quality. Not currently being collected but could be easily added to monitoring.	HIgh	High

Process or Parameters	Importance for quantitative understanding	Current Level of Certainty about magnitude, composition, or controls	Need for additional or on-going data collection or process studies	Priority for study in next 1-5 years
Phytoplankton community composition, monthly time-scales, at sufficiently high spatial resolution, and higher temporal/spatial resolution to test mechanisms	High	**Moderate:** 20 year near-monthly Bay-wide record from USGS and ~40 year record for Suisun and Delta. But few higher resolution data sets or special studies.	**Very high**	**Very high**
Frequency and magnitude of detection of HABs or HAB toxins	High	**Low**: Limited data on HABs and toxins, and	**Very high**	**Very high**
Phytoplankton community composition in salt ponds, particularly HAB-forming species	High	**Low:** Limited data to date, but of high concern.	**Very High**	**Very High**
Surrogate measures for phytoplankton composition	Low	**Low:** The use of phytoplankton pigments or digital image recognition approaches could be piloted that would eventually increase the amount of composition data that could be collected	**Very High**	**Very High**

CURRICULUM VITAE *calendar year 2015*

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1974 M. S.	University of North Carolina at Chapel Hill (Marine Sciences)	
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1969 - 1970	Faculty Research Assistant, University of Maryland, Natural Resources Institute, Chesapeake Biological Laboratory, Solomons, MD.
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1983 - 1988	Associate Professor, University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, Solomons, MD.
1988-present	Professor, University of Maryland, Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD.
1992-present	Graduate Faculty, University System of Maryland.
1998-present	Graduate Faculty, University of Maryland System Inter-Institutional Graduate Council.

Awards and Special Recognition

1982	Awarded certificate of appreciation by Tri-County Council of Southern Maryland (Presented by Maryland Governor Harry Hughes)
1990	Nominated for the PEW Scholars in Conservation and the Environment Fellowship.
1992	Nominated for Computerworld Smithsonian Awards: Environment, Energy and Agriculture.
1997	Nominated for the PEW Scholars in Conservation and the Environment Fellowship.
1999	The CES President's Award for Excellence in Application of Science.
2003	Distinguished Service Award, Estuarine Research Federation.
2009	Received Odum Award for lifetime achievement (with W. M. Kemp, HPL) from the Coastal and Estuarine Research Federation
2009	President Elect - Coastal and Estuarine Research Federation (2009-2011)
2012	President - Coastal and Estuarine Research Federation (2011-2013)

2013   Past President - Coastal and Estuarine Research Federation (2013-2015)
2015   Distinguished Service Award, Estuarine Research Federation.
2015   Admiral of the Chesapeake Bay Award for work towards understanding and restoring
        Chesapeake Bay. Presented by Gov Martin O'Malley, January 2015

III.   Research

A.   Areas of professional expertise

Estuarine Ecology: nutrient cycling; benthic processes; water quality studies.
Seagrass Ecology: distribution and growth; trophic processes; restoration.
Ecosystem Modeling and Analysis: estuary-land interactions; materials budgets; synthesis studies.
Environmental Education: graduate, undergraduate, general public.

B.   Peer-Reviewed Publications

1. Papers in Refereed Journals (last 5 years)

Kemp, W. M. and W. R. Boynton. 2012. Synthesis in estuarine and coastal ecological research: What is it, why is it important, and how do we teach it? The H. T. Odum Synthesis Essay. Estuaries and Coasts. Vol. 35: 1-22. [UMCES Cont. No. 4689]

Boynton, W. R. and S. W. Nixon. 2012. Budget Analyses of Estuarine Ecosystems, Chapter 17, pp 443-464; In: John Day et al (eds). Estuarine Ecology Wiley-Blackwell, NJ 550p. [UMCES Cont. No. XXXX requested]

Kimmel, D. G., W. R. Boynton and M. R. Roman. 2012. Long-term decline in the calanoid copepod Acartia tonsa in central Chesapeake Bay, USA: an indirect effect of eutrophication? Est. Cstl. Shelf Sci. 101: 76-85. [UMCES Cont. No. 4663]

Brady, D. C., J. M. Testa, D. M. Di Toro, W. R. Boynton and W. M. Kemp. 2012. Sediment flux modeling: calibration and application for coastal systems. Est. Cstl. Shelf Sci. Vol. 117: 107-124.

Lee, Y. J., W. R. Boynton, M. Li and Y. Li. 2013. Role of late winter-spring wind influencing summer hypoxia in Chesapeake Bay. Estuaries and Coasts Vol 36(4): 683-696. [UMCES Cont. No. 4726]

Testa, J. M., D. C. Brady, D. M. DiToro, W. R. Boynton, J. C. Cornwell, and W. M. Kemp. 2013. Sediment flux modeling: simulating nitrogen, phosphorus, and silica cycles. Est. Cstl. Shelf Sci. Vol. 131: 245-263. [UMCES Cont. No. XXXX requested]

Boynton, W. R., C. L. S. Hodgkins, C. A. O'Leary, E. M. Bailey, A. R. Bayard, and L. A. Wainger. 2013. Multi-decade responses of a tidal creek system to nutrient load reductions: Mattawoman Creek, Maryland USA. Estuaries and Coasts DOI 10.1007/s12237-013-9690-4. [UMCES Cont. No. XXXX requested]

Harris, L.A., C.L.S. Hodgkins, M.C. Day, D. Austin, J. Testa, W. Boynton, L. Van Der Tak and N. Chen. 2014. Optimizing recovery of eutrophic estuaries: impact of destratification and re-aeration on nutrient and dissolved oxygen dynamics. Ecological Engineering Vol 75: 470-483.

