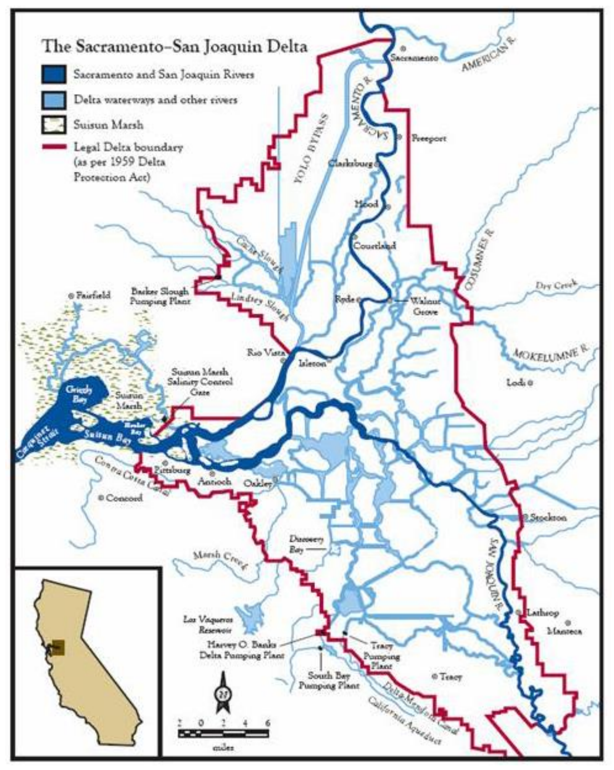
RECOMMENDATIONS FOR A MODELING FRAMEWORK TO ANSWER NUTRIENT MANAGEMENT QUESTIONS IN THE SACRAMENTO-SAN JOAQUIN DELTA

Trowbridge, P.R.[a], M. Deas[b], E. Ateljevich[c], E. Danner[d], J. Domagalski[e], C. Enright[f], W. Fleenor[g], C. Foe[h], M. Guerin[i], D. Senn[a], and L. Thompson[j]

A White Paper Prepared for: Central Valley Regional Water Quality Control Board (Region V)



Source: http://users.humboldt.edu/ogayle/hist383/SacramentoDeltaMap.png

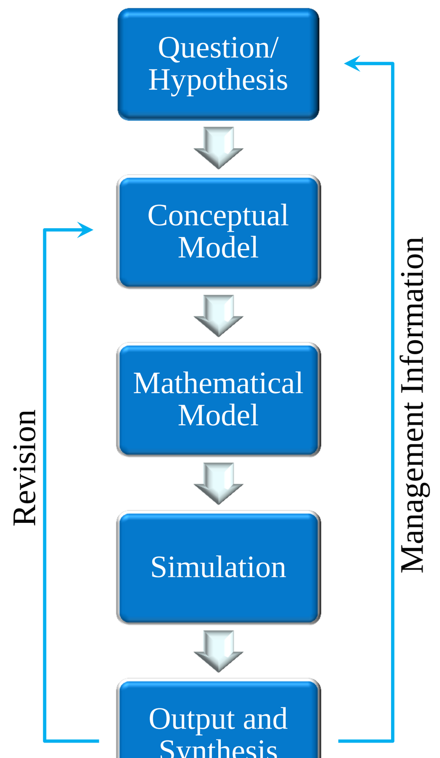


Figure 1. Modeling Approach

Table 1. Desired general characteristics for Delta hydrodynamic and water quality models

No.	Characteristic	Explanation
1	Reasonably accessible in terms of costs and learning curve for end user (required)	Source code, software and training can be obtained at reasonable cost. A knowledgeable technical user should be capable of running the model. Compliant with copyright licensing requirements if developed with public funds.
2	Track record and peer review	Models should have a history of successful applications addressing nutrient management questions. Model equations and software should be verified and validated through a California Water and Environmental Modeling Forum peer review process, or equivalent, prior to a large scale investment in model development.
3	Support for technical continuity over multi-year period	Active and sufficiently large user community, substantial institutional support.
4	Sufficiently resolved/mechanistic to model management scenarios	To be determined based on technical characteristics in Table 5.
5	Scalable	Platform(s) can accommodate iterative development, both in terms of complexity of the domain and the range of processes/constituents to be modeled.

