REGIONAL MONITORING PROGRAM
FOR WATER QUALITY IN THE SAN FRANCISCO BAY

Model Development Plan to Support Nutrient Management Decisions in San Francisco Bay

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Model Development Plan to Support Nutrient Management Decisions in San Francisco Bay

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1. Introduction

San Francisco Bay has long been recognized as a nutrient-enriched estuary, but one that has exhibited resistance to some of the classic symptoms of nutrient overenrichment, such as high phytoplankton biomass and low dissolved oxygen. However, recent observations indicate that the Bay's resistance to high nutrient loads is weakening, leading regulators and stakeholders to collaboratively develop the San Francisco Bay Nutrient Strategy.[1] The Nutrient Strategy aims to address four overarching management questions (Table 1), and lays out an approach for building the scientific foundation to inform the related upcoming, and potentially costly, management decisions. Among its recommendations, the Nutrient Strategy calls for developing models to quantitatively characterize the Bay's response to nutrient loads; explore ecosystem response under future environmental conditions; and test the effectiveness of load reduction scenarios and other scenarios that mitigate or prevent impairment. While multiple hydrodynamic models exist for San Francisco Bay, there are no integrated hydrodynamic and water quality models capable of quantitatively exploring ecosystem response to nutrients under current conditions or predicting response under future scenarios.

This short white paper presents a recommended plan for developing and applying models to inform nutrient management decisions in San Francisco Bay. As part of a model planning effort, funded by the San Francisco Bay Regional Monitoring Program[2], SFEI staff solicited input from regulators, stakeholders, and scientists to refine the management and science questions that modeling will help address (Table 2), and identify model requirements (Table 3). We then convened a team of modeling experts (Table 4) to provide input on model platform selection based on these criteria, and guidance on the broad approach to model development and application. The details of model development will be addressed in a subsequent modeling work plan.

2. Recommendations: Platform and Approach

Candidate model platforms were evaluated relative to the criteria in Table 3, with observations summarized in Appendix A. The following section outlines the recommendations for the modeling platform and approach to model development.

2.a Recommended Platform: Deltares

The Deltares suite of models emerged as the recommended model platform. Key reasons for the selection of the Deltares models include:

1. *Widely accepted and validated hydrodynamic, sediment, and water quality models, in a combined platform*
2. *Large international user group*

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

2 http://sfei.org/rmp

3. *Open source and freely available hydrodynamic code and water quality code* While the current open-source Delft3D hydrodynamic code is for structured grids, a flexible grid Deltare code is under development and planned for addition to the open-source model. The water quality model, DELWAQ, works atop both the structured and flexible grid models. Structured and unstructured grids can be linked, so the Bay nutrient model can become more sophisticated as needed, and the model can migrate from the structured platform to the unstructured platform. These advanced capabilities will also allow the platform to be used by additional users who may have more advanced requirements, increasing the size of the community and garnering wider support for on-going model development.
4. *Strong water-quality/phytoplankton/grazing model, coupled to hydrodynamics and sediment* DELWAQ includes all the major biogeochemical and phytoplankton growth processes available in other widely-used models. Moreover, DELWAQ has a user-interface process library that allows users to adjust processes, and model developers at Deltares are available to suppor any advanced modifications. Advanced water quality modeling features are under development, including approaches for so-called 'dynamic coupling' between phytoplankton and the benthos, which may be important for applications for scenarios in the Bay under which phytoplankton biomass is strongly influenced by benthic grazing.
5. *User-friendly interface that will allow a range of individuals to work with the model*
6. *Structured grid model available from USGS-Santa Cruz that can serve as a starting point, and flexible mesh model under development* A flexible mesh model is being developed through a USGS-Deltares collaborative study in the Bay/Delta[3], and there is the potential for products from that work to eventually serve as the hydrodynamic model for the Bay nutrient model. In this sense, we expect that directing nutrient-related funding toward developing the nutrient model with Deltares platforms will leverage substantial resources already being directed toward hydrodynamic and sediment transport model development throughout the Bay-Delta.
7. *Institutional support:*
    a. The on-going use of the Deltares platforms by the USGS for multiple projects offers the likelihood that a Deltares-based model will continue to be developed and used in the Bay by other groups, creating opportunities for collaborations and exchange.
    b. The model developers, Deltares, have expressed strong interest in collaborating on this nutrient modeling initiative. Deltares is an 800-person nonprofit research institute that has worked on model development and application for 35 years, and can offer opportunities for exchange of researchers and training that will speed model development in the early stages, and help ensure that the model is sustained for future applications. Deltares and USGS have collaborated similarly under cooperative agreements over the past several years.