Cornwell, J. C., M. S Owens, W. R. Boynton and L. A. Harris. 2015. Sediment-water nitrogen exchange along the Potomac River estuarine salinity gradient. J. Coastal Research (*available on-line*).

Zhang, Qian, Damian C. Brady, Walter R. Boynton, and William P. Ball, 2015. Long-Term Trends of Nutrients and Sediment from the Nontidal Chesapeake Watershed: An Assessment of Progress by River and Season. Journal of the American Water Resources Association (JAWRA) 1-22. DOI: 10.1111/1752-1688.12327

2. Technical Reports (last 5 years)

Bailey, E.M., W.R. Boynton, and R.J. Karrh. 2011. Maryland Chesapeake Bay water quality monitoring program. Ecosystem processes component (EPC). Quality Assurance Project Plan for Water Quality Monitoring in Chesapeake Bay for FY2012. July 2011 – June 2012. Final Report to MD DNR. Ref. No. [UMCES] CBL 10-201. Bailey, E.M., W.R. Boynton, and R.J. Karrh. 2011. Maryland Chesapeake Bay water quality monitoring program. Ecosystem processes component (EPC). Quality Assurance Project Plan for Water Quality Monitoring in Chesapeake Bay for FY2012. July 2011 – June 2012. Final Report to MD DNR. Ref. No. [UMCES] CBL 10-201.

Bailey, E.M., W.R. Boynton, M.A.C. Ceballos and K.K. Politano. 2011. Monitoring of Sediment Oxygen and Nutrient Exchange Measurements in Eastern Bay, Tangier Sound and Tributaries in Support of TMDL Development 2009. Final Report to Maryland Department of the Environment Technical and Regulatory Services Administration. Ref. No.[UMCES]CBL 11-004. [UMCES Technical Series No. TS-610-11-CBL].

Boynton, W.R., E. Bailey, C. Sperling, J. Barnes, N. Kaumeyer, J Frank, and C. Murray. 2011. 2010 Water Quality Monitoring Program for the Mill Creek Sub-Estuarine System and Patuxent Creeks Located in Calvert County, Maryland. Ref. No. [UMCES] CBL 11-013 A [UMCES Technical Report Series No. TS-615-11].

Boynton, W.R., L.A. Wainger, E.M. Bailey, A.R. Bayard, C.L. Sperling, M.A.C. Ceballos. 2011. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 28. Jul. 1984 – Dec. 2010. Ref. No. [UMCES] CBL 11-024. [UMCES Technical Series No. TS-620-11-CBL].

Meyer, J. L. et al (Boynton a co-author). 2011. Review of EPA's draft approaches for deriving numeric nutrient criteria for Florida's estuaries, coastal waters, and southern inland flowing waters. EPA Science Advisory Board Report, i-40 http://www.epa.gov.sab.

Boynton, W.R., C.L.S. Hodgkins, J. Barnes, N. Kaumeyer, J. Frank, M.A.C. Ceballos. 2012. 2011 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland. Ref. No. [UMCES] CBL 12-006A [UMCES Technical Report Series No. TS-635-12].

Boynton, W.R., L.A. Wainger, E.M. Bailey, A.R. Bayard, C.L. S. Hodgkins, and M.A.C. Ceballos. 2012. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 29. Jul. 1984 – Dec. 2011. Ref. No. [UMCES] CBL 12-020. [UMCES Technical Series No. TS-637-12-CBL].

Boynton, W. R. 2012. An overview of nutrient dynamics in riverine estuaries, pp. 3-9: In Nutrient dynamics in riverine estuaries: understanding, modeling and managing inputs. New South Wales, Australia Office of Environment and Heritage, University of Technology, Sydney, Australia. p.46.

Hodgkins, C. L. S., W. R. Boynton, N. Kaumeyer, M.A.C. Ceballos, and J. M. Barnes. 2013. 2012 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland. Ref. No. [UMCES] CBL 2013-022 [UMCES Technical Report Series No. TS-648-13].

Boynton, W.R., L.A. Wainger, E.M. C. O'Leary, C.L. S. Hodgkins, A.R. Bayard, and M.A.C. Ceballos. 2013. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 Report No. 30. Jul. 1984 – Dec. 2012. Ref. No. [UMCES] CBL 13-055. [UMCES Technical Series No. TS-655-13-CBL].

Hodgkins, C.L.S., W.R. Boynton, M.A.C. Ceballos, C.A. O'Leary and J.L. Humphrey. 2014. 2013 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland. Ref. No. [UMCES] CBL 2014-012 [UMCES Technical Report Series No. TS-660-14.

Boynton, W.R., J.M. Testa, C.L.S. Hodgkins, J.L. Humphrey and M.A.C. Ceballos. 2014. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 31. Jul. 1984 – Dec. 2013. Ref. No. [UMCES] CBL 2014-051. [UMCES Technical Series No. TS-645-14].

W.R. Boynton, J.M. Testa, E.M. Bailey, M.A.C. Ceballos, C.L.S. Hodkgins, J.L. Humphrey, and L.L Magdeburger. 2014. Back River Sediment Flux Measurements in Support of Water Quality Modeling 2014. Ref No. [UMCES] CBL 2014-065. [UMCES Technical Report Series No. TS-667.14].

Hodgkins, C.L.S., M.C. Day, J.L. Humphrey, L.A. Harris, J.M.Testa, and W.R. Boynton. 2015. 2014 Water Quality Monitoring Program for Tidal Creeks in Calvert County, Maryland. Ref. No. [UMCES] CBL 2015-015[UMCES Technical Report Series No. TS-668-15]

J.M. Testa, L.A. Harris, W.R. Boynton, C.L.S. Hodgkins, J.L. Humphrey and M.C. Day. 2015. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 32. Jul. 1984 – Dec. 2014. Ref. No. [UMCES] CBL 2015-043. [UMCES Technical Series No. TS-674-15].