Table 2. Desired general characteristics for Delta hydrodynamic and water quality models

No.	Characteristic	Explanation
1	The model(s) must have a hydrodynamic platform and transport component. For most applications, the spatial domain of the hydrodynamics model should cover the majority of the legal Delta, including flooded islands and marshes.	Water exchange between the channels and flooded islands and marshes affects both the hydrodynamics and biogeochemical conditions. To answer some specific management questions fine scale models that only cover a part of the Delta may be more appropriate.
2	The model(s) must have water quality modules for nutrient water quality, sediment transport, and macrophytes.	Meyer et al. (2009) concluded that a Bay-Delta model was needed to integrate hydrology, nutrients, herbivory, phytoplankton production and community composition. Some components will have to be modeled qualitatively or with less accuracy because processes are not well understood and/or data are lacking.
3	The nutrient water quality module must simulate nutrient and carbon transformations, primary productivity from phytoplankton, and grazing by zooplankton and benthic invertebrates.	Nutrient dynamics (water column and benthos) and how they relate to primary production are required to assess management actions. Underlying physical models of hydrodynamics, salinity, and water temperature are necessary to support the water quality module.
4	The nutrient water quality module should be compatible with higher trophic level ecological models (e.g., food for fish models) but not necessarily model higher trophic levels directly.	Model output should be at an appropriate temporal and spatial scale to support higher trophic level ecological models. For example, the output of the water quality module should provide useful (but not necessarily all) inputs to the models of fish growth and behavior developed by NOAA and other resource agencies.
5	The sediment transport module should be capable of two-way linkages with the nutrient water quality module.	Suspended sediments can influence nutrient biogeochemical reactions through exchange between the water column and sediments, transport of nutrients with the sediment, and influence on water clarity.
6	The macrophyte module should be capable of two-way linkages to both the nutrient water quality module, sediment transport module, and the hydrodynamics and transport model.	Because macrophytes can affect hydrodynamics (e.g., through increased channel roughness) and aquatic system biogeochemistry, linkages between the macrophyte representations and these other modules are necessary.
7	The dimensionality (e.g., 1-D, 2-D, or 3-D) and temporal resolution of the model(s) must be appropriate for answering the management questions.	Some modeling objectives may require 3-D representation in deeper, wider areas to characterize longitudinal, lateral, and vertical variability. 2-D representations (depth averaged) may be useful to characterize wide, shallow areas (e.g., flooded islands) that experience little or no vertical stratification. 1-D representations may be effective in relatively narrow, shallow channels where vertical and lateral gradients are minimal. The majority of modeling objectives will require hourly output (though simulation time step may be considerably shorter) to represent diurnal patterns in temperature, salinity and flow, which are critical inputs to chemical and biological models. However, not all model applications will require hourly resolution. In particular, modeled scenarios for climate change may require computations on a daily or longer interval to simulate extended periods of time in a computationally efficient way.
8	Model(s) should be compatible with other hydrodynamic and water quality models selected by the San Francisco Regional Board for use in Suisun and San Pablo Bays, and with watershed models of river loads to the Delta	To the extent possible, consideration should be given to existing models for the Bay to leverage and provide synergy with ongoing efforts. For hydrodynamics and certain water quality models, integrated models of the Bay-Delta are strongly preferred to capture interactions and fluxes between the Bay and the Delta. At a minimum, models should be compatible in geography, be compatible in the processes modeled, and provide independent hydrodynamics and water quality outputs that can be exported/imported to other, appropriate software platforms.

Background

Management actions in the Delta related to nutrients could cost billions of dollars to implement in the coming decades depending on decisions that will come before the Central Valley Regional Water Quality Control Board (Water Board). The complexity of the Delta ecosystem and the range of questions to be addressed demand that numerical, processed-based water quality modeling (Figure 1) be part of Delta management efforts. In light of this fact, the Water Board convened the Modeling Science Workgroup in 2015, and tasked it with advising on the development and use of water quality models as one component of the Water Board's Nutrient Research Plan. The Charge to the Modeling Science Workgroup was to provide advice to the Water Board on:

- The types of models would be needed to answer the nutrient management questions raised by stakeholders,
- Organizational arrangements to support and maximize the benefits of models, and
- Cost estimates for the modeling task and how such work might be phased over time.

The key findings of the Workgroup for each of these topics are summarized below.

Types of Models Needed

To address the nutrient management questions in the Delta, (Figure 2) modeling will need to include hydrodynamics, nutrient water quality, primary productivity, benthic and pelagic grazing, sediment transport, and macrophyte-related processes. Models should also have the desired characteristics of accessibility, credibility, scalability, and a large enough user community (including institutional support) to ensure continuity through time. Meeting all of these general and technical characteristics (Tables 1 and 2, respectively) may not be possible with any one model; therefore, these characteristics are considered guidelines, not necessarily requirements. Answering the management questions sufficiently is the real performance standard. In certain cases, a simple model may provide sufficient answers when applied and evaluated by skilled analysts.

The existing hydrodynamic and water quality models that have been applied to the Delta were reviewed and evaluated for this report. However, none of the existing models include all the important processes, meet all of the desired model characteristics, or address each of the identified nutrient management questions explicitly.

Organization and Approach

Developing and maintaining the water quality models for the Delta will be a significant undertaking that will cost millions of dollars. Therefore, the modeling approach should be carefully planned to minimize costs and maximize benefits. With this in mind, the Modeling Science Workgroup identified the following recommendations.