2.b Approach

It is recommended that modeling work for the Bay Nutrient Model move forward in two phases (Figure 1). Phase I would involve setting up the base hydrodynamic and water

[3] CASCaDE II http://www2.unesco-ihe.org/The-San-Francisco-Bay-Delta-model

quality models. In Phase II, the base model will be applied to address focused nutrient questions, and specific modules will be refined, as-needed, to incorporate additional processes, or decrease (or better quantify) uncertainty.

SFEI will serve as the hub for this model. While nutrient management decisions will remain the primary driver and focus behind model development, an additional goal is to facilitate the model's use and development as a community model that can be used for a broad range of applications, and build regional capacity to apply this model for the purpose of addressing both management questions and fundamental research questions. The calibrated and validated base model will be shared freely with all interested users, and periodically updated to incorporate model refinements. The stipulation for all users will be that any refinements or improvements to the model will also open-source and freely available, and archived at the model hub.

The "community model" approach would have benefits both for the nutrient efforts and for other topics of interest to the RMP, regulators, dischargers, and environmental managers/planners. By adopting a platform like the Deltares suite – a powerful platform that is also flexible, scalable, and user-friendly – and engaging the regional modeling community in its development and application, the model will receive wide use beyond nutrient issues. This wide use will contribute to model enhancements and model maintenance. Nutrient-related funding will be directed toward developing components that are essential for nutrients, and collaborators may pursue funding from other sources to develop additional model capabilities, ultimately expanding the user community.

Among the possibilities for in-kind support from Deltares, they have proposed support for a website to host the base community model, documentation, updates, etc..

2.b.i Phase I: Set-Up of Base Model

To initiate work on model development, a modeling "Core Team" will be convened, comprised of regional, national, and international experts. The expertise of the Core Team will cover the major technical areas (e.g., hydrodynamics, biogeochemistry, phytoplankton dynamics), and will be complemented by individuals with specific expertise as needed. Initially, the Core Team will aid in developing a Modeling Work Plan. Once work commences, the Core Team will be augmented by full-time or part-time/contractual modeling staff who will carry out much of the hands-on work. The Core Team will serve three primary functions, with individuals contributing differently based on expertise and availability:

- Technical guidance during project start-up, and periodically for regular project updates
- In-depth, hands-on support from some individuals on specific topics, as needed
- On-going technical review of progress and major products.
- Carrying out base model development, calibration/validation, and modeling experiments to test hypotheses or sensitivity to inform next steps in development and help prioritize among field studies or monitoring data collection.

Phase I work will be carried by Core Team members, which will be comprised of SFEI staff and close external collaborators from academic institutions, research institutions (e.g., USGS, Deltares), and consulting firms. Work will include:

Task I.1 Develop an overarching Work Plan for the first 3-5 years of effort, including a more detailed plan for Year 1.