Kemp, W. M. and W. R. Boynton. 2015. Coupling of Carbon, Nitrogen, Silica and Phosphorus Cycles in Coastal Ecosystems: Climate Effects and Trophic Implications. Annual Report to National Science Foundation OPUS Program. Reporting period Mar 2014 – April 2015.

C.   Contracts and Grants (past 5 years)

    1. Awarded

    Forecasting responses of Delmarva Lagoons to changing landuse and climate (L. Harris PI; W. R. Boynton co-PI). NOAA-Sea Grant (time donated) Feb 09 – Dec 11.

FY11 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with L. Wainger) Jul 2010 – Jun 2011. $120,000.

Determining shallow water susceptibility to nutrient and sediment loads. MD-DNR. L. Wainger PI; W. Boynton co-PI (time donated) $38,835 Jul 2010 – Jun 2011.

Water Quality Monitoring Program for the subestuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; May. 2009 - Jun 2011. $16,061 and $19,032.

A field campaign to improve water quality models for the Potomac River estuary. DC – WASA. L. Harris PI; W. Boynton co-PI. $39,258. Aug 2010 – Jan 2011.

Ecofore 10: Modeling Ecological Responses to Climate and Nutrients. NOAA, Ecological Forecasting Program. 2006- 2012 $2.28 million total; W.M. Kemp, Lead P.I., (Co-P.I. 5-yr program; Boynton total $52,029/yr during 2011).

Water Quality Monitoring Program for the subestuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; Jul 2011 – Jun 2012. $26,136

Determining shallow water susceptibility to nutrient and sediment loads. MD-DNR. L. Wainger PI; W. Boynton co-PI (time donated) $41,165 Aug 2011 – May 2012.

FY12 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with L. Wainger) Jul 2011 – Jun 2012. $120,000.

CHRP07: Modeling hypoxia and ecological responses to climate and nutrients. NOAA, Ecological Forecasting Program. 2006-2012 W.M. Kemp, Lead P.I., (Co-P.I. 5-yr program; Boynton total $49,984 during final years; 2011-2013).

Water Quality Monitoring Program for the sub-estuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; Jul 2012 – Jun 2013. $26,136.

FY13 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with L. Wainger) Jul 2012 – Jun 2013. $120,000.

Forecasting watershed loading and lagoon response along the Delmarva Peninsula due to changing land-use and climate (L. Harris lead PI). Regional Sea Grant Program Feb 2012 – Feb 2013. $106, 814 (no-cost extension requested through 2014).

One-Day Water Quality Data Collection in the lower Patuxent River. Southern Maryland Electric Cooperative. Nov 2012 – Oct 2013. $16,832.

FY14 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with L. Wainger) Jul 2013 – Jun 2014. $125,000.

Water Quality Monitoring Program for the subestuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; Jul 2013 – Jun 2014. $27,427.

FY15 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with J. Testa and L. Harris) Jul 2014 – Jun 2015. $125,000.

Water Quality Monitoring Program for the sub-estuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; Jul 2014 – Jun 2015. $27,427. (with L. Harris).

Back River Sediment Flux Measurements in support of water quality modeling. Whitman, Requardt and Associated, LLC; 1 August, 2014 – 31 July, 2015. $44,791 (with J. Testa).

Coupling of Carbon, Nitrogen and Phosphorus cycles in coastal ecosystems: climate effects and trophic implications. National Science Foundation (OPUS); 15 February, 2014 – 14 February, 2016. $97,107 (with W. M. Kemp who receives equal funding).

FY16 Maryland Chesapeake Bay Water Quality Monitoring Program Ecosystems Processes Component. MD DNR. (with J. Testa and L. Harris) Jul 2015 – Jun 2016. $125,000.

Water Quality Monitoring Program for the sub-estuary comprised of Mill Creek, St. John's Creek, Back Creek, the Narrows and Solomons Harbor located in Dowell, Drum Point, Lusby, Olivet and Solomons, Calvert County, Maryland. Calvert County Commissioners; Jul 2015 – Jun 2016. $27,427. (with L. Harris).

2. Submitted
    Currently negotiating with:

    1) MD-DNR for FY 17 Biomonitoring funds (with J. Testa and L. Harris);
    2) Calvert County Board of County Commissioners for continued monitoring of Calvert County tidal creek systems (with L. Harris).

D.   Invited Seminars and Presentations (last 5 years)

Lee, Y.J., W. Boynton, M. Li, and Y. Li 2011. The Role of Spring Wind in Controlling Summer Hypoxia, NOAA CHRP Hypoxia Modeling Meeting, Cambridge, Maryland.

Sperling, C.L., W.R. Boynton, D. Jasinski, E.M. Bailey, and M.C. Ceballos. 2011. Community metabolism in Chesapeake Bay: historical and contemporary measurements. Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Poster Presentation.

Harris, L., C. Sperling, W. Boynton, M. Niesen, and K. Davis Ziombra. 2011. An exploration of metabolism in the Chesapeake Bay using the metabolic theory of ecology. Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Oral Presentation.

Sperling, C.L., W.R. Boynton, D. Jasinski, E.M. Bailey, and M.C. Ceballos. 2011. Community metabolism in Chesapeake Bay: historical and contemporary measurements. Maryland Water Monitoring Council Annual Conference. December 1. Linthicum, MD. Poster Presentation.

Boynton, W. R., J. M. Testa, W. M. Kemp and J. C. Cornwell. 2011. The Corsica River estuary needs a pollution diel: How much is enough? Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Invited Poster Presentation.

Boynton, W. R., Y. Lee, W. M. Kemp and M. Brooks. 2011. Case study of the Back River estuary: Strong management actions and ecosystem lag times. . Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Invited Oral Presentation.

