Note: At the March 2018 SC meeting we discussed the potential for an advance in funding being available in FY19, and that a slate of projects related to that funding would also be included in the FY19 Program Plan. During subsequent discussions with the NMS Planning Subcommittee we agreed to bring projects related to the funding advance to the SC at the September 2018 meeting. The Requested Actions below are therefore related primarily to the Core Program and 3 proposed projects.

Item 5 Requested Actions

1. Approve $1,391393 in NMS funding from new revenue and reserves to implement items C.1-C.5, P.1, and P.3 in the FY19 Program Plan.

2. Approve $128,675 to support P.2

The project descriptions were developed to be relatively short text and with more of the technical detail included in the figures and figure captions. The figures and captions are intended to provide (hopefully) interesting context -- But please don't let those get you bogged down. The main text provides the bulk of the information on next year's plan.

FY2019 NMS Budget - Proposed

Anticipated Revenue

	Source	
R.1	Nutrient Permit FY2019	880,000
R.2	RMP CY2019	400,000
R.3	Nutrient Permit Supplement 2019	200,000
	Total Revenue	**1,480,000**

Expenses

	1 **Program**	**New Funds**
	Monitoring	
C.1	Ship-based channel monitoring: sampling, analysis	173,511
C.2	Mooring Network: data analysis, interpretation, maintenance	360,810
	Modeling	
C.3	Biogeochemical model development and application	310,629
	Program coordination	
C.4	Science Program Coordination	289,285
C.5	Program management	107,221
	Program subtotal	*1,241,456*
	2 **Projects**	
P.1	Algal toxins in bivalves: sampling, toxin measurements	101,937
P.2	Nutrient Flux to the coastal ocean: transport, transformations, and effects	128,675
P.3	Chlorophyll intercalibration study (jointly with DRMP)	48,000
	Project subtotal	*278,612*
	Total	**1,520,068**
	Surplus or (Deficit)	(40,068)
	***Starting Reserves**	54,000
	Transfer from/to Reserves	(40,068)
	Ending Reserves	13,932

*Reserve value is an estimate based on projected final spending on FY2018 activities (estimated based on May 31 totals) . The estimate is conservative, and will be finalized and revised after FY2018 books close

C.1 Ship-based sampling and sample analysis
FY19 Estimated NMS Cost = $180,042
Collaborators: USGS, UCSC, SFEI

Ship-based samples will be collected and analyzed for multiple nutrient-related parameters. Discrete samples and in-situ sensor-based measurements will be collected during USGS cruises aboard the R/V Peterson on ~12 full-bay cruises and ~12 South Bay cruises (Figure 1), with SFEI staff participating as a field technician(s) during cruises. The overall program is jointly funded by USGS, the RMP, and the NMS, with field program design a continuation of the USGS' long-term research program in San Francisco bay, and the NMS funds supporting several nutrient-specific measurements (Table 1). Data from the ship-based program play critical roles in nearly all of NMS' activities, including condition assessment, hydrodynamic and biogeochemical model calibration and validation (Figure 2), and improved understanding of nutrient behavior and nutrient-related effects within SFB.
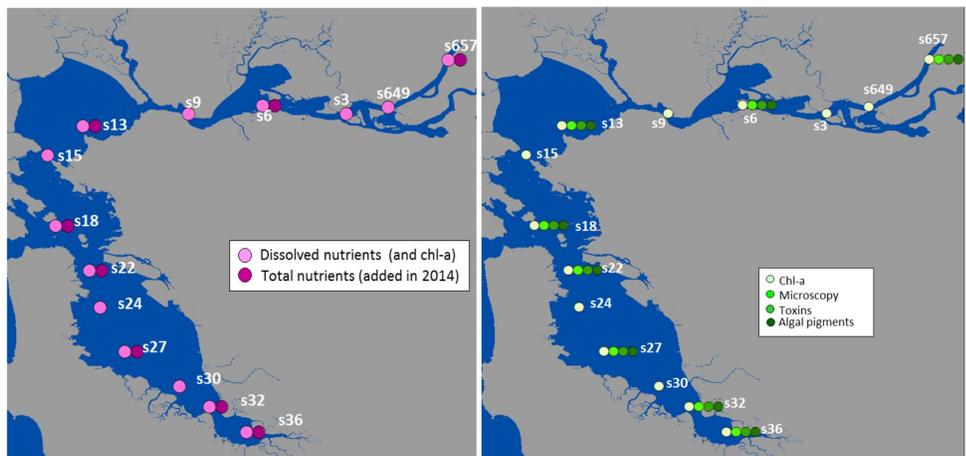

Figure 1 Station locations for discrete sample collection for nutrient-related parameters during biweekly and monthly USGS cruises

Table 1 Overall Ship-Based Program Funding Distribution: USGS, NMS

NMS	USGS core program*
- Nutrient analyses (USGS national lab)	- Collection of samples for chlorophyll and ancillary data (e.g., suspended particulate matter, dissolved oxygen, salinity)
- Analysis of integrated toxin samples (SPATT), discrete toxin samples, and algal pigments (at UCSC)	- Vertical profiles for multiple parameters
- Basic data QA/QC and basic reporting	- Underway flowthrough data collection (salinity, T, chl-a fluorescence, turbidity/optical backscatter)
- Additional staff support on cruises to support the collection of NMS-related samples: inorganic nutrients, total nutrients, microscopy, algal pigments, and particulate algal toxins; spatially integrated toxin samples (SPATT)	- Program management, scientific oversight
	- Data management for USGS parameters plus inorganic nutrients
	- Ship maintenance, fuel, crew, etc.

*USGS core program funding includes USGS in-kind funding and funding from the Regional Monitoring Program
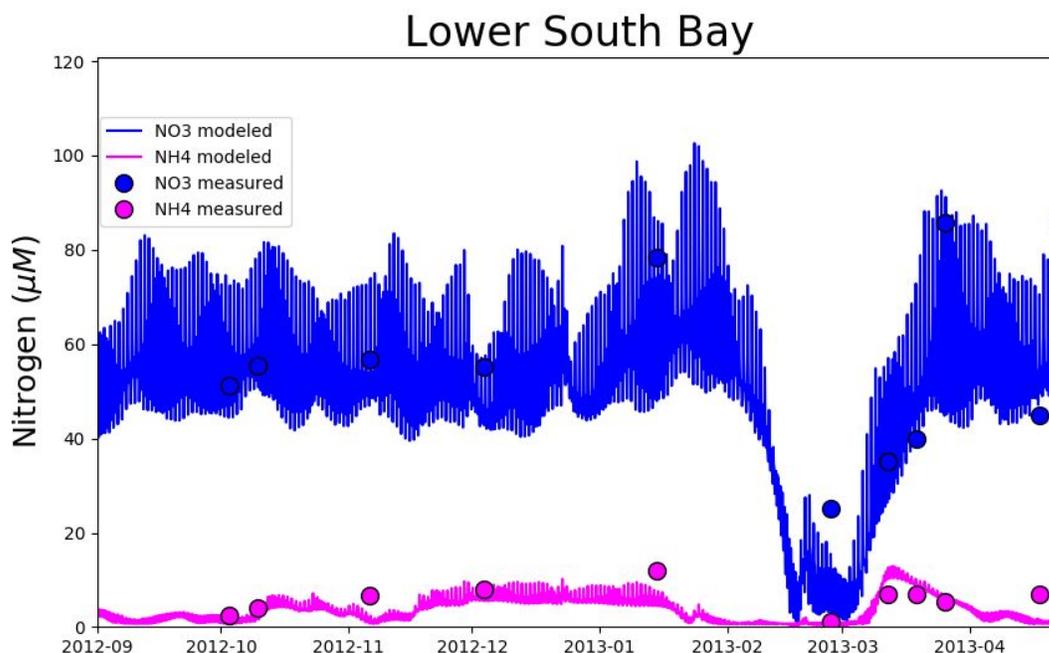
Lower South Bay

Figure 2 Measured and modeled concentrations of nitrate (NO3) and ammonium (NH4) in Lower South Bay (LSB), September 2012-April 2013. Measured data is from samples collected during USGS cruises in Lower South Bay (combining s34 and s36). Modeled values are hourly data, predicted using the current version of the NMS' coupled hydrodynamic/biogeochemical model (see C.3). The modeled concentrations are predictions for a fixed location in LSB (s36, Figure 1), and the large, high-frequency variations result from a combination of LSB's strong tides and spatial heterogeneity in water quality. Model output and observations suggest that the substantial DIN decrease beginning mid-February resulted from a major phytoplankton bloom (see Figure X)

Deliverables

Nutrient and chl-a data will be made publicly available through USGS's website. Datasets for toxins, phytoplankton microscopy, and pigments will also be made publicly available through the NMS. Results will be summarized in the NMS Annual Report (funded through other projects). Similar to past years, data will be used within numerous other NMS activities(e.g., model calibration [see C.3], condition assessment, assessment framework development).