Task I.2. Adopt and refine an existing hydrodynamic model to serve as the initial hydrodynamic model input (HYD.1) for use within DELWAQ, to develop the water quality model. Options include: using the existing USGS-Santa Cruz Delft hydrodynamic model (making any necessary refinements), adapting existing hydrodynamic output from the SUNTANS model, or using output from the Deltares flexible grid model currently under development for the Bay/Delta by USGS and Deltares. The goal is to have a "good enough" hydrodynamic model upon which to develop the early stages of the water quality model (e.g., Years 1-2). Some effort within Task I.2 may be directed toward exploring the pros and cons of the hydrodynamic model options, and identifying the most cost-effective and time-effective option. Details on this task will be developed in the Work Plan, including minimum requirements for the hydrodynamic model.

Task I.3 Create necessary input files. This will include creating point inputs from publicly owned treatment works (POTWs) and incorporating POTW flows. In addition, watershed inputs may be important for the salinity balance, and simulating stratification, in some areas of the Bay. Existing data for watershed inputs will first be sought from other modeling efforts; however, some watershed hydrological simulations to generate flow time-series and loads may eventually be needed, but will be part of a subsequent task. Additional data inputs include time series of suspended sediments (for estimating light levels), clam biomass and grazing rates, and ambient nutrient concentration and phytoplankton biomass data for model calibration.

Task I.4 Develop water quality/phytoplankton/grazing model (WQ.1). The standard DELWAQ code contains the vast majority of the biogeochemical/ecological processes that need to be included in the base model. In this task, effort will be directed toward setting up WQ.1 within DELWAQ, and using the model to carry out sensitivity analysis and hypothesis testing at subembayment scales, or in simplified space/time domains. The team of technical advisors strongly recommended pursuing this path of gradual development to more complex and larger-scale models. The rationale for pursuing this path is that sensitivity analysis becomes increasingly computationally-intensive, and data interpretation becomes much more complex as a model becomes larger and more highly resolved. These focused studies will provide output that will ultimately help us reach the goal of a calibrated/validated model more rapidly. In addition, experiments that will be carried out in these studies will address key science questions (e.g., questions 1, 2, and 4 in Table 2), and, through sensitivity analysis, inform what additional field data collection is needed to improve model calibration. Details of this task, including priority experiments to conduct, will be identified in the work plan. In general, work will include:

1.4.a Using DELWAQ, perform simplified domain experiments for sensitivity analysis and hypothesis testing/generating (e.g., 1-box, 2-box)

1.4.b For key subembayments (e.g., Lower South Bay, South Bay, Suisun Bay), develop aggregated models (e.g., several grid cells up to 10s of grid cells) and carry out sensitivity analysis, initial calibrations, and focused experiments that address high priority science questions (Table 2). In these studies, water quality will be driven by real hydrodynamic input (using HYD.1) that has also been aggregated to the same grid.

I.5 Establish Base Hydrodynamic and Water Quality models (HYD.2 and WQ.2) that will be used for projects in Phase II.

I.5.a Refine hydrodynamic platform. While work commences on water quality development in Task I.4, the hydrodynamic platform will be further refined to meet additional requirements. At appropriate stages, a revised hydrodynamic model (HYD.2) will be migrated over and become the driver for DELWAQ. Necessary refinements and appropriate junctures for migration will be identified in the Work Plan.

I.5.b Refine water quality model (WQ.2). Building from the subembayment-scale studies in Task I.4, the water quality model will be coupled with the new hydrodynamic input (HYD.2), refined within the subembayments studied in Task 1.4.b, and provisionally calibrated at the full Bay scale. The product will be the refined water quality model, WQ.2. Further refinement of the calibration, extending the calibration/validation to other years, and application of the model will be carried out in Phase II.

2.b.ii Phase II Focused Modeling Projects

Once the base model is developed, modeling work will proceed as a series of projects (Figure 2). In general, these projects will include

- Further refinement and calibration of the model at the full Bay scale, including extending the calibration/validation to other years.
- Applying the base model to address specific science or management questions related to nutrient loads, nutrient cycling, and ecosystem response (Table 2);
- Experiments, and sensitivity or uncertainty analysis, using the base model to test hypotheses related to ecosystem response, and to inform additional field data or model refinement; and
- On-going improvement of the base model, such as additional effort toward necessary improvements to hydrodynamics, sediment transport, or water quality modules.