Brady, D., J. testa, W. Kemp, W. Boynton and D. DiToro. 2011. Estimating organic matter deposition and decay with a long-term sediment flux database and a mechanistic model. Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Invited Oral Presentation.

Y. Lee and W. R. Boynton. 2011. The role of regional climate and other factors in controlling hypoxia. Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Oral Presentation.

Owens, M., J. Cornwell, W. Boynton, L. Harris and E. bailey. 2011. Denitrification in the tidal Potomac: controls by redox, salinity and by riverine nitrate inputs. Coastal and Estuarine Research Federation Biennial Conference. November 6-11. Daytona Beach, FL. Oral Presentation.

Cornwell, J.C., J. O'Keefe, M.S. Owens, T.E. Jordan, E.M. Bailey and W.R. Boynton. Sedimentary Phosphorus and Nitrogen Fluxes Change with Seasonal Increases in Estuarine Salinity. American Society of Limnology and Oceanography (ASLO) 2011 Aquatic Sciences Meeting. February 13-18, 2005. San Juan, Puerto Rico, USA. Oral Presentation (J.C. Cornwell-Presenter).

Bailey, E.M., W.R Boynton and M.R. Hall. 2011. How Low Can It Go? The Chesapeake Bay Shallow Water DO Limbo Stick. Poster presentation at the *Societies, Estuaries and Coasts: Adatpting to Change*, Coastal and Estuarine Research Federation 21th Biennial Conference, November 6-10, 2011, Daytona Beach, FL, USA. Poster Presentation-*Presenter.*

Bailey, E.M., W.R Boynton and M.R. Hall. 2011. How Low Can It Go? The Chesapeake Bay Shallow Water DO Limbo Stick. Poster presentation at the Maryland Water Monitoring Council 17th Annual Conference, December 1, 2011. North Linthicum, Maryland, USA. Poster Presentation-*Presenter.*

Boynton, W. R. 2011. Roundtable discussion of Chesapeake Bay TMDL. Chesapeake Environmental

Protection Association. SERC. Shadyside, MD 25 jan. 2011

Boynton, W. R. 2011. Restoration of the Corsica River: Lessons learned for the Parker Creek system. American Chestnut Land Trust Keynote Speaker Annual Meeting, Prince Frederick, MD 5 Feb. 2011.

Boynton, W. R. Meeting Synthesis : what did we learn here and how do all these pieces fit together? AERS meeting, Solomons, MD 9 April, 2011.

Boynton, W. R. Annual summary of Solomons Harbor monitoring results. Calvert County Board of County Commissioners. 19 April, 2011.

Boynton, W. R. Introduction to Chesapeake Bay ecology. NOAA-sponsored Phytoplankton Rocks program at Huntingtown High school, Huntingtown, MD 21 May, 2011.

Boynton, W. R. Introduction to Chesapeake Bay ecology. NSF-REU Program seminar. CBL. 10 June, 2011.

Boynton, W. R. Introduction to Chesapeake Bay ecology. Chesapeake Bay Foundation teachers workshop. CBL. 13 July, 2011.

Boynton, W. R. State of the Chesapeake Bay. South River Federation Annual Meeting. Mayo, MD 11 October, 2011.

Boynton, W. R. Success stories concerning Chesapeake Bay restoration. Joint TMAW-NTWG workshop. UMBS, USGS offices, Baltimore, MD 12 October, 2011.

Boynton, W. R. Envisioning the ecosystem present and future. Chesapeake Bay STAC Retreat. Herrington Harbor, 27 March, 2012.

Boynton, W. R. (with S. W. Nixon and J. Cloern). On the value of long-term monitoring of estuarine and coastal marine ecosystems. COMPASS presentation on Capital Hill, Washington, DC May, 2012.

Boynton, W. R. Nutrient dynamics in riverine estuaries: Understanding, modeling and managing inputs. . New South Wales, Australia Office of Environment and Heritage, University of Technology, Sydney, Australia. May 2012.

Boynton, W. R. Success stories involving restoration in Chesapeake Bay. Tri-County Council of Southern Maryland. Hughesville, MD June, 2012.

Boynton, W. R. Chesapeake Bay emerging success stories. Maryland BayStat Briefing for MD Governor Martin O'Malley. Annapolis, MD July, 2012

Boynton, W. R. Nitrogen budgets for identification of nutrient removal "hotspots" at the Land-sea interface. Plenary Speaker CERF Conference in Mar del Plata, Argentina. Nov 2012.

Boynton, W. R. From Patuxent to Chesapeake Bay: reflections on a lifetime of measuring and understanding troubled ecosystems. Invited Public Lecture. Salisbury University, Salisbury, MD.

November, 2012.

Boynton, W. R. Annual summary of Solomons Harbor monitoring results. Calvert County Board of County Commissioners. April, 2013.

Boynton, W. R. Master Naturalist Class. Estuarine Ecology. Prince Frederick, MD April, 2013

Boynton, W. R. Chesapeake Bay Restoration. Graduate Class. Towson State University. May, 2013
Boynton, W. R. CBL Docent Lecture Ecology of Chesapeake Bay. Solomons, MD May, 2013

Boynton, W. R. South River Federation Annual Meeting. Restoration success stories in Chesapeake Bay. Edgewater, MD June, 2013

Boynton, W. R. NSF-REU Program at CBL. Introduction to estuarine ecology. Solomons, MD June 2013

Boynton, W. R. Chesapeake Bay Foundation Summer Teachers Program. Introduction to Chesapeake Bay Ecology. Solomons, MD July, 2013

Boynton, W. R., C. L. S. Hodgkins, C. O'Leary, E. M. Bailey, A. R. Bayard and L. A. Wainger. Multi-decade responses of a tidal creek system to nutrient load reductions: Mattawoman Creek, MD USA. International Congress for Conservation Biology, Baltimore, MD July, 2013. (presentation by L. Wainger)

Boynton, W. R. Chesapeake Bay Foundation program for the Metropolitan Science Writers Association. Chesapeake Bay success stories. Shadyside, MD September, 2013

Boynton, W. R. Washington Surburban Sanitary Commission. Invited Staff Seminar. Water quality trends in the Patuxent River estuary. Laurel, MD September, 2013

Lee, D. Y., Y. J. Lee and W. R. Boynton. Inter-annual variability of winter-spring phytoplankton in Chesapeake Bay from 1985-2010. Coastal and Estuarine Research Federation 22th Biennial Conference, November, 2013, San Diego, CA. USA.