Budget Justification

Over the course of the year, 300 station-date samples will be analyzed for a suite of nutrients (ammonium, nitrate + nitrite, reactive phosphorus, dissolved silicate; total N and total P will be measured at 75% of the sites) at the USGS national laboratory at a total cost of $40,000. A portion of FY19 nutrient analyses were covered by the FY18 NMS budget, leading to lower nutrient analysis costs in FY19 ($24,000). Phytoplankton taxonomy will be performed by microscopy on ~250 samples for phytoplankton community composition (225 grab samples, 25 net tows) and biovolume ($45k); additional phytoplankton or harmful-algae (HA) related measurements (molecular/sequencing techniques, phycotoxins, algal pigments, etc.; total of $50k) for cross-validation with microscopy data and imaging flow cytobot output, and to inform monitoring program refinement and to support investigation of HA-related mechanistic science and management questions. The SFEI staff labor budget covers the following effort (0.3 FTE distributed across two staff; $43,542): participating as field technicians on all USGS cruises; and

overall project management, including coordinating laboratory analyses (with UCSC and other non-USGS labs), cruise and sample collection planning, and data management.

C.2 Moored Sensor High-Frequency Observation Network: data analysis, interpretation, and maintenance
FY19 Estimated NMS Cost = $360,810
Collaborators: SFEI, UC Berkeley (Stacey), USGS-Sacramento (Bergamaschi, Downing, et al)

San Francisco Bay is a dynamic and heterogeneous system. Data collected during USGS cruises over the past 40 years (see C.1) have played critically-important roles in shaping both our current understanding of the major factors regulating water quality in SFB, and in documenting water quality changes over that time. We also know, from other research in SFB, including along South Bay's broad shoals, that important water quality indicators - e.g., salinity, temperature, chl-a, nutrients, dissolved oxygen, suspended sediments, etc. - have strong spatial gradients (Cloern et al., 1985; Huzzey et al., 1990; Lucas et al., 2008; Thompson et al., 2008), and can change substantially over fairly short time scales (e.g., hours to days), shaped by tidal forcings, wind, day-night variations in biological cycles, and other factors.

Therefore, in order to collect the necessary data to inform nutrient management decisions, the NMS prioritized developing an moored sensor network for high-frequency *in situ* measurements, focused initially in South Bay and Lower South Bay (Figure 3). Analysis of limited existing data for sloughs and creeks, along with early mooring network data, indicated that DO levels in sloughs frequently fell below the Bay's 5 mg/L DO standard (SFEI 2015), and further highlighted the complex spatial and temporal variations in key water quality parameters (Figure 4). Two key aims for the mooring network were to allow for more comprehensive condition assessment, and to foster data collection that will allow us to better characterize and quantify ecosystem response to SFB's high nutrient loads, including by aiding the calibration of numerical models (SFEI 2014). This project description briefly highlights major moored-sensor activities during FY18, and describes the major focus of proposed work in FY19.
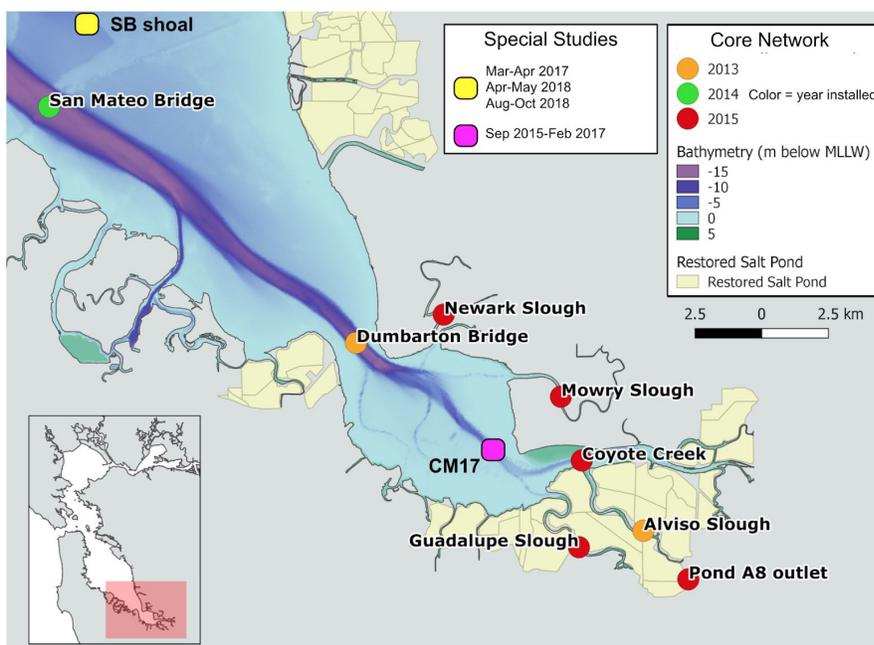

Figure 3 NMS Moored Sensor Network in Lower South Bay and South Bay. The network has been in its current configuration since May 2015. Sensors at each site take readings every 15 minutes for multiple parameters (salinity, temperature, depth, dissolved oxygen, turbidity, chlorophyll-a, and fluorescent dissolved organic matter (fDOM)). Sites are visited every ~3 weeks for servicing, calibration, and downloading data.
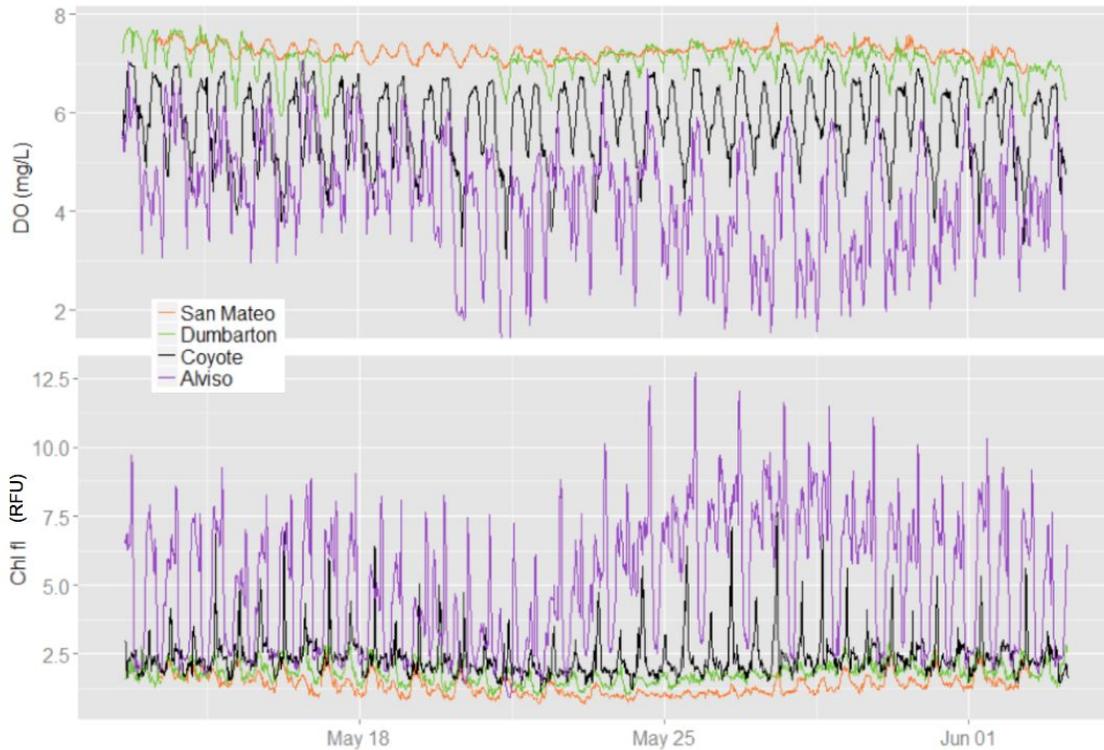
Figure 3 Dissolved oxygen (mg/L) and chl-a fluorescence (relative fluorescence units, RFU) along a northwest-southeast transect from the San Mateo Bridge to Alviso Slough, early-May to mid-June 2015.