An early step in Phase II will involve revisiting the priority science questions to be tested through modeling, and developing a refined list of prioritized modeling studies, based on the experience developed in Phase I and progress in other areas of the Nutrient Science Program. Table 2 presents several example questions, identified during this white paper's development, and through other Nutrient Strategy activities. The project list will be refined during 2015-2016, specifically within the context of modeling work and more broadly through the process of developing the detailed science plan for implementing the Nutrient Strategy.

Modeling work on Phase II projects will be carried out using the base community model developed during Phase I . Individual projects will be completed by the Core Team, external collaborators, or a combination of the two. The approach for selecting teams to work on specific projects will vary by project, and may depend on several factors, including the required expertise, time-sensitivity of the final product, and available budget. In some cases, the Core Team may be well-positioned to carry out the work; in other cases, sole-sourcing to a specific group or putting out a request for proposals may be the best route.

2.b.iii Technical Review

A Modeling Advisory Team (MAT), or external peer review group, will provide technical oversight of the modeling effort, including work carried out by the Core Team and by external collaborators funded by the nutrient modeling program (Figure 1). The MAT will consist of technical experts in relevant disciplines, and will carry out high-level review of modeling program goals, approach, and technical work products. The process for selecting MAT members, frequency with which the MAT will be convened, and its process for reviewing work products will be further defined in the governance structure for the San Francisco Bay Nutrient Management Strategy, which is under development.

2.c Timeline, Deliverables, and Anticipated Costs

2.c.i Phase I

A first draft of a work plan for Phase I is targeted for completion in Q1 2014, and work would begin shortly after its completion. The time required to recruit key personnel to do the hands-on model set-up and refinement may ultimately dictate when work begins.

With 1-2 full-time staff supported by part-time collaborators and technical advisors, Phase I will take 2-3 years to complete. Over that time period, intermediate work products will be developed, including:

- A brief technical report, based on sensitivity analyses in Task I.4, that identifies the highest priority monitoring or data collection needs to be carried out through components of the Nutrient Strategy
- One or more technical reports that address key questions related to the relative importance of factors that regulate ecosystem reponse (e.g., the potential influence of clams, light, residence time, or NH_4^+ on phytoplankton production or biomass accumulation in Suisun Bay; factors that could explain increases in biomass in South Bay).
- Provisionally-calibrated Base Model consisting of HYD.2 and WQ.2, with calibration/validation developed for the focus subembayments
- Model documentation, progress updates, and recommendations for next steps in model refinement based on analysis of base model set up

The major costs associated with Phase I include:

- Salary support for modelers, either working as SFEI staff or in a joint appointment with a closely collaborating institution
- Support for other members of the Core Team providing technical guidance or part-time hands-on technical support

- Support for the MAT
- Overall project science coordination and management

It is estimated that completing Phase I will require 2-3 years effort and will cost \$500,000/year. The funding provisionally allocated for Year 1 is ~\$280,000 (through the RMP). This amount should allow for substantial progress to be made in Year 1; however it will need to be augmented during Year 1 by other funds to ensure sufficient progress.

2.c.ii Phase II

Work on Phase II projects would begin in Year 2, while work is still underway on Phase I. The main early work in Phase II will be related to refining the calibration at the full-Bay scale.

Phase II efforts will directly address questions at the full-Bay that provide input to considerations among management options (Table 2 Questions 5-7). At this stage, it is difficult to accurately estimate the timeline or annual costs, both of which will depend on experience gained during Phase I, and the pace at which work needs to be completed. However, it is reasonable to expect that Phase II modeling costs will be on the order of \$500,000/year over a period 5 or more years.