•A Successful Modeling Approach Cannot Focus Only On Modeling – Support for Data Management, Data Synthesis and Monitoring Is Equally Important.

•Establish a Good Governance Process – A Steering Committee, such as the committees for the Regional Monitoring Programs, will be needed to guide the process and make decisions regarding best allocation of resources.

•Phased Implementation – Add Nutrients into Existing Models as a First Step. A phased implementation approach should be followed with two general stages: the first stage should be to employ existing models as a platform to develop and test the desired logic and linkages for appropriate water quality processes, and the second stage should be to refine and add complexity to the models, or transferring previously developed logic to more complex models, to improve system representation as needed.

•Select the Right Model for the Job – The Need for Multiple Models. A variety of different types of models will be needed to answer all of the management questions.

•Hold an Annual Delta Nutrient Modeling Workshop: There should be an annual workshop where modelers, scientists, field monitoring staff, and managers come together to share results, confirm conceptual models, and discuss model modifications and applications.

Costs

The cost of the modeling effort is estimated to be $1,675,000 per year in 2015 dollars. The annual cost estimate is similar to, but higher than, past budgets and budget estimates for modeling ($600,000 to $1,500,000). The reason for the increased cost is that the proposed approach includes more than just modeling. It also includes data management, data synthesis, and monitoring. Ideally, total costs will be shared by multiple agencies and funders so that each participant will leverage significant outside resources. The program is expected to last for 10 years, split into two 5-year phases.

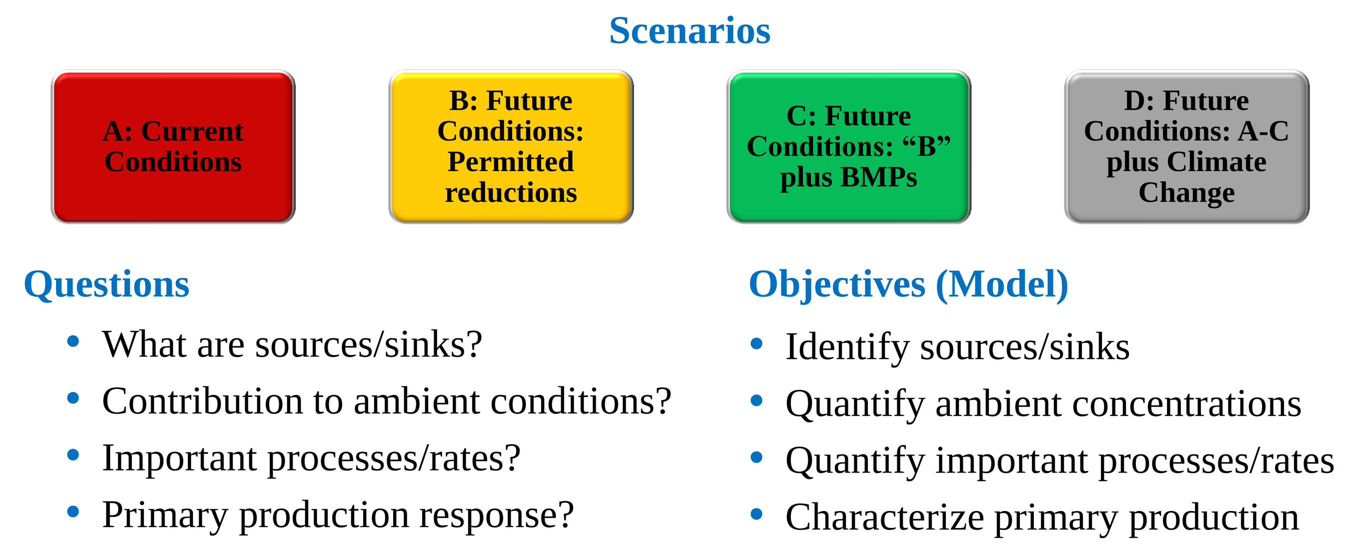


Figure 2.Scenarios, Key Questions, and Objectives of Modeling

Table 3. Potential water quality models or modules (in parentheses) available for selected models

Representation	Parameter	SCHISM: CoSINE - HEM3D[3] (CoSINE)	SCHISM: CoSINE - HEM3D[3] (HEM3D)	SUNTANS	CASCaDE (DELWAQ)	DSM2	RMA2 (RMA11)	EFDC	CE-QUAL-W2	UnTRIM (DELWAQ)	SI-3D (SI2DWQ)
Density	Salinity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Density	Water Temp.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nutrients	Nitrogen[1]	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Nutrients	Phosphorus[1]	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Primary Production	Algae/Chloro-phyll a[1]	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Primary Production	Macrophytes	No	No	No	No	No	No	No	Yes	No	No
Dissolved Oxygen	Dissolved Oxygen	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sediment	Sediments (bed)[2]	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Sediment	Sediment transport	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No

[1] These parameters may be included in the main model or as an add-on or module to the main model. They be represented as a single aggregate term or more specific species may be included.
[2] Representation of sediment in the model or modules is not described in detail.
[3] CoSINE and HEM3D are two different water quality modules that could be used with SCHISM. They each support different parameters.