Hopkinson, C., J. Day, W. R. Boynton, M. Kemp, R. Lane and E. Roy. 2014. An approach to quantifying impacts of major disturbances on oysters at the ecosystem level. International Conference on Shellfish Restoration. Charleston, SC December, 2014.

Boynton, W. R. 2014. Case studies within the Chesapeake Bay Ecosystem. US-EPA Chesapeake Bay Program STAR Trends Conference, Annapolis, MD March 2014.

Boynton, W. R. 2014. Water Quality Status of Chesapeake Bay. Chesapeake Bay Foundation Staff Training seminars. Tangiers Island, VA February, 2014.

Boynton, W. R. 2014. On Synthesis in Estuarine Ecology. Keynote Presentation at the Spring 2014 AERS meeting. Ocean City, MD March 2014.

Boynton, W. R. 2014. Nutrient History of Chesapeake Bay. Salisbury State University. April, 2014.

Boynton, W. R. 2014. State of Estuarine Science: Opening Presentation. Open Source Community Modeling Conference. Annapolis, MD. May, 2014.

Boynton, W. R. and J. Testa. 2014. State of Science on Nutrient Pollution. ACT/NOAA Nutrient Sensor Challenge. White House Conference Center, Washington, DC. September, 2014.

Boynton, W. R. 2015. Impact of Phosphorus on water quality. The State of the Science of Phosphorus Conference. Sponcered by Chesapeake Bay Foundation and Maryland Grain Producers. Chesapeake Community College. January, 2015

Boynton, W. R. and L. Harris. 2015. History of Patuxent River Ecology. 2015 Patuxent River Conference. Jefferson Patterson Park, Calvert County, MD June, 2015

Boynton, W. R. 2015. Bay water Quality: What's going to happen? Chesapeake Bay Foundation Trustee Meeting, Annapolis, MD. June, 2015.

Boynton, W. R. 2015. Impact of Nutrients on Chesapeake Bay and Signs of Resilience. The Nature Conservancy, Delmarva Conservation Partnership, Chesapeake Community College. July, 2015.
Boynton, W. R. 2015. Introduction to Chesapeake Bay Ecology. Chesapeake Bay Foundation Summer Teachers Program. Solomons, MD July, 2015.

Boynton, W. R. 2015. Nutrients: The good, the bad and the TMDL. Chesapeake Bay Commission. Alexandria, VA. September, 2015.

Boynton, W. R. 2015. Chesapeake Bay Ecology and Habitat Issues. Leadership Maryland, Hebron, MD. September, 2015.

Boynton, W. R. 2015. An Introduction: History of Chesapeake Bay and Watershed. Alliance for the Chesapeake Bay Watershed Forum. Shepardstown, WV. September, 2015.

Boynton, W. R. 2015. Impact of Phosphorus and Nitrogen on Estuarine Water Quality. Crop Management School for MD, VA, WV and DE. Ocean City, MD. November, 2015.

Kemp, W. M., J. Testa and W. R. Boynton. 2015. Decadal-scale trends in nitrogen and related variables in a stratified estuary. Coastal and Estuarine Research Federation 23th Biennial Conference, November, 2015. Portland, OR. USA.

Boynton, W. R., J. Testa, C. Hodgkins, M. Ceballos, E. Bailey and J. Humpfrey. 2015. Sediments tell the story of ecosystem restoration in the Back River estuary, MD. Coastal and Estuarine Research Federation 23th Biennial Conference, November, 2015. Portland, OR. USA.

Hodgkins, C., L. Harris, W. R. Boynton, J. Testa and M. Day. 2015. A small estuarine system "on the edge": watershed development vs water quality conditions. Poster. Coastal and Estuarine Research Federation 23th Biennial Conference, November, 2015. Portland, OR. USA.

Harris, L., W. R. Boynton, J. Cornwell, M. Pennino, C. Hodgkins, C. Palinkas, M. Day, M. Owens and J. Testa. 2015. Changing nutrient budgets for an urban estuary. Coastal and Estuarine Research Federation 23th Biennial Conference, November, 2015. Portland, OR. USA.

Lee, Y., D. Lee and W. R. Boynton. 2015. Winter-spring chlorophyll-a concentration and phytoplankton community composition in Chesapeake Bay. Poster. Coastal and Estuarine Research Federation 23th Biennial Conference, November, 2015. Portland, OR. USA.

E.	Symposia Organized/Chaired for Professional Meetings

Boynton, W. R. 2010 - 2012. Chair of the CBP Tidal Monitoring and Assessment Workgroup (TMAW). Annapolis, MD

Kemp, W. M. and W. R. Boynton. Trends, patterns, and shifts in time-series of coastal ecological data: Invited Session, Session Co-Chairs. Coastal and Estuarine Research Federation Biennial Conference. November 6-11, 2011. Daytona Beach, FL.