Major FY18 activities

- Sensor network maintenance (maintenance at 3 week intervals, 2 field days per interval + 1-2 days field set-up / break-down).
- Developed codes for automated data cleaning, with a primary focus on DO%sat, DO_mgL, T, and S. Reprocessed all data since 2013, documented, and data is now publicly available. Viewable at www.enviz.org, or obtained by request from SFEI-NMS staff. The QA/QC protocols are described within an upcoming moored sensor program update (draft July 2018)
- Applied DO data from Lower South Bay stations within a DO-related condition assessment project (see Figure 4; draft technical report, June 2018)
- Mechanistic interpretation of DO and other data for elucidating mechanisms contributing to DO decreases and for quantifying transformation rates. (see Figure 5; progress report or draft technical report, Q1 2018)
- South Bay shoal deployment (4/3/2018-5/23/2018; same parameters as other sites, plus *in situ* nitrate sensor, additional chl-a fluorometer, and acoustic velocity measurements). Data is still being processed, but early indications are that 2-3 modest to sizable phytoplankton blooms were captured (Figure 6).
- Field-testing new instrument package and biofouling controls to maximize data quality during deployments. For the program's first several years the NMS relied on YSI EXO instruments. After assessing other suitable field instruments, we piloted a comparably-priced instrument from SeaBird, and now have two instruments in service.

As part of field-testing, we have conducted multiple side-by-side deployments with the YSI EXO. Results from a recent deployment are shown in Figure 7.

● Application of high frequency mooring data for model calibration (see Figures 8-10). As the NMS hydrodynamic and biogeochemical models undergo further refinements, we have begun relying heavily on high frequency data from the NMS network and other research groups. Salinity and elevation data have proven valuable for calibrating hydrodynamic model runs for Core Modeling work and for LSB model development. We have also begin using long-term turbidity records from high-frequency sensors from around SFB to develop time-space varying turbidity and light attenuation estimates.

Work in FY19 will focus on the following:

1. Continued field maintenance of mooring network, as described above, and continued refinement of automated data cleaning protocols, moving attention to chl-a.

2. Data synthesis, analysis and interpretation, including one or more of the following:
    a. Exploring high-frequency chl-a data and estimating gross primary production rates using sensor data, including comparisons between shoal and channel observations.
    b. Assessing the importance of vertical variations in DO concentration, including influence on to mechanistic interpretations.
    c. Continued work on sediment and light field analyses, and wrap up version of these analyses.
    d. Finalize technical report DO mechanistic interpretations from mooring data.

3. Critically evaluating the current mooring network structure, and, if warranted, moving resources to other locations in SFB, as proposed in the NMS Observation Program description (Figure 11, SFEI 2016).

4. Related to refining mooring program effort, two pilot efforts will move forward in FY2018
    a. Deploy and interpret data from the South Bay shoal mooring again in Summer/Fall 2018.
    b. Work with USGS-Sac collaborators to deploy additional sensors on existing mooring infrastructure in Suisun Bay. USGS-Sac maintains 3 moorings in Suisun Bay and the western Delta. Extensive field work is planned for late summer / early-fall related to changes in Suisun Marsh gate operations. NMS funds will be pooled with resources from other agencies.
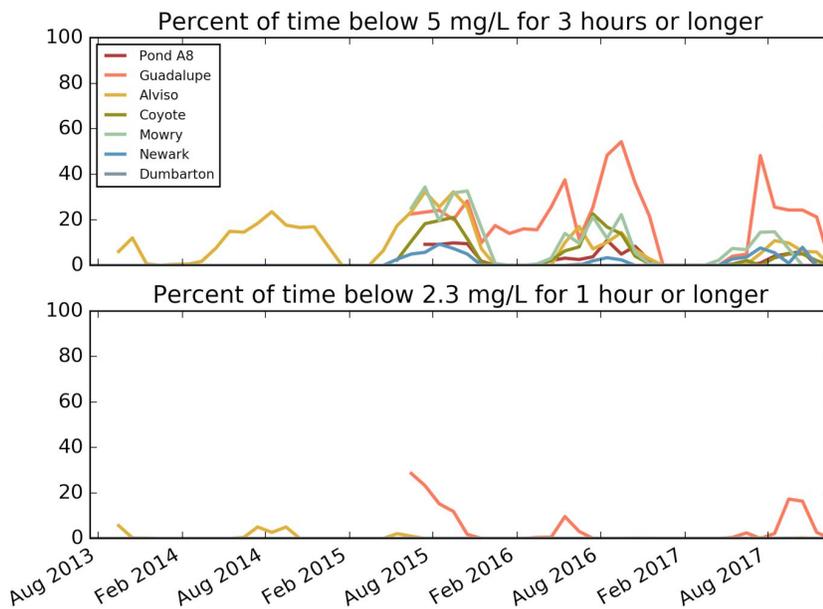
Figure 4 Percent of time each month in which DO is 5 mg L^{-1} or below for 3 hr or longer (top) and 2.3 mg L^{-1} or below for 1 hr or longer (bottom). Fish and benthos can be affected by both the DO deficit and a deficit's duration. Since low DO often occurred within fairly narrow windows in SFB's dynamic sloughs, considering both deficit and duration offers a potential path toward characterizing severity.

Figure 5 Net DO consumption rate (g O$_2$ m^{-2} d^{-1}) in Alviso Slough, calculated using the tidal symmetry method, an ecosystem-scale approach that is under development through this project. In the top plot, light blue circles are DO consumption estimates for individual tidal cycles, black dots are monthly median values, and vertical gray bars are monthly interquartile range. Values in the bottom four plots are daily averaged values.

