Nutrient Modeling
Year 1 Work Plan

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1. Introduction

This document describes planned Year 1 (August 2015-July 2016) modeling tasks conducted as part of the San Francisco Bay Nutrient Management Strategy, and serves as a Year 1-focused update to the San Francisco Bay Nutrient Management Strategy (NMS) Modeling Work Plan (SFEI #733, December 2014)[1]. The general structure of the nutrient modeling project is unchanged from the NMS Modeling Work Plan, including the use of a phased approach.

2. Year 1 Goals

In general, the Year 1 modeling effort will be driven by the following general goals:

- Build the NMS program's modeling capacity
- Develop prototype water quality models and apply these models in:
    - Targeted modeling tests to inform the direction of future modeling activities and data collection needs (e.g., sensitivity analyses, determination of model complexity required to adequately simulate important processes).
    - Simulations or 'experiments' designed to obtain initial answers to several priority science and management questions.

In broad terms, during the first half of Year 1 (8/2015-1/2016), modeling work will focus on developing baseline modeling capacity, including: evaluation of hydrodynamic model options, both for Year 1 applications and over the longer term; building capacity through developing prototype water quality models; and developing modeling infrastructure (tools for data analysis, capacity for computationally intensive runs). The remainder of the year will be devoted to two initial modeling applications: (i) a full bay, tracer study, and (ii) a water quality model of South Bay and Lower South Bay (LSB).

[1] http://www.sfei.org/sites/default/files/biblio_files/2016%20RMP%20Detailed%20Workplan%20and%20Budget%20FINAL.pdf

To identify a specific set of Year 1 modeling tests and simulations/experiments, we utilized the following guidelines:

a. Develop a Year 1 workflow that is efficient and supports the multi-year modeling effort (i.e., the need to develop the foundational modeling components for the complex modeling work in Year 2 and beyond).
b. Make early progress on addressing a subset of the priority science and management questions. Results obtained in Year 1 may be provisional and highly uncertain, but can nonetheless inform future NMS science priorities (e.g., data collection).
c. Balance guidelines *a* and *b*: Select the science questions such that the topics can be reasonably well-explored using Year 1 prototype models; and that on-going model development is an inherent part of exploring the questions.

Based on these goals and guidelines, we identified a subset of questions to guide Year 1 modeling work, grouped into science questions, technical data and modeling questions, and applied / management questions. The specific activities and anticipated progress related to these questions are discussed in Section 3.

3. Priority Questions and Topics for Year 1

3.1 Science questions

What is the relative importance of clams versus light limitation in controlling blooms in South Bay and LSB? To what extent can changes in clam grazing or light levels (i.e., changes in suspended sediment concentrations) explain increases in phytoplankton biomass there?

Clam grazing and sediment-driven light limitation are commonly seen as the leading mechanisms for preventing algal blooms in nutrient-rich Bay waters. Bracketing the degree to which these mechanisms are able to attenuate blooms is an important step in understanding nutrient/algae balances in South Bay and LSB. In addition to quantitatively exploring the relative importance of these factors, incorporating spatially and temporally variable grazing and light levels will be important aspects of model calibration and validation for phytoplankton biomass.

Are sloughs and ponds a significant driver of water quality in Lower South Bay?

Lower South Bay has a unique morphology including broad shoals, slough networks, and former salt ponds undergoing restoration. Differences in depth, light levels, and flushing rates will lead to substantial differences in process rates and water quality conditions within these compartments. Since restoration efforts began in the mid 2000s, the area of salt ponds in tidal communication with the Bay has grown from zero to an area approximately equal to the open-Bay area of Lower South Bay (30×10^6 m^2). Because of both the substantial differences in biogeochemical conditions and the large restored salt pond area, exchange between these compartments may substantially influence Bay and slough water quality in ways that have not been previously quantified or taken into consideration.

A phased approach will be taken to modeling sloughs and salt ponds. First, the potential magnitude of effects from pond and slough processes will be estimated to determine their relative importance. These estimates will be derived from process rates in the literature, current configurations of the system and existing models of select portions of the domain. The priority of subsequent slough and pond modeling will depend on the estimated influence of those features on key water quality endpoints (e.g., DO, chl-a). The first phase of quantitatively exploring the potential influence of pond and slough processes on water quality will begin in the fourth quarter of FY16.

What is the basic form and sensitivity of dose:response curves in Lower South Bay and South Bay, for nutrients, sediment, inflow, and heat flux?