Boynton, W. R. (and others). Chesapeake Bay Program STAC workshop. Evaluation of Chesapeake Bay dissolved oxygen umbrella criteria concept. Annapolis, MD Mar 16-17, 2011.

Boynton, W. R. (with CBP and TMAW staff). Developed and presented a series of workshops concerning Chesapeake Bay water quality criteria assessment. March, April and December, 2013. Annapolis and Baltimore, MD

Kemp, W. M., W. R. Boynton, J. Testa and D. Brady. Synthesis Research in Estuarine and Coastal Science: Focus on process and application. SCI-039. Coastal and Estuarine Research Federation 22th Biennial Conference, November, 2013, San Diego, CA. USA.

F.	Active Memberships in Professional Societies

Atlantic Estuarine Research Society (AERS)
Coastal and Estuarine Research Federation (CERF)
American Society of Limnology & Oceanography (ASLO)

## IV.	Teaching and Training

A.	University System of Maryland Courses Taught

Course No.	Title	Institution	Semester	Enrollment	Credit Hrs.	Co-Instructors
MEES 610	Land margin Interactions	CBL	2011	14	4	Fisher, Castro, Boynton
MEES 610	Land-Margin Interactions	CBL	2012	7	4	Fisher, Castro, Boynton
MEES 610	Land-Margin Interactions	CBL	2013	12	4	Fisher, Castro, Boynton
Guest Lecturer in Mitchelmore Class……..CBL…………2013……………………………………Mitchelmore						
MEES 608k	Synthesis Seminar	CBL/HPL	2014	10	1	Kemp and Boynton

Guest Lecturer in Mitchelmore Class……..CBL…………2014……………………………………Mitchelmore

Guest lecturer in AL Course   AL   2015   10   1   Englehartd

B.   Graduate Students Supervised as Major Advisor

1. Degrees Completed

None since 2011

2. Students Currently Supervised

None

3. Current Graduate Student Committee Memberships

Jessica Foley	MS	MEES	CBL
Richard Friesner	Ph.D.	GMU	GMU
Britt Dean	MS	VIMS	VIMS

4. Research Internships Supervised

None

V.   **Outreach and Service**

A.   Editorships: None

B.   Public Service (last 5 years)

The Nature Conservancy, DC and Maryland Chapter, Board Member, 2011-present

Patuxent Riverkeeper, Executive Board; Nov 2007 to 2015

Research on Chesapeake Bay. Participated in video for American Chemical Society. Solomons, MD. 21 November, 2011

Nutrients in Chesapeake Bay. Educational video production arranged by UMCES. Solomons, MD May 2013

Public school teacher workshop. Tom Wisner Legacy Program. Calvert County Marine Museum, Solomons, MD January, 2013

Patuxent River Wade-In. Jefferson Patterson Park. Calvert County. June, 1988-2015

Capitol Hill Oceans Week (CHOW). Assisted CERF in planning and presenting a Capitol Hill

briefing on Human Health in the Coastal Zone coupled with Capitol Hill House and Senate Office visits. May, 2013.

CBL Docent Lecture. 2014. Nutrients…why all the concern? CBL April, 2014.

CBL Outreach Program 6th – 9th graders. Nutrients and Chesapeake Bay. Solomons, MD July, 2014.

Calvert County Master Naturalist Program. Aquatic Ecosystem Component. Prince Frederick, MD April, 2012-2015

NSF-REU Program. Chesapeake Bay Ecology. Solomons, MD June 2014.

Chesapeake Bay Foundation Summer Teacher Program. Overview of Chesapeake Bay Health. Solomons, MD July, 2014

Alliance for the Chesapeake Bay, Senior Advisor. 2014-2015. Annapolis, MD

C.   Federal/State/Local Government

Patuxent River Commission, Member, Aug. 2003 - 2012.

Maryland Chesapeake Bay Trust, Science Advisory Board 2008-2015.

Member, Maryland Coastal Bays, STAC, 2004-Present.

EPA Science Advisory Board, Florida Nutrient Criteria Assessment Panel, November, 2010 – February 2011

San Francisco Bay Estuary Program. Provided seminars on estuarine monitoring and participated in regional planning workshop. Oakland CA. 28-30 June, 2011.

Consultant for U. S. Dept of Justice concerning Deepwater Horizon oil spill in the Gulf of Mexico. September, 2013 – January, 2015

Consultant for American Rivers concerning possible removal of the Patapsco River Blodie Dam. January – June, 2014

Chesapeake Bay Trust Governor's Science Advisory Panel, Annapolis, MD October, 2014-2015

Maryland Sea Grant and Calvert Marine Museum Senator Bernie Fowler Oral History Project, Prince Frederick, MD October, 2014

Regional Sea Grant Coastal Bays User Workshop, Ocean City, MD March, 2014 (directed by L. Harris).

Annual review of Calvert County tidal water quality. Calvert County Board of County

Commissioners. Prince Frederick, MD April, 1986-2015.

Maryland Department of Natural Resources Mattawoman Creek Planning Workshop. Hosted the event at CBL June, 2014.

Provided testimony for Chesapeake Bay Commission to Maryland Senate and House of Delegates concerning phosphorus issues in Chesapeake Bay (P-Management tool). February, 2015

Hosted EPA Trainers workshop at CBL. March, 2015.

Chesapeake Bay Program TMAW Technical Workgroup Chairman, Annapolis, MD. 2010 – 2014.

D.   International

E.   University System of Maryland

        None

F.   UMCES and Laboratory

        Tenure and post-tenure review committee for faculty at UMCES and other institutions, 1989-
              present.

        CBL Faculty Search Committees, 2005 – Present

        Organized "The Knot Class" for CBL students and staff - Feb 2012 and April 2013

        Assisted with CBL "Run for Research" event. September, 2015.