This version of the net DO consumption rate does not include terms such as reaeration or DO production during primary production. In that sense it can be thought of as a conservative estimate of oxygen demand (benthic + water column). Loss rates in Alviso Slough were consistently the highest (most negative) of all sites. In several instances, rates were most negative in the days-weeks after large pulses of phytoplankton biomass (as measured by chl-a) entered the slough due to exchange with salt ponds.
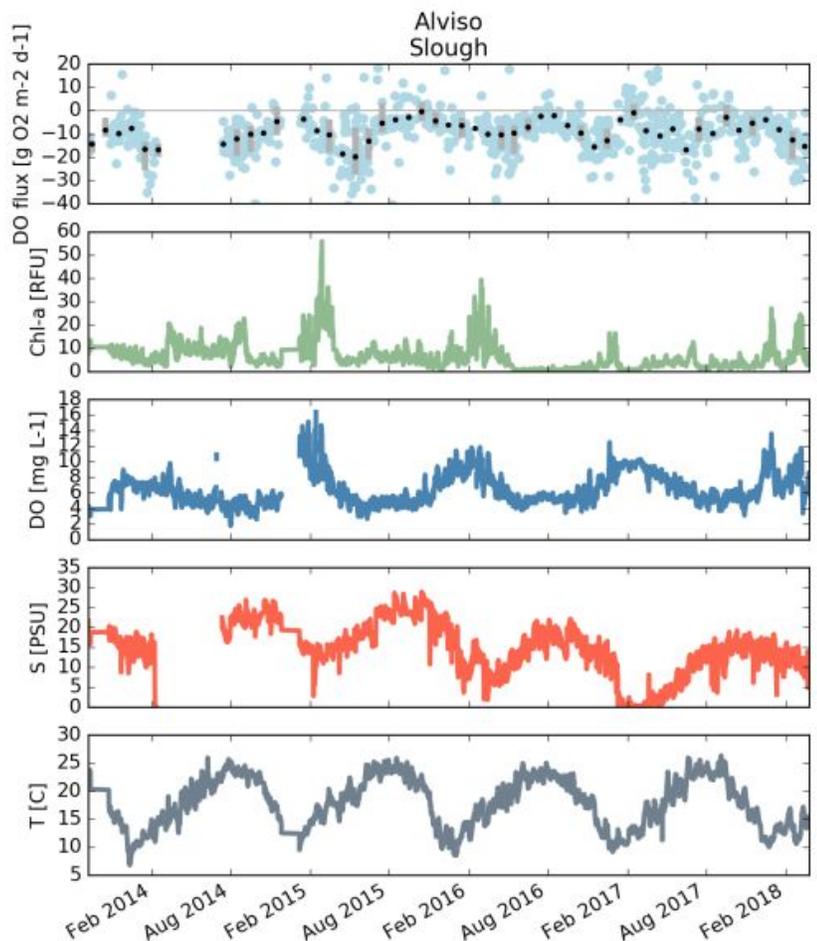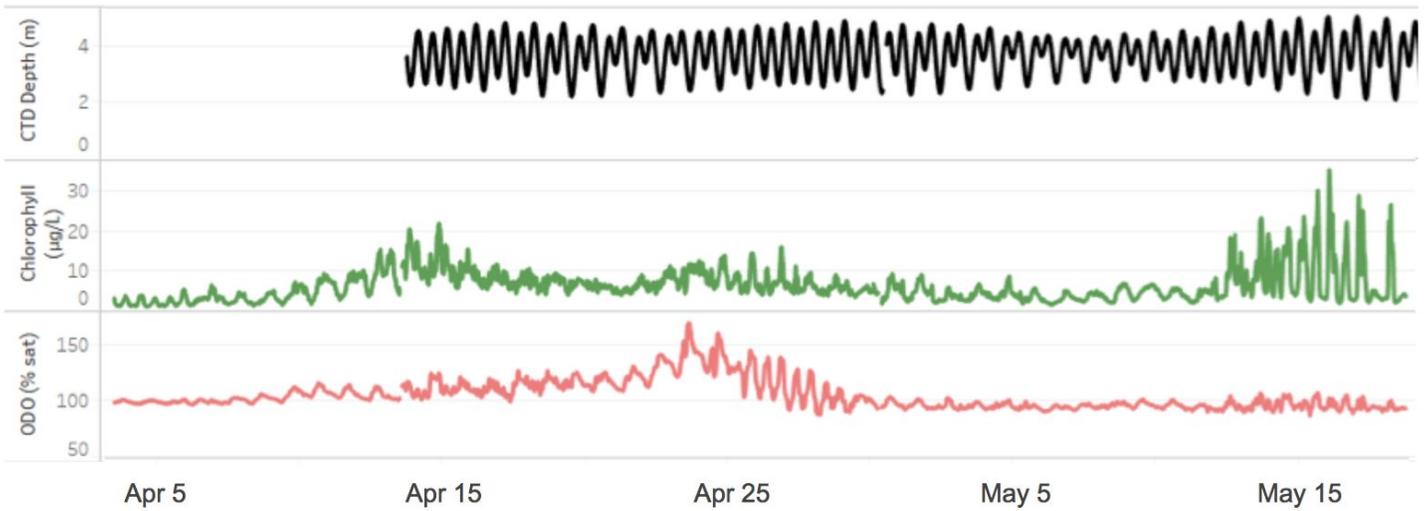
Figure 6 South Bay shoal mooring deployment, Spring 2018: depth (top), chl-a (middle), DO saturation (bottom). Elevated chl-a fluorescence along with supersaturated DO (>100%) are consistent with substantial phytoplankton production.
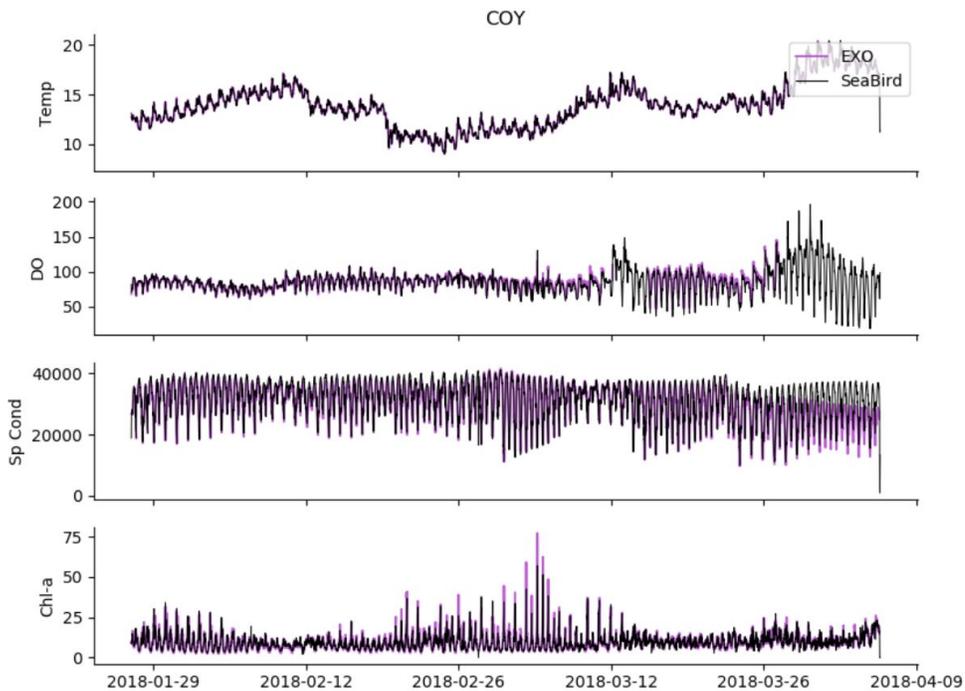