Nutrient loads and freshwater inflow are two primary drivers through which local management action might alter water quality in LSB. Sediment loads from the open bay, increasing temperatures from climate change, and changes in grazer abundance represent long-term variations in external forcings. Sensitivity analysis of water quality metrics to external forcing factors and basic management scenarios (e.g., changes in nutrient loads) will start in FY17. The first step will be identifying the most relevant scenarios (v.v. external forcing and management actions) for which detailed modeling should inform management decisions, and to identify data collection needs for associated model calibration.

3.2 Data and modeling technical questions

An important early goal of the modeling effort is to identify the appropriate level of model complexity for addressing different management questions. The complexity of water quality models varies from the simplest 1-box NPZ parameterization to models with millions of 3-D grid cells, dozens of water quality constituents, and processes including growth and competition among multiple phytoplankton species. “Simple” models may be sufficient for exploring some topics, while other topics may require orders-of-magnitude more complex simulations. Additional complexity comes at the cost of extensive effort in model development, long model run-times, greater data requirements for input and validation, and greater effort required for interpreting model output. San Francisco Bay, being a large and complex system, likely requires correspondingly complex models to answer some management questions with sufficient confidence. The appropriate level of complexity for answering specific science and management questions, though, still needs to be determined.

Activities in FY16 will refine our understanding of the necessary level of complexity by assessing the model complexity required to reproduce several important biogeochemical features observed in South Bay and Lower South Bay:

1. *The large bloom of 2003 in Lower South Bay and South Bay*
2. *Semidiurnal drops in summertime DO at Dumbarton Bridge*
3. *Spatial and seasonal trends in ammonium and nitrate concentrations*

4. *Long-term trends in chl-a*

The ability to capture these phenomena depends not only on the range of processes and spatial and temporal scales included in the model, but also on a host of tunable process rates. In reproducing the above features, we will also refine our understanding of the sensitivity of model results to tunable parameters. This will, in turn, inform future data collections needs targeting important parameters which are under-constrained by simulations and existing data.

3.3 Applied and management questions

What is the spatial region of influence of major discharges, and how does it vary with season?

POTW discharges influence nutrient concentrations not only in the vicinity of their outfalls but also in the areas where their plumes are transported. Transport and mixing of effluent away from outfalls is subject to the action of tides, winds, freshwater flows and circulation patterns within the Bay. Tying these transport processes to discharges is important for both nutrient-related and more general water quality objectives. The regions of influence of discharges will help determine the feasibility of monitoring strategies, the efficacy of mitigation actions, and constrain source attribution.

4. Year 1 Approach and Scope

Year 1 modeling work began in August 2015. Table 1 presents modeling tasks beginning in August 2015 and extending through the end of CY2016 (17 months). Tasks are organized into three categories: Hydrodynamics; Water Quality; and Basic Capacity and Framework. Collaboration and use of existing tools is central to efficiently tackling the nutrient modeling agenda, with specific examples described where relevant in the subsections below.

4.1 Model domain and major processes

Where

In order to avoid the temptation to model "everything," we have chosen realistic boundaries to the first year's effort and focus on building the program's foundation while also beginning to explore several important questions. In particular, the bulk of water quality modeling efforts will be directed toward subembayment-scale investigations, specifically South Bay and Lower South Bay. Within South Bay and Lower South Bay, open Bay areas (deep subtidal, shoals, intertidal) will be the primary habitats simulated, only roughly incorporating slough and pond portions of the bay on an as-needed basis. Science questions related to sloughs and ponds will rely on a combination of realistic, low-resolution hydrodynamic data in these areas and idealized box-model geometries.

What

The water quality model will focus on nutrient cycling and basic phytoplankton dynamics. Processes influencing dissolved oxygen will be simulated, and dissolved oxygen output reviewed, alongside other parameters. However, modeling studies related to dissolved oxygen will not begin until the end of CY2016. Phytoplankton species composition will not be a focus of work in CY2015 or CY2016.

4.2 Hydrodynamics

We are actively working with modelers at the USGS, DWR, UC Davis, UC Berkeley and Deltares to leverage as much of the existing hydrodynamic models and expertise as possible. The NMS effort is providing partial support for the USGS' Bay/Delta CASCaDE II hydrodynamic model development (CASCaDE II) effort. This model is being developed within the Deltares Flexible Mesh (DFM) platform, in collaboration with scientists from Deltares. The CASCaDE II model will continue to be the primary, long-term source of hydrodynamic data for the nutrient modeling. Several other models will potentially serve as stand-ins while CASCADE and the underlying flexible mesh model are being finalized. In particular, hydrodynamics from existing SUNTANS applications in South Bay and SCHISM applications in Suisun Bay are actively being considered in terms of their suitability to drive Year 1 water quality models. As of this report's writing, initial feasibility tests of the SUNTANS have been successful and work is currently proceeding along that front.