G.   Other Professional Service

        President-elect, President and Past-President Coastal and Estuarine Research Federation 2009-
        2015

CURRICULUM VITAE (ABBREVIATED)

James D. Hagy III

US EPA / NHEERL / Gulf Ecology Division
1 Sabine Island Drive, Gulf Breeze, FL 32561
hagy.jim@epa.gov; PH (850) 934-2455

EDUCATION

Ph.D. Marine Ecology. 2001. University of Maryland at College Park, College Park, MD

M.S. Marine Ecology. 1996. University of Maryland at College Park, College Park, MD

B.S. Biology. 1991. Duke University, Durham, NC

PROFESSIONAL BACKGROUND

January 2016 – Present. Research Ecologist, US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. Gulf Breeze, FL.

January 2013 – January 2016. Acting Branch Chief, Ecosystem Dynamics and Effects Branch, US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. Gulf Breeze, FL.

October 2004 - January 2013. Research Ecologist, US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. Gulf Breeze, FL.

January 2002 - October 2004. Post-Doctoral Ecologist. US Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. Gulf Breeze, FL.

RESEARCH INTERESTS
Coastal Systems Ecology, Coastal Eutrophication and Hypoxia, Management of Nutrient Pollution, Ecosystem Modeling, Coastal Food Webs, Statistical Modeling of Environmental Data

PROFESSIONAL AFFILIATIONS

- Coastal and Estuarine Research Federation (At-Large Board Member and Treasurer, 11/2013 – 11/2017)
- Gulf Estuarine Research Society, Member

EPA LEADERSHIP & MANAGEMENT ACTIVITIES

- Deputy Project Leader, Safe and Sustainable Water Research Program, Project 4.02 (Nutrient Thresholds and Targeting). Nov 2014-present
- Task Leader, Safe and Sustainable Water Resources Research Program, Task 2.3.A (Science to Support Nutrient Criteria). October 2011-September 2015.
- Mentorship Experience: Oak Ridge Institute for Science and Education, 2 Post-Docs, 1 MS level participant. EPA Student Services Contractors

EPA PROGRAMMATIC AND TECHNICAL ACTIVITIES
- Member, San Francisco Bay Assessment Framework Technical Team, San Francisco Water Board, December 2013-present
- Member, South Atlantic Bight Estuary Nutrient Task Force, 2015
- ORD Technical Lead for Numeric Nutrient Criteria Development for State of Florida - 2008-2013
- EPA Representative to Willard Spur Science Panel. Advising State of Utah on nutrient criteria development for Willard Spur of the Great Salt Lake. 2011-2014
- ORD Technical advisor to Region 4 on review of proposed change to Florida dissolved oxygen standard. 2012-present
- ORD technical advisor to Region 4 on review of proposed Florida numeric nutrient criteria. 2012-2014
- ORD technical advisor to Region 4 on review of proposed water clarity, chlorophyll-a, and dissolved oxygen site-specific alternative criteria for the Fenholloway River, FL. 2011-present.
- State of Mississippi Technical Advisory Group for Estuary Nutrient criteria development. 2011-present.
- EPA Presenter to EPA Science Advisory Board. EPA approach to numeric nutrient criteria development for Florida estuaries. December 13, 2010.
- EPA Presenter to EPA Science Advisory Board. EPA approach to development of numeric nutrient criteria for streams to protect downstream estuaries. December 14, 2010.
- Member, Florida/Alabama Panhandle Sea Level Rise Steering Committee, Sponsored by NOAA/CSCOR. 2007-2008.
- Invited Panelist, Hypoxia in the Northern Gulf of Mexico, Assessing the State of the Science, New Orleans, LA. April 25-27, 2006
- Member, OW/OST National Estuaries Experts Working Group, 2005-2007.

SELECTED JOURNAL PUBLICATIONS

Hagy, J. D.. Seagrass Depth of Colonization in Florida Estuaries. *Submitted to Estuaries and Coasts*. In Revision

Hagy, J. D. III, Vincent, A. M., and J. Flippin. Dissolved oxygen requirements of Florida-resident saltwater species applied to water quality criteria development. *In revision.*

Le, Chengfeng, J.C. Lehrter, B.A. Schaeffer, C. Hu, M.C. Murrell, **J.D. Hagy III**, R. M. Greene, and M. W. Beck. 2016. Bio-optical water quality dynamics observed from MERIS in Pensacola Bay, Florida. *Estuarine Coastal and Shelf Science*. DOI 10.1016/j.ecss.2016.02.003

Beck M. W., M. C. Murrell**,** and **J. D. Hagy III**. 2015 Improving estimates of ecosystem metabolism by reducing effects of tidal advection in dissolved oxygen time series. *Limnology and Oceanography: Methods* DOI 10.1002/lom3.10062

Beck, M W. and **J. D. Hagy III**. 2015 Adaptation of a weighted regression approach to evaluate water quality trends in an estuary. *Environmental Modeling and Assessment.* 20(6): 637-655 DOI 10.1007/s10666-015-9452-8

Le, Chengfeng, J. C. Lehrter, C. Hu, B. Schaeffer, H. MacIntyre, **J. D. Hagy** and D. L. Beddick. 2015. Relation between inherent optical properties and land-use and land-cover across Gulf Coast estuaries. *Limnology and Oceanography.* DOI: 10.1002/lno.10065 February 2015.