Figure 7 Data comparison from side-by-side deployments of EXO and SeaBird sensor packages. Note SpCond deviations around mid-March, likely due to fouling of EXO SpCond sensor. Although the SeaBird instrument has other advantages, its longer SpCond (i.e., salinity) field life is one major improvement.
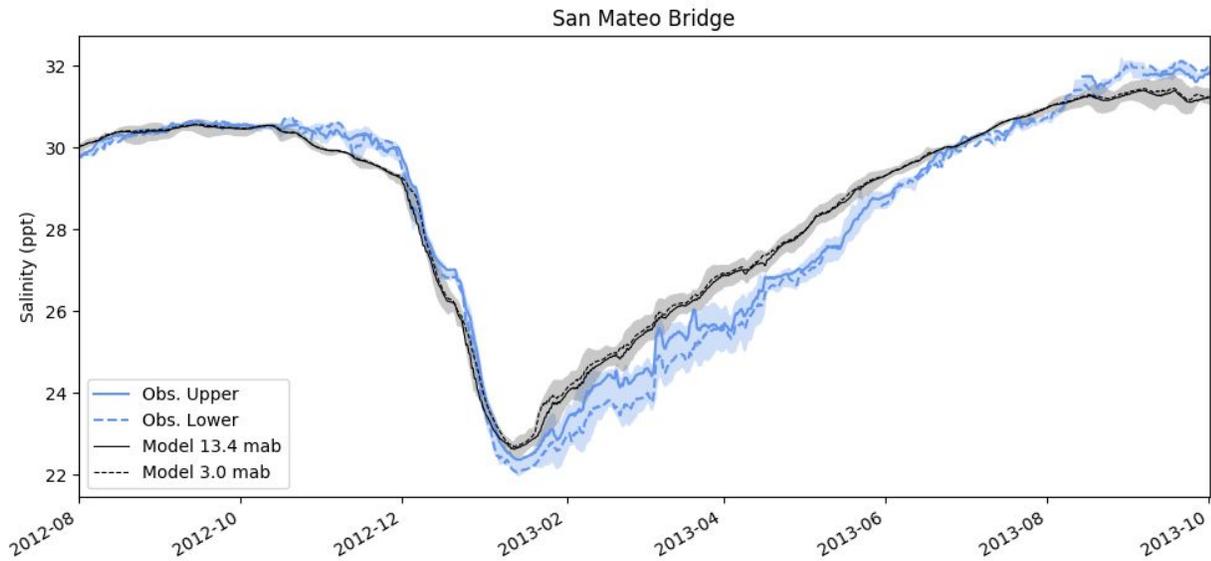
Figure 8. Application of high-frequency salinity data from moorings for updated NMS hydrodynamic runs completed in FY18. Blue and black curves depict daily average observed and modeled salinities, respectively, at two vertical locations in the water column at San Mateo Bridge (13.4 meters above bottom, and 3 meters above bottom); shaded areas show daily ranges of 15-min data. The model captures the major salinity patterns at San Mateo Bridge. However, the model over-represents salinity during late-winter and early-Spring, perhaps due to underestimating freshwater inputs to South Bay from local creeks. In additional, alto the model predicts small but extended periods of vertical salinity differences (i.e., stratification), the modeled salinity differences are smaller than those observed.
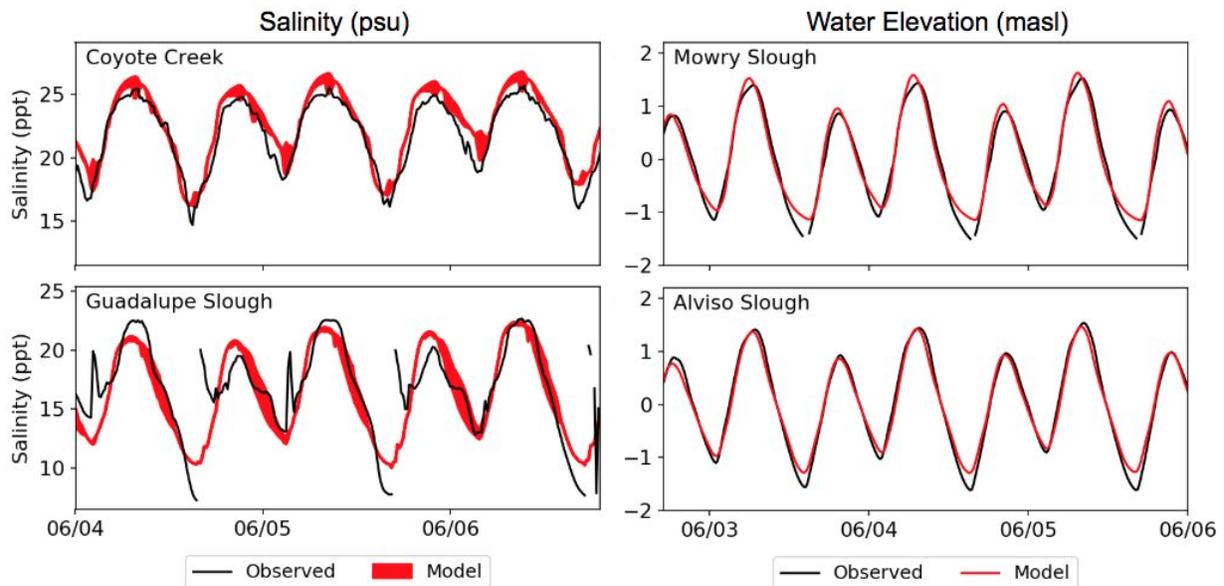

Figure 9 Mooring data (depth, salinity) is playing an important role in calibrating the NMS Lower South Bay hydrodynamic model, which was a major focus of the NMS modeling team during FY18. After further hydrodynamic refinements in the first half of FY19, it will be possible to begin running biogeochemical simulations for examining factors regulating DO and other parameters.

Figure 10 Left: Using high-frequency turbidity data at multiple stations throughout SFB to generate time- and space-varying estimates of light attenuation. Data are available for ~20 stations (subset shown to the left), with overall data availability extending from 1992-present. Although some sites have very little data (e.g., Golden Gate, <1 yr), most of the sites have >5 years of data and several have records extending 20+ years. In many cases, pairwise comparisons indicate that turbidity signals (daily-average) at neighboring stations are highly correlated (e.g., CM17:Dumbarton, r=0.78; Dumbarton:San Mateo, r=0.57; Mallard:Benicia, r=0.69; Point San Pablo:Benicia,r=0.77; Point_San_Pablo:Richmond_Bridge, r=0.63).

First, we developed a set of statistical models, using data from neighboring stations, to fill temporal data gaps at each stations, yielding a daily-average turbidity values for each station from 2000-2016. Current work is focused on spatially-interpolating these values to each grid cell of the NMS biogeochemical model. That dataset will be used for sensitivity analysis modeling work in FY19. It will also be used as a training or calibration dataset for a sediment transport model that is under development, through collaborations with Deltares, UNESCO-IHE, and USGS.