Table 1 Priority management questions

1.	Is San Francisco Bay currently experiencing nutrient-related impairment, or is impairment likely in the future?
2	What nutrient loads can the Bay assimilate without impairment of beneficial uses?
3	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?
4	What load reductions or other management strategies may be effective at mitigating current problems or preventing future problems from occurring?

Table 2 Example management-motivated science questions for focused projects in Phase II

Detailed Question	Notes	Relevant Spatial Scales[1]	Relevant Temporal Scales[2]
1. What are the relative magnitudes/contributions of factors that control ecosystem response to nutrients?	*Response*: phytoplankton biomass, DO, phyto comm compos. (?), HABs (?) *Regulating factors*: light attenuation, clam grazing, NH4-inhibition, nutrient abundance	*DO:* geomorphic feature *Biomass*: subsegment or geomorphic feature	*DO and Biomass*: deep subtidal areas = tidal; shallow subtidal areas: tidal to event
2. To what extent can observed changes in ecosystem response over the past ~25 years be explained by actual or hypothesized changes in regulating factors?	Being able to predict these changes, using known changes in drivers, or changes in drivers within realistic ranges, will provide needed confidence in model to explore plausibility of future impairment scenarios	*Biomass*: subsegment or geomorphic feature	*Biomass*: deep subtidal areas = tidal; shallow subtidal areas: tidal to event
3. What are the contributions of anthropogenic nutrient loads to low DO in shallow poorly-exchanging margin habitats? (e.g., low DO in sloughs)		*DO and Biomass:* geomorphic feature	*DO and Biomass*: tidal to event
4. What is the natural capacity to assimilate or process nutrients, at the subembayment (or finer) scale?	Pelagic and benthic nitrification, denitrification	subsegment	seasonal
5. Under what future conditions would impairment be expected? What magnitude(s) of changes in drivers could lead to a tipping point, and are those changes quantitatively plausible/probable?	*Causes:* prolonged stratification, loss of clams, increased water clarity *Effects:* Large blooms, low dissolved O_2, acute nuisance blooms, HABs, shifts in species composition	geomorphic feature to segment	tidal to decadal
6. Once hydrodynamics and (mixing, dilution, transformation) are taken into account, what spatial scales are relevant in terms of regulation/permitting?	- effectiveness of control measures - nutrient trading	Geomorphic feature to subsegment	Tidal to seasonal
7. If there are current or future impairments, what magnitude of effect would different control measures have on mitigating or preventing those problems at the subembayment (or finer) scale?	e.g., load reductions, wetlands, shellfish beds	subsegment	seasonal

[1]The spatial scales potentially considered and their approximate distance ranges of aggregation and averaging are as follows:

- Bay (100+ km) – areas within the bay do not need to be distinguished
- Segment (10+ km) – differences among Bay segments (Suisun, San Pablo, etc.,) are needed
- Sub-segment (1-10 km) – areas within segments (e.g., east vs. west shoreline) need to be distinguished
- Geomorphic features (0.1-1km) – mudflats, main channel, etc., are differentiated (intertidal mudflats vs. shallow subtidal vs. deep/channel)
- Geomorphic subfeatures (~10-100m) – sub-channels, discrete flats, wetlands, etc., are modeled

[2]Temporal scales to be considered may include:

- Decadal (10+ years) – needed for persistent contaminant fate, long term geomorphic change
- Interannual (1+ years) – to distinguish wet vs. dry year processes and responses
- Seasonal (weeks to months) – wet vs. dry season processes and responses
- Tidal (days to weeks) – differentiation between portions of tidal (spring/neap) cycles
- Event/diurnal (hours to days) – responses to weather events or day/night cycles