NOTE: This table summarizes the general capabilities (in a general sense), which water quality parameters are included within each model and/or its add-on/modules. Some models have parameters than can be included, but are not included in the current Bay and Delta applications. Other models list some parameters as under development, but not yet available for the current Bay and Delta applications. This table does not necessarily include all parameters included in the model.

Table 4. Recommended plan for phased implementation of hydrodynamic and water quality mechanistic models

Module	Phase 0 – Existing Models (no cost)	Phase I	Phase II
Hydrodynamics and Transport Model	Hydrological connectivity between river main stems, bypasses, sloughs, barriers (water level, flow velocity, water temperature, salinity) Water withdrawal operations, barriers, and gates (i.e. variable pumping rates)	Continued refinement of spatial domain as needed for the specific application	Continued refinement of spatial domain as needed for the specific application
Nutrient Water Quality	Nutrient water quality models are in the development stage for some Delta models.	Water column nutrients and carbon species (NO3, NH4, DON, PON, PO4, PP, DOC, POC) Phytoplankton growth and decay (total biomass) Dissolved oxygen Light transmission (empirical relationship)	Nutrients, carbon and oxygen exchange with sediments Zooplankton grazing Benthic grazing Impacts of toxic contaminants (e.g., pesticides) on algae Phytoplankton speciation Algal toxins Light transmission calculated from sediment, phytoplankton, carbon models
Sediment Transport	None	Integrated water column and bedded sediment model	Accretion and burial of water quality constituents Erosion and remobilization of water quality constituents
Macrophytes	None	Macrophyte effects on flow using field data on the locations of dense macrophytes	Macrophyte growth and decay through nutrient water quality module

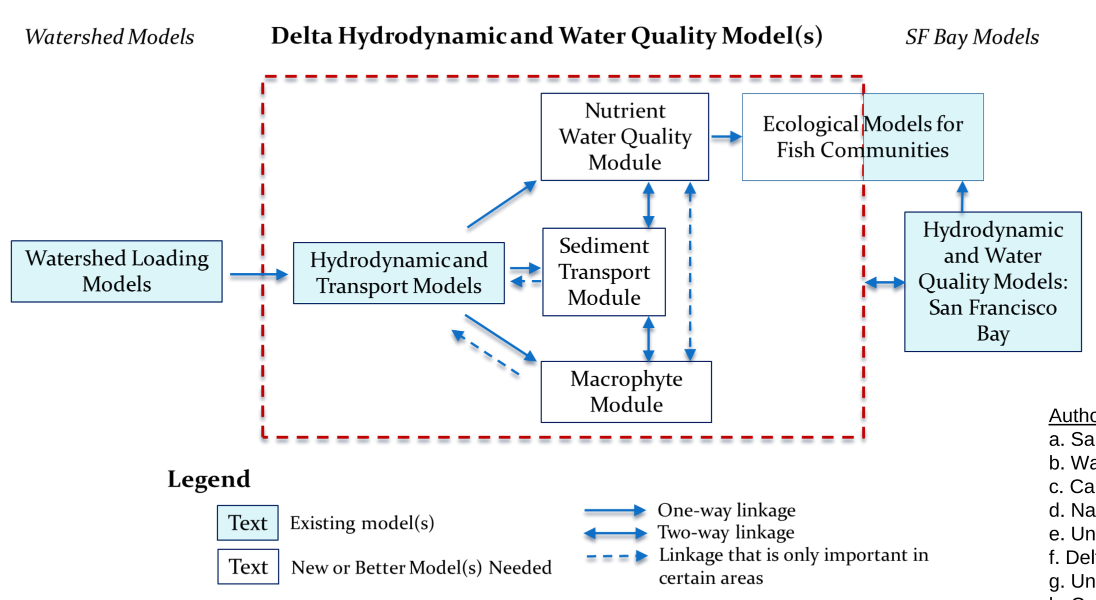


Figure 3. Diagram of the model components for nutrients in the Delta

Authors:
a. San Francisco Estuary Institute (corresponding author:philt@sfei.org)
b. Watercourse Engineering, Inc. (Committee Chair)
c. California Department of Water Resources
d. National Oceanic and Atmospheric Administration
e. United States Geological Survey
f. Delta Stewardship Council
g. University of California Davis
h. Central Valley Regional Water Quality Control Board
i. Resource Management Associates, Inc.
j. Sacramento Regional County Sanitation District