Below: Turbidity at San Mateo and Dumbarton Bridges, Jan 30 - Feb 15 2017. Curves depict 15 min data after applying a basic moving average smoother (75-min window), and illustrate the potential promise that this spatial-interpolation approach may hold.
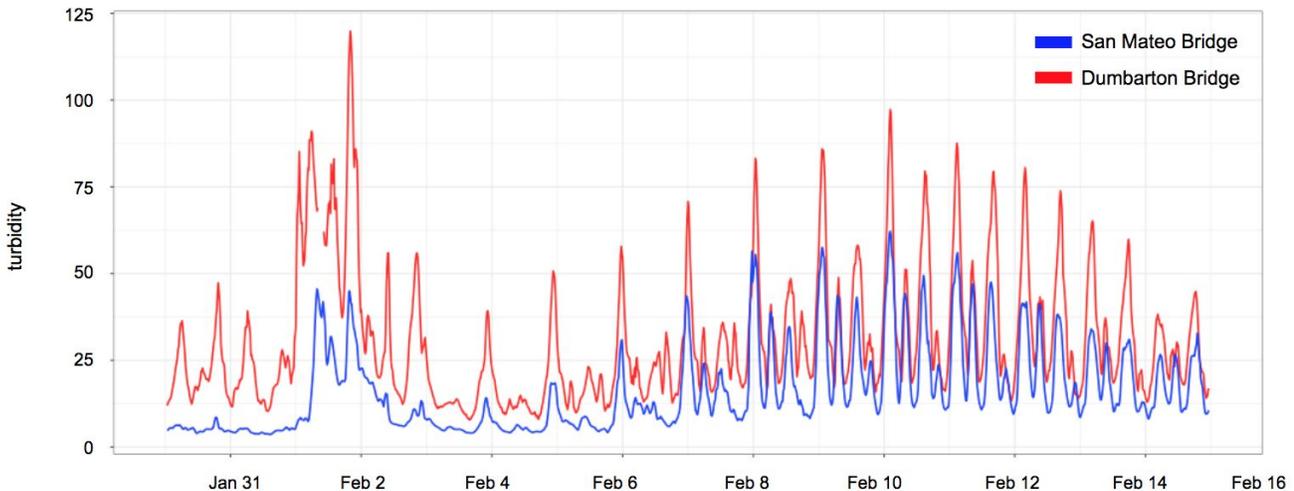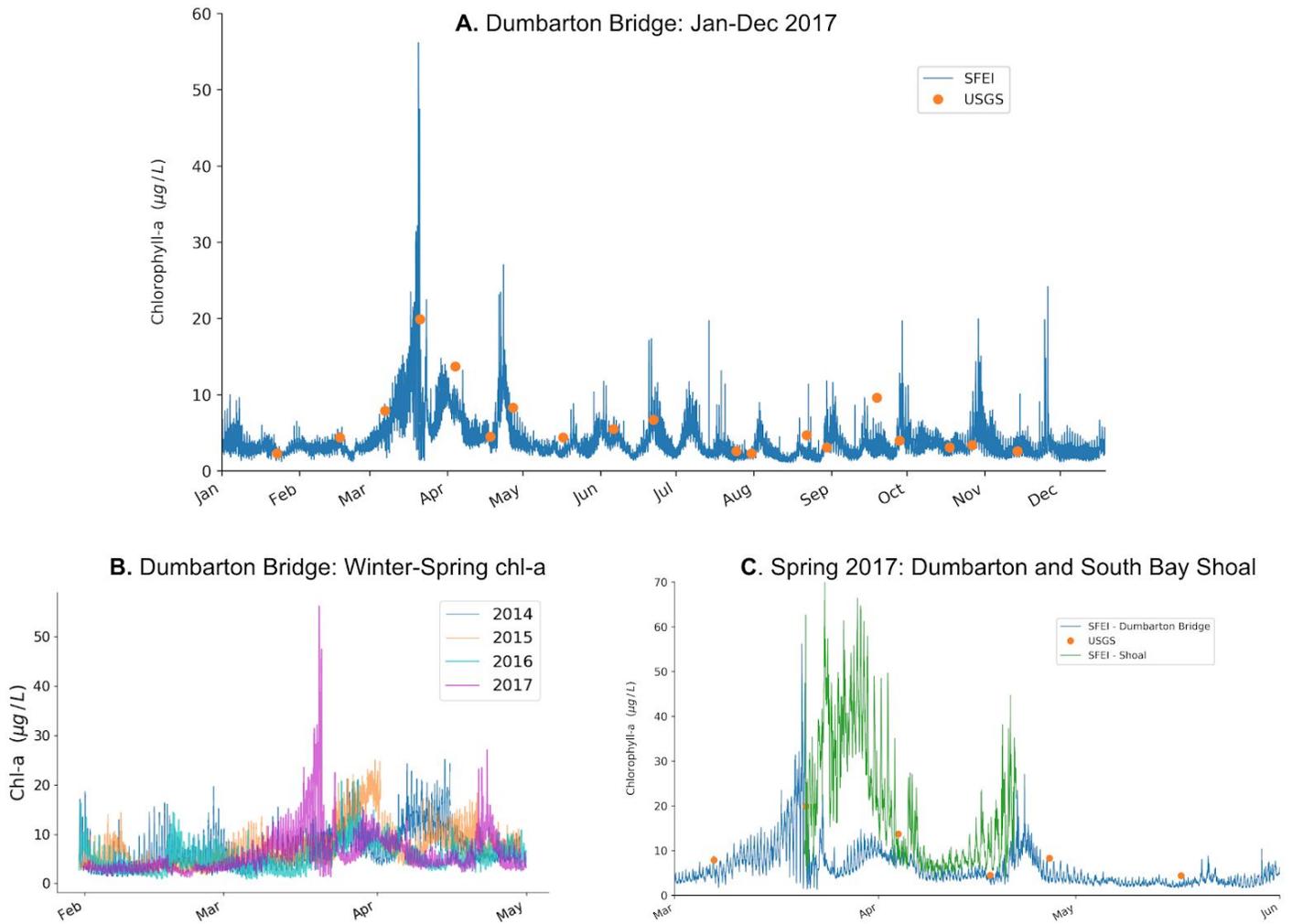
Figure 11 High frequency (15-min) chl-a measurements in South Bay. **A**. Chl-a measured at the Dumbarton Bridge during USGS biweekly cruises and with NMS mooring. Despite the offset in sampling location between USGS discrete samples and mooring location, and the uncertainties or artifacts often associated with in-vivo chl-a measurements values agree reasonably well. The high-frequency data exhibits considerable temporal variability in phytoplankton biomass that recurs at multiple time-scales: sub-daily tides (hours); spring-neap (~biweekly variations in the max-min envelope) and seasonal (spring bloom). **B.** Interannual variations in spring chl-a signal at Dumbarton Bridge. Strong variations at multiple time-scales happen in all years. However, the timing and amplitudes of peaks are quite different. While the multiple modes of temporal variability illustrate the complex balance of processes that regulate phytoplankton production, our goal is to take advantage of these strong patterns to identify causal factors, including identifying locations where blooms originate. We will approach this through analysis of the observational data and also through exploring the output of biogeochemical models that have been calibrated/validated using these data. **C.** Differences in magnitude and phasing of blooms in South Bay's deep channel (Dumbarton Bridge) and shoal. Several studies have documented differences in bloom dynamics between South Bay's channel (Cloern et al. 2005; Lucas et al., 2008; Thompson et al., 2008). Through analysis of observational data and model output, we aim to further characterize the factors regulating production and quantitatively explore spatial variations in primary productivity, biomass sources and transport (e.g., What causes the biweekly-to-monthly chl-a peaks at Dumbarton Bridge (**A**): production in the channel; biomass transport from production zones along the shoals; biomass transported from salt ponds?). We contend that calibrating biogeochemical models using this type of data will improve mechanistic accuracy of models, decreased uncertainty, and informed quantitative estimates of model uncertainty, all of which will enhance the NMS' ability to address management questions.
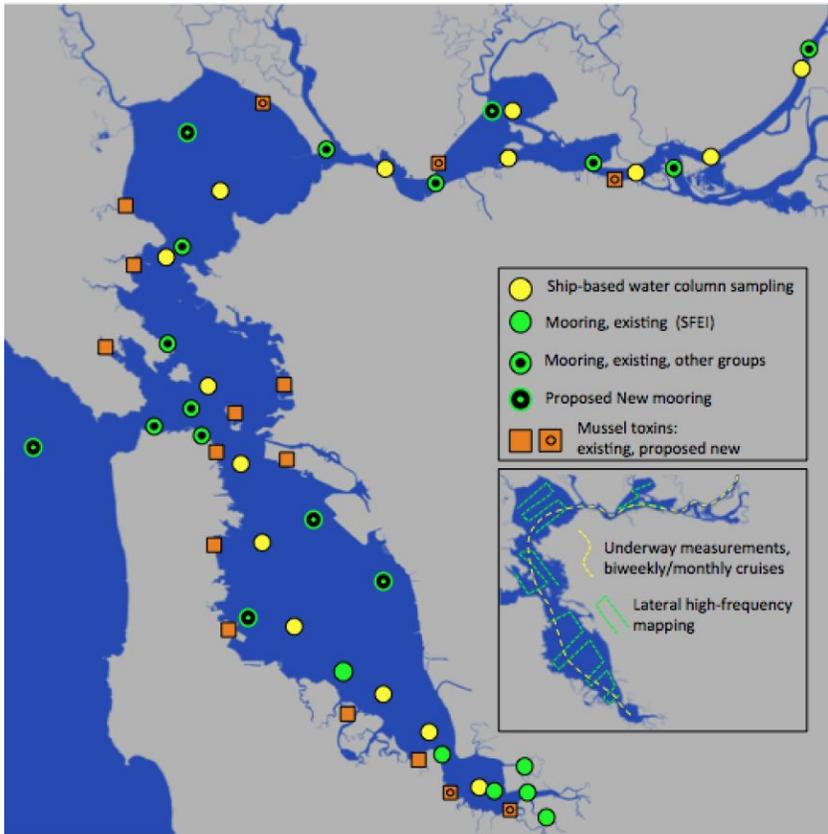
Figure 11. Proposed future NMS Observation Network v1.0 (NMSOPv1.0), including moored sensor network collecting high-frequency data from *in situ* measurements (see SFEI 2016). Details of the mooring network -- including exact locations and analytes -- are proposed as a strawman design, with the expectation that they will be tested and modified, working toward a robust and sustainable program design.