4.3 Water Quality

The primary water quality model will be DELWAQ, developed by Deltares. As described in the Modeling Work Plan (SFEI #733), DELWAQ has recently become open source, and includes a fairly exhaustive set of well-tested processes for nutrient cycling, phytoplankton, and sediment:water coupling.

Water quality modeling activities will proceed through several tasks (Table 1). As noted above, these tasks were identified to achieve three overarching goals: build modeling capacity; assess the resolution, scale, and biogeochemical complexity necessary to adequately capture major processes; and, along the path toward accomplishing the first two goals, reach initial answers to several priority science questions. Although these are appropriate overarching goals for a Year 1 effort, and the breadth and pace of activities presented in Table 1 is aggressive (but realistic), the specific goals and tasks do not lend themselves well to classic assessment of model skill, or precise definitions of success. However, the descriptions provided in Appendix A.2 provide additional context for how work will proceed including specific goals and success metrics.

4.4 Deliverables

Progress reports will be prepared in August 2016 (Year 1) and December 2016 (Year 1.5). Those progress reports will summarize key outcomes for major tasks and challenges encountered. Based on lessons learned in Year 1 (e.g., related to required resolution, scale, and complexity to capture important processes), we will also present a revised Year 2 modeling plan.

Table 1 Timing of Year 1 (August 2015 - July 2016) Modeling Activities and Deliverables. Activity dates extend through December 2016.
A: items to be included in Year 1 progress update (July 30 2016)
B: items to be included in subsequent 6 month update (December 15 2016)

		CY15		CY16			
		Q3/15	Q4/15	Q1/16	Q2/16	Q3/16	Q4/16
1	**Hydrodynamics**						
1.1	On-going development of DFM (via CASCADE/USGS)					A	
1.2	Include/update flow input data for LSB and South Bay						
1.3	Tools for creating low-res data from high-res model						
1.4	SUNTANS-DWAQ offline coupling						
1.5	Develop hydro input for FY2016 and FY2017 prototype WQ model activities						
1.6	Refined LSB model					A	
2	**Water Quality model**						
2.1	Initial, simplified basin models						
2.2	Include loads in model						
2.3	Test simulations with realistic hydro						
2.4	Setting up whole-Bay WQ simulations with limited number of parameters						
2.5	Conservative tracer for POTWs					A	
2.6	Bay-scale nutrient transformation					A	B
2.7	Calibration and skill assessment, low- and med-res, South Bay and LSB focus					A	B
	i. 2003 bloom						B
	ii DO at Dumbarton						B
	iii Chl-a increase						B
	iv Seasonal/spatial NH4/NO3					A	B

2.8	Sensitivity analysis for model parameters					A	
2.9	Investigate role of salt ponds/sloughs						B
2.10	Full bay runs with phytoplankton. (preliminary)						B
3	**Basic capacity and framework**						
3.1	Procuring software, licenses.						
3.2	Tool development for batch runs, data visualization						
3.3	Computing resources - apply for and obtain supercomputer time						

Appendix

A.1 Excerpted from *Nutrient Management Strategy Detailed Modeling Workplan, #733*

Table A.1.1: Priority Management Questions and Associated Modeling Questions

Management Question	Science Questions for Modeling
1. Is San Francisco Bay currently experiencing nutrient-related impairment, or is impairment likely in the future?	Not applicable. Questions about impairment will be addressed through the assessment framework and monitoring components of the Nutrient Management Strategy
2. If nutrient-related impairment is occurring, or future impairment is likely, what are the relative contributions of different nutrient sources to impairment, and how do these contributions vary spatially or temporally?	How much do nutrient loads from known sources contribute to ambient nutrient concentrations in: (1) each subembayment of the Bay by season; and (2) South Bay sloughs by season? How much do nutrient loads from known sources contribute to phytoplankton blooms and low dissolved oxygen in: (1) each subembayment of the Bay by season; and (2) South Bay sloughs by season? Do the models indicate that all the major sources of nutrients to the Bay are accurately being measured? What is the relative importance of ammonia inhibition of primary production on phytoplankton biomass compared to other factors? What is the relative importance of nutrient concentrations or ratios relative to harmful algal blooms compared to other factors?
3. What nutrient loads can the Bay assimilate without impairment of beneficial uses?	Under what future conditions would adverse impacts be expected? *Scenarios:* prolonged stratification, loss of clams, increased water clarity, stochastic introduction(s) of opportunistic harmful phytoplankton species, changes in nutrient load mass or speciation, water diversions.
4. What load reductions or other management strategies may be effective at mitigating current problems or preventing future problems from occurring?	What potential effects would different control measures have on mitigating current or future problems at the subembayment (or finer) scale? *Scenarios:* Changes in wastewater treatment, habitat restoration, water management, etc.