Beck, M W. and **J. D. Hagy III**. 2015 Adaptation of a weighted regression approach to evaluate water quality trends in an estuary. *Environmental Modeling and Assessment.* DOI 10.1007/s10666-015-9452-8

Lehrter, JC, D.S. Ko, M.C. Murrell, R.M. Greene, **J.D. Hagy**, B.A. Schaeffer, B. Penta, and R.W. Gould. 2013. Nutrient distributions, transports, and budgets on the inner margin of a river-dominated continental shelf. *Journal of Geophysical Research - Oceans*. 118: 4822-4838

Schaeffer, B.A., **J. D. Hagy** and R. Stumpf. 2013. An approach to developing numeric water quality criteria for coastal waters: a transition from SeaWiFS to MODIS and MERIS satellites. *Journal of Applied Remote Sensing**. 7(1),), 073544 (Jun 18, 2013). doi:10.1117/1.JRS.7.073544

Murrell, M.C., R.S. Stanley, J. C. Lehrter, and **J. D. Hagy III**. 2013. Plankton community respiration, net ecosystem metabolism, and oxygen dynamics on the Louisiana continental shelf: implications for hypoxia. *Continental Shelf Research*. 52: 27-38.

Schaeffer, B. A., **J. D. Hagy**, R. Conmy, J. C. Lehrter, and R. Stumpf. 2011. An approach to developing numeric water quality criteria for coastal waters using the SeaWiFS satellite data record. *Environmental Science and Technology*. 46: 916-922 DOI: 10.1021/es2014105

Greene, R.M., J. C. Lehrter, and **J.D. Hagy III**. 2009. Multiple regression models for hindcasting and forecasting midsummer hypoxia in the Gulf of Mexico. *Ecological Applications.* 19(5): 1161-1175

Breitburg, D. L., J. K. Craig , R. S. Fulford, K. A. Rose, W. R. Boynton, D. Brady, B. J. Ciotti, R. J. Diaz, K. D. Friedland, **J. D. Hagy III**, D. R. Hart, A. H. Hines, E. D. Houde, S. E. Kolesar, S. W. Nixon, J. A. Rice, D. H. Secor, and T. E. Targett. 2009. Nutrient enrichment and fisheries exploitation: Interactive effects on estuarine living resources and their management. *Hydrobiologia*. 629:31-47 (doi: 10.1007/s10750-009-9795-8)

Murrell, M. C., J. G. Campbell, **J. D. Hagy III**, J. Caffrey. 2009. Effects of irradiance on benthic and water column processes in a shallow micro-tidal estuary: Pensacola Bay, Florida, USA. *Estuarine, Coastal and Shelf Science* 81: 501-512.

Hagy, J. D. III and M. C. Murrell. 2007. Susceptibility of a Gulf of Mexico estuary to hypoxia: An analysis using box models. *Estuarine, Coastal and Shelf Science*. 74: 239-253.

Hagy, J. D. III, J. C. Lehrter, and M. C. Murrell. 2006. Effects of Hurricane Ivan on water quality in Pensacola Bay, FL USA. *Estuaries and Coasts.* 29(6A): 919-925.

Hagy, J. D., W. R. Boynton, and D. A. Jasinski. 2005. Modelling phytoplankton deposition to Chesapeake Bay sediments during winter-spring: interannual variability in relation to river flow. *Estuarine, Coastal and Shelf Science*. 62: 25-40.

Hagy, J. D., W. R. Boynton, C. W. Keefe, and K. V. Wood. 2004. Hypoxia in Chesapeake Bay, 1950-2001: Long-term change in relation to nutrient loading and river flow. *Estuaries* 27(4): 634-658.

Hagy, J. D., L. P. Sanford and W. R. Boynton. 2000. Estimation of net physical transport and hydraulic residence times for a coastal plain estuary. *Estuaries* 23(3): 328-340.

BOOK CHAPTERS

Hagy, J.D. and W. M. Kemp. 2012. Estuarine Food Webs. In: J. Day, W.M. Kemp and A. Yanez-Arancibia, eds. Estuarine Ecology. 2nd Edition.

SELECTED TECHNICAL REPORTS

Hagy, J. 2015. Science supporting numeric nutrient criteria for lakes and their watersheds: A synopsis of research completed for the US Environmental Protection Agency. US Environmental Protection Agency, Office of Research and Development, Washington, DC. EPA/600/R-15/262. 505 pp (including attached technical reports produced by TetraTech, Inc. under contract to US EPA).

Sutula, M., R. Kudela, D. Senn, and E. Novick. (Contributing Authors: G.M. Berg, S. Bricker, J. Cloern, R. Dugdale, J. D. Hagy III, M. Beck, L. Harding) 2015. Scientific Basis to Assess the Effects of Nutrients on San Francisco Bay Beneficial Uses. Technical Report #864, June 2015. Prepared for San Francisco Regional Water Quality Control Board (Contract 11-151-120), San Francisco, CA: 71 pp

Georgia-South Carolina Estuaries Technical Team (M. Alber, M Frischer, D Greenfield, J. Hagy III, J. E. Sheldon, E. Smith, R. F. Van Dolah, B. Woodson) 2015. An Approach to Develop Numeric Nutrient Criteria for Georgia and South Carolina Estuaries. A Task Force Report to EPA, GA EPD, and SC DHEC. 59 pp.

Murrell, MC, JR Aukamp, DL Beddick, R Devereux, RM Greene, **JD Hagy III**, BM Jarvis, JC Kurtz, JC Lehrter, and DF Yates. 2013. Gulf of Mexico hypoxia research program data report: 2002-2007. U. S. Environmental Protection Agency, Washington, DC. EPA/600/R-13/257.

EPA 2012 (**J. Hagy**, contributing author). Technical support document for U.S. EPA's proposed rule for numeric nutrient criteria for Florida's estuaries, coastal waters, and south Florida inland flowing waters. Volume 1: Estuaries. November 30, 2012. 365 pp.

Hagy, J. D., J. C. Kurtz and R. M. Greene. 2008. An approach for developing numeric nutrient criteria for a Gulf coast estuary. US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC. EPA/600/R-08/004. 48 pp.