FY19 Deliverables:

1. Refined / cleaned dataset for additional year of data, and application of enhanced QAQC protocols to additional parameters (e.g., chl-a).

2. Several technical reports or progress reports, developed using C2 funding (FY19 or past years), or based on analysis using C2 data with analysis and write-up funded by other NMS projects:

    a. Moored sensor program summary
        [Draft and Final: Q1 FY19]

    b. DO-related habitat characterization report (DO condition, fish abundance).
        [Draft: Q1 FY19; Final: Q2 FY19]

    c. Mechanistic interpretations of factors contributing to periodically low DO at slough sites and physical and biogeochemical factors.
        [Progress report or Draft, Q1; Final, Q4 FY19]

    d. Improved understanding of transport/lateral exchange in LSB using salinity and velocity data (in collaboration with UC Berkeley)
        [Draft technical report/manuscript, Q2 FY19]

    e. Turbidity, SSC, and light attenuation: evaluating the fe
        [Progress report or draft technical report, Q3 FY19]

    f. Chl-a sensor data: data synthesis, uncertainty analysis, and interpretations related to biomass sources, primary production rates, including summary of 2017 and 2018 results from the South Bay shoal mooring.
        [Progress report or draft technical report, Q4 FY19]

3. Phase II of Mooring Program: proposed structure for next phase of mooring work (stations, analytes), and initials steps implementing that new structure (within time/budget constraints)
4. Summary of major observations in the NMS FY19 Annual Report (e.g., NMS FY16 Annual Report)

Budget Justification: Partial support for 3 staff for field work, data management, data analysis and interpretation, and report preparation (0.75 FTE, 0.5 FTE, and 0.2 FTE for junior, masters, and PhD-level scientists; $197,000); field support (including boat, fuel, and field technicians; $70,000); equipment/supplies ($30,000); support for USGS-Sac field campaigns and analysis in Suisun Bay ($20,000), and analysis of discrete samples for instrument calibration ($5,000)

C.3 Core Modeling Program: development and application
FY18 Estimated NMS Cost = $310,629
Collaborators: SFEI, Deltares, USGS, UC Berkeley

The overarching goal of the NMS Modeling Program is to develop and apply numerical models to inform major nutrient management decisions for San Francisco Bay (Table 1). In a system as

Table 1 Modeling-Related Management Questions
Source apportionment: What sources contribute nutrients to habitats throughout SFB? source = f(space, season, year)
How do habitat- or subembayment-specific features and physical/biological forcings influence or regulate nutrient-related responses? • Responses: chl, DO, HABs • Forcings: loads, tides, wind, suspended sediments, salinity/stratification (Qfresh), upwelling, invasive species (clams), etc. • Future Forcings → Future Responses
Dose:Response -- How will regions of San Francisco Bay respond to incremental increases/decreases in nutrient inputs?
If nutrient reductions are needed, how effective will different potential management management alternatives be, and what are the most effective and cost-efficient alternative?

complex as San Francisco Bay, numerical models are essential tools for quantitatively exploring the interactions between the numerous physical, biological, and chemical processes that influence ecosystem response to anthropogenic nutrients, and for predicting condition under various management alternatives. Work has been underway within the NMS Modeling Program for ~3 years, during which time we have followed a tiered approach (Figure 12): developing strong foundations in hydrodynamic and biogeochemical modeling; testing and refining those foundational tools through interim modeling studies; and building toward applying the models to explore scenarios.
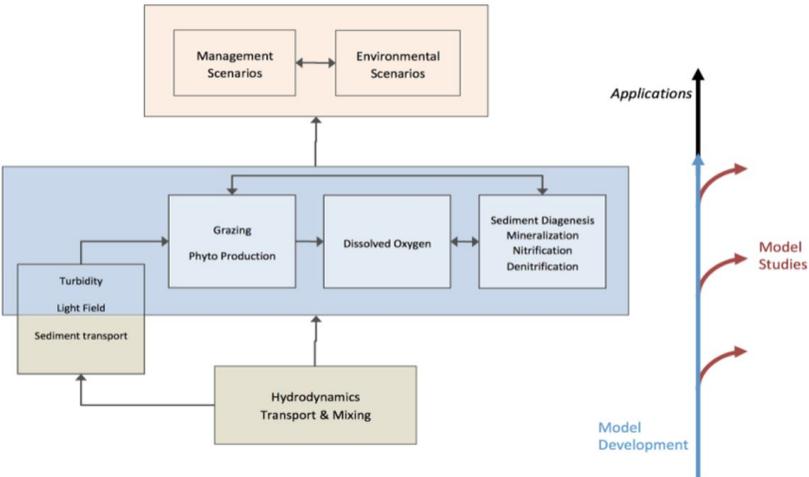

Figure 12 NMS Modeling Program Tiered approach to model development and application.
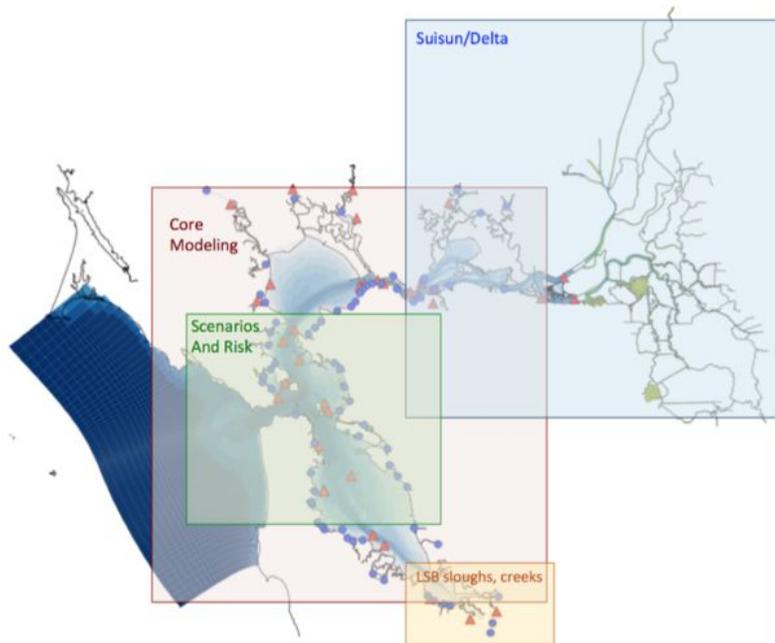
Figure 13 Overview of major NMS modeling program activities. This project description focuses primarily on Core Modeling

Over the past year, modeling work has moved forward in four major project areas (Figure 13). The project areas focus on region- or topic-specific issues, but use the same or complementary models and inputs. This section focuses primarily on the Core Modeling Program.