A.2 Model Skill Assessment and Success Metrics

The method for evaluating model skill as well as the decision of what level of skill is sufficient are highly dependent on the particular application. The focus for nutrient modeling in FY16 is primarily to establish modeling capacity rather than an operational, predictive system. To that end, the model evaluation activities generally stop shy of comprehensive model validation. The discussion of model evaluation below is broken down into specific applications, following the questions outlined above.

Relative importance of clam grazing versus light limitation in controlling blooms in South Bay?
A fully realistic prognostic model for blooms in South Bay is beyond the scope of the FY16 modeling efforts. However, there is ample data to constrain many of the relevant processes, and significant progress can be made in the context of a diagnostic, process study. The hydrodynamic features required for reproducing a South Bay bloom are primarily the evolution of stratification and flushing at the sub-embayment scale. Comparisons of model output against successive Polaris transects will provide a sufficient validation of the salinity dynamics, including freshwater sources and stratification.

The biogeochemical model will use light extinction data from USGS cruises to establish baseline conditions, and compare modeled chl-a and dissolved oxygen against observed profiles. Blooms are suspected to have significant lateral variability (Lucas et al, 2009) which longitudinal observations cannot capture. Satellite chlorophyll observations (MERIS) can augment the longitudinal data, though these comparisons may be more qualitative in the near term. The role of clams is more difficult to quantify from the existing observations in South Bay. Data in the literature will be used to estimate the potential range of clam grazing rates, and model results will be used to put those rates (and uncertainty) in context with other processes.

Are sloughs and ponds a significant driver of nutrient transformations in Lower South Bay?
Assessing the role of sloughs and ponds places further demands on the resolution of margin areas in the hydrodynamic model. Fully resolving the multitude of channel and pond connections in Lower South Bay is beyond the time constraints of FY16, but scaling and sensitivity studies will provide valuable information. To this end, a multi-box model dimensioned to match the overall geometry of Lower South Bay and its margins is the tool of choice. Transport in the open bay will be extracted from realistic hydrodynamic runs as above, while transport and dispersion in the sloughs and ponds remain a significant unknown. Long-term monitoring data from SFEI and USGS moorings are the best path towards evaluating model skill. Recent biogeochemical modeling work, such as Lake and Brush, 2015, will serve as a guide for evaluating model skill.

What is the basic form and sensitivity of dose:response curves in Lower South Bay and South Bay, for nutrients, sediment, inflow, and heat flux?
Similar to the slough and pond study from above, the dose:response study is diagnostic, and not an attempt to create a forecast model. Nonetheless, the result will be highly dependent on rate parameters within the model, necessitating a companion sensitivity study. This sensitivity

study will explore the range of parameter combinations that yield salinity, chlorophyll, nitrate and dissolved oxygen predictions comparable to measurements.

Can a simple 2-4 box model reproduce the large bloom of 2003?
This study is in essence a validation exercise. The fundamental test of the model is whether a reasonable set of parameters can be found which yield a bloom under 2003 conditions similar to the observed bloom, while not predicting a bloom of that magnitude in previous or later years. While exchange between South Bay and the rest of the Bay can be constrained with the previously mentioned hydrodynamic model, variation in boundary concentrations of nutrients and biomass still represent a large source of uncertainty.

Likewise, can a simple model capture long term trends in chl-a?
The test of the model in this application is its skill in hindcasting long term trends. Again, the potential lack of sufficient boundary condition data may confound modeling efforts. However, in addition to actual biomass or chl-a concentrations, we will also assess relative change in chl-a when key parameters and process rates are varied over realistic ranges.

What is the spatial region of influence of major discharges, and how does it vary with season?
This application directly leverages the hydrodynamic model to provide transport and dispersion estimates throughout the bay. A three-dimensional validation of the salinity field over the course of representative wet and dry years is the primary skill metric. The lack of long-term salinity data away from the longitudinal axis of the estuary is anticipated to be one important data limitation that needs to be addressed. To this end, the use of SFEI/USGS monitoring data in Lower South Bay, a set of regional NOAA current-meter deployments in 2012 and 2013, and select short-term deployments in San Pablo Bay and Suisun Bay will bolster the hydrodynamic validation. We note that in FY16, limited resources are being directed toward improving the hydrodynamic model. The goal of these validation metrics is to understand model performance and identify those aspects of the hydrodynamics needing further calibration in the future.

References

Lake, S.J. and M. Brush, 2015. Contribution of nutrient and organic matter sources to the development of periodic hypoxia in a tributary estuary. *Estuaries and Coasts* 38:2149–2171.

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