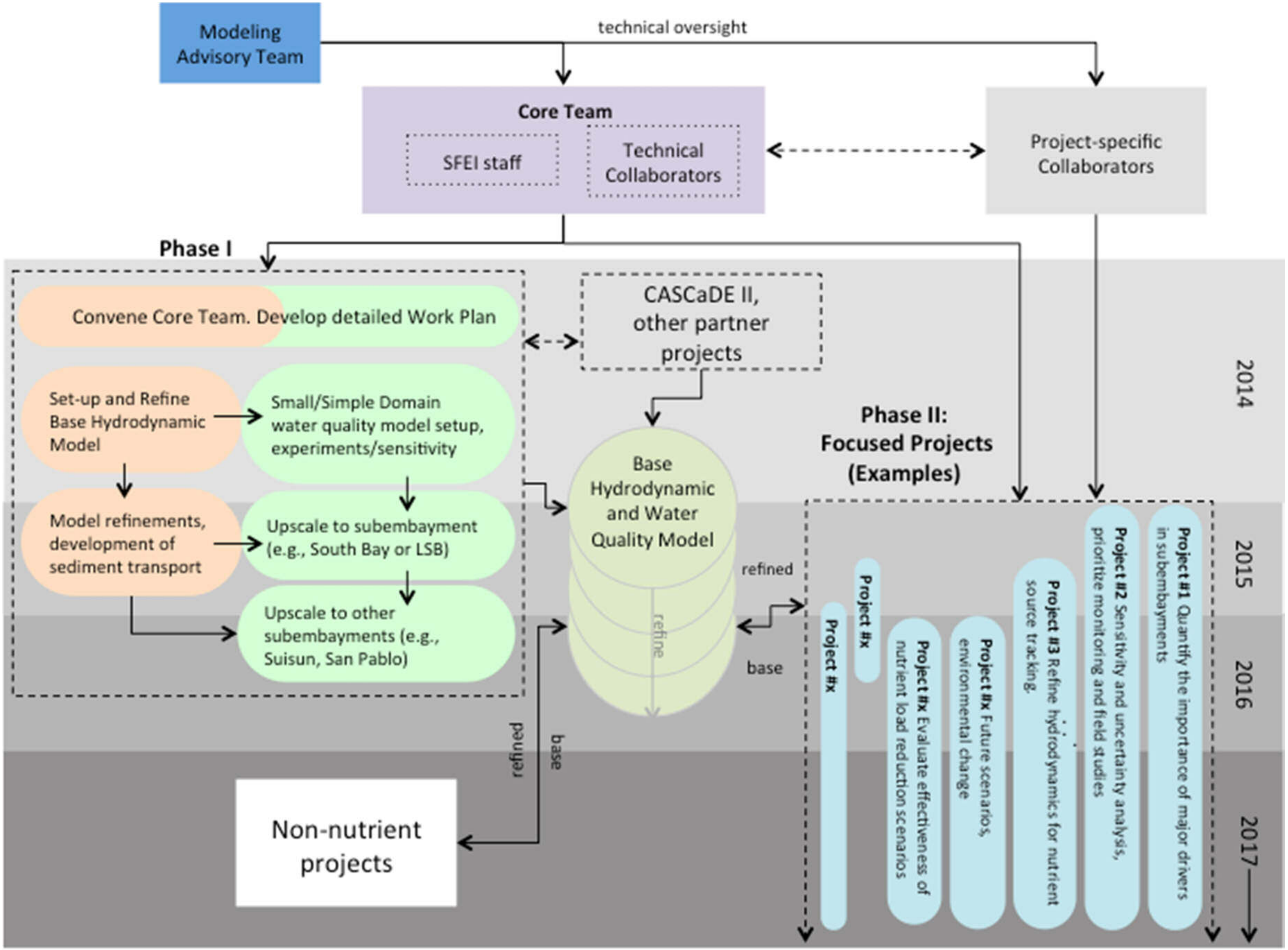
Table 3 Model requirements that guided model platform selection