Major Core Modeling Activities (FY17-18) and Status

Hydrodynamics: Fully migrated from the interim hydrodynamic model (SUNTANS) to Delft Flexible Mesh (DFM), which will be the workhorse going forward. Multiple modeling efforts in the region are using DFM platform, which is freely available from Deltares and open source (or will be soon), and will allow for more opportunities for collaboration and shared resources in the future.

- Developed a refined grid (Figure 14), building on past grids from the USGS-Deltares grid. (Collaborator: RMA)
- Freshwater Inputs
  - Updated a hydrological model for the Bay Area, using new land-use and precipitation data, and generated daily streamflow predictions for 44 river and storm freshwater inputs for 2000-2016.
  - Generated daily freshwater flow rate and nutrient load estimates for all WWTPs and refineries for 2000-2016, including seasonal and interannual variability where applicable, by building upon other efforts (SFEI 2014, HDR 2018).
- Calibrated the model for WY2013. In addition to USGS cruise and other data for calibration, WY2013 is a particularly data-rich because of an observational dataset generated by a NOAA study in which instruments were deployed throughout SFB for measuring water velocities (ADCP; see bottom of Figure 14). In addition to SFEI staff effort, two masters students from Technical University Delft (Netherlands) contributed to grid development and model calibration, through a collaborator at Deltares
- Modeled and observed data were compared in a comprehensive model validation effort (water elevation, velocity, salinity from USGS cruises, high-frequency salinity measurements at mooring stations)
- Effluent plumes from each WWTP were simulated using conservative tracers, both for testing model behavior and to illustrate future approaches for exploring source attribution (recognizing that source fingerprints will be substantially different for reactive transport).
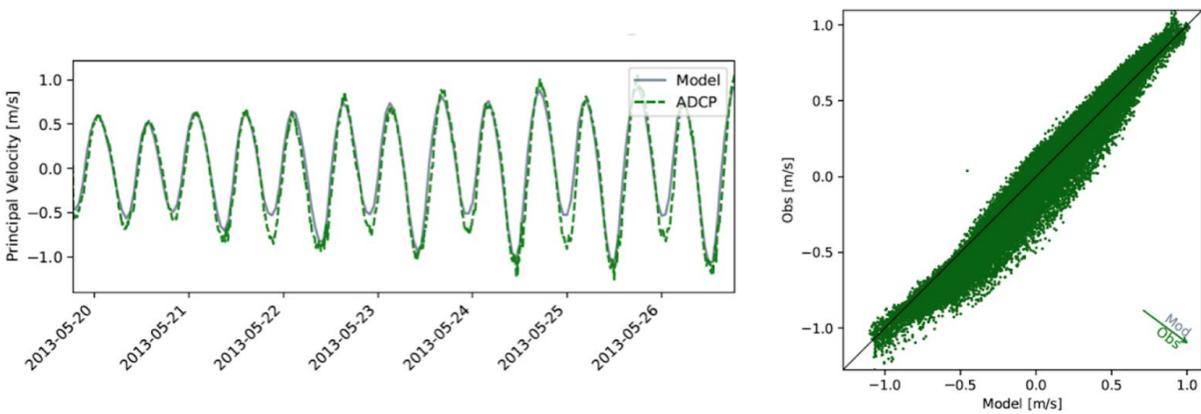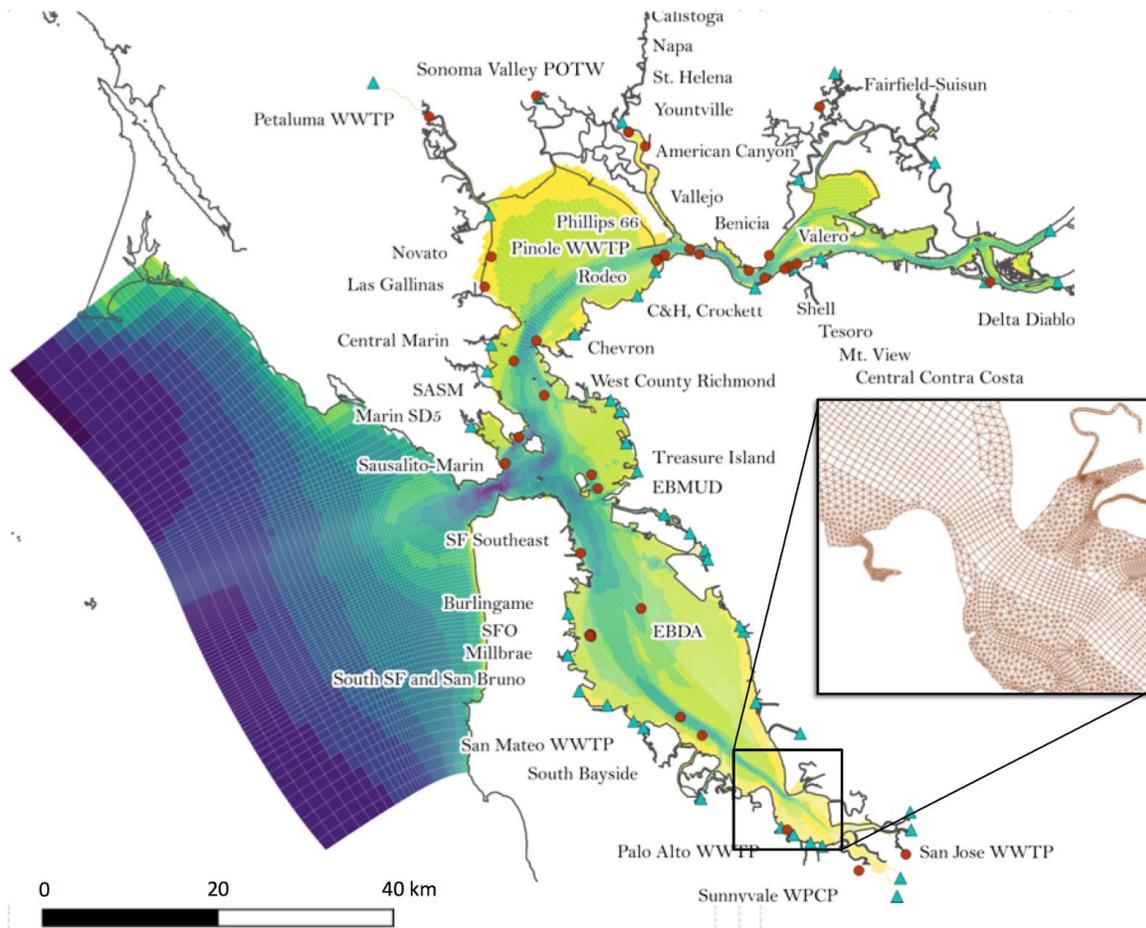
Figure 14 NMS Core Model grid. Red circles: WWTP outfalls; Blue triangles: river/creek inputs. Bottom: (left) Comparison of modeled and measured (ADCP) velocities vs. time, and (right) scatter plot of observed vs. modeled velocities for the full record.

Water Quality / Biogeochemistry:

Light availability / Suspended Sediment

- Empirically-based light attenuation estimates: Using long-term records of high frequency turbidity data (Figure 10), along with lower-frequency ship-based sampling (USGS, light attenuation and SPM; CA DFW, secchi depth along shoal) to generate a time-space varying light field. Work is continuing. Initial results, and subsequent refined results, will be incorporated into the biogeochemical model, allowing for sensitivity analysis. These results will also be used to tune mechanistic sediment transport models (below)
- Mechanistic sediment transport modeling
  - Early work has been completed on a dynamic sediment transport, in collaboration with Deltares and a third TU-Delft masters student.
  - In Summer 2018 a USGS and NMS jointly funded 2-yr postdoc will focus further on the development of a mechanistic sediment transport model, using additional observational data from intensive sediment transport studies in SFB, along with the empirically-based light field results (above), using the NMS DFM hydrodynamic model