Peer-reviewed model	○ history of successful application addressing these types of management questions
Reasonable "buy in" costs and learning curve for end user	○ Average technical user level ○ Reasonable cost of training and required resources ○ Freely available and open-source
Support for technical continuity over multi-year period	○ Large user community ○ Substantial institutional support ○ Sufficiently state of the art (avoid obsolescence before project completion)
Sufficiently resolved/mechanistic to model management scenarios	○ Appropriate spatial and temporal resolution ○ 3D capability ○ Water Quality (nutrients, phytoplankton) ▪ Standard capabilities (nutrient transformations, dissolved oxygen) ▪ Sediment:water interface processes ▪ Multiple phytoplankton classes ▪ Zooplankton grazing ▪ Filter-feeding benthos ○ Contaminant transport ▪ Integrates appropriate sediment transport ▪ Approximate relevant contaminant dynamics
Scalable	○ Platform(s) can accommodate grid aggregation, starting "simple", and adding complexity on an as-needed basis.

Table 4 Technical team that advised on model selection

	Affiliation	Expertise
Dr. Li Erickson	USGS	Sediment transport modeling
Dr. James Fitzpatrick	HDR Hydroqual	Water quality modeling in (nutrients, dissolved oxygen, phytoplankton response)
Dr. Oliver Fringer	Stanford University	Hydrodynamic modeling
Dr. Edward Gross	RMA	Hydrodynamic modeling
Dr. Lisa Lucas	USGS	Hydrodynamic modeling, phytoplankton modeling

Figure 1 Schematic of approach to model set-up, refinement, and application



Appendix

The following section provides an overview of other platforms considered and their pros and cons relative to the criteria in Table 3.

A.1 Hydrodynamics

Delft3D

- Pros:
    - Basic hydrodynamics and sediment transport in Delft3D are peer-reviewed and public domain
    - USGS (Santa Cruz) uses Delft3D for Bay modeling and has provided preliminary agreement to collaborate
    - DELTARES is available for Delft3D support
    - Initial San Francisco Bay hydrodynamic model is available
- Cons:
    - Does not provide flexibility of unstructured meshing in present open source version

EFDC

- Pros:
    - Basic hydrodynamics and sediment transport in EFDC are peer-reviewed and public domain
    - EFDC integrates the CE-QUAL water quality and contaminant transport model
    - Training courses available through private parties
- Cons:
    - Does not provide flexibility of unstructured meshing
    - Only consultants are presently using it in San Francisco Bay
    - No planned future institutional support for model improvement

SUNTANS

- Pros:
    - State-of-the-art open-source peer-reviewed hydrodynamics platform supported by Stanford University
    - Unstructured grid capabilities
    - Stanford is available for SUNTANS support
    - Initial San Francisco Bay hydrodynamic model is available
- Cons:
    - No known use for water quality and contaminant transport studies
    - Higher requirements for end user modeling experience

UNTRIM

- Pros:
    - State-of-the-art hydrodynamics are peer-reviewed
    - Unstructured grid capabilities

  - USACE is using UNTRIM for focused transport studies in San Francisco Bay and Delta
  - Initial San Francisco Bay hydrodynamic model is available
- Cons:
  - Not public domain
  - Only consultants are presently using it in San Francisco Bay

A.2 Water Quality/Contaminant

Overall the water quality contaminant transport models are formed from a similar computational basis. The decision for which model should be used can be based on availability of expertise, training, and resources during model implementation.

RCA

  - RCA is public domain and peer-reviewed
  - Performs both water quality and contaminant transport
  - Allows for grid aggregation
  - Hydroqual is available for support

WASP/CE-QUAL

  - WASP and CE-QUAL public domain and peer-reviewed
  - Performs both water quality and contaminant transport
  - Allows for grid aggregation
  - National sources of EPA and USACE support are available with extensive documentation and examples

DELFT-Water Quality

  - DELFT-Water Quality is peer-reviewed
  - Recently made public domain (March 2013) timeframe
  - Performs both water quality and contaminant transport
  - Allows for grid aggregation
  - DELTARES is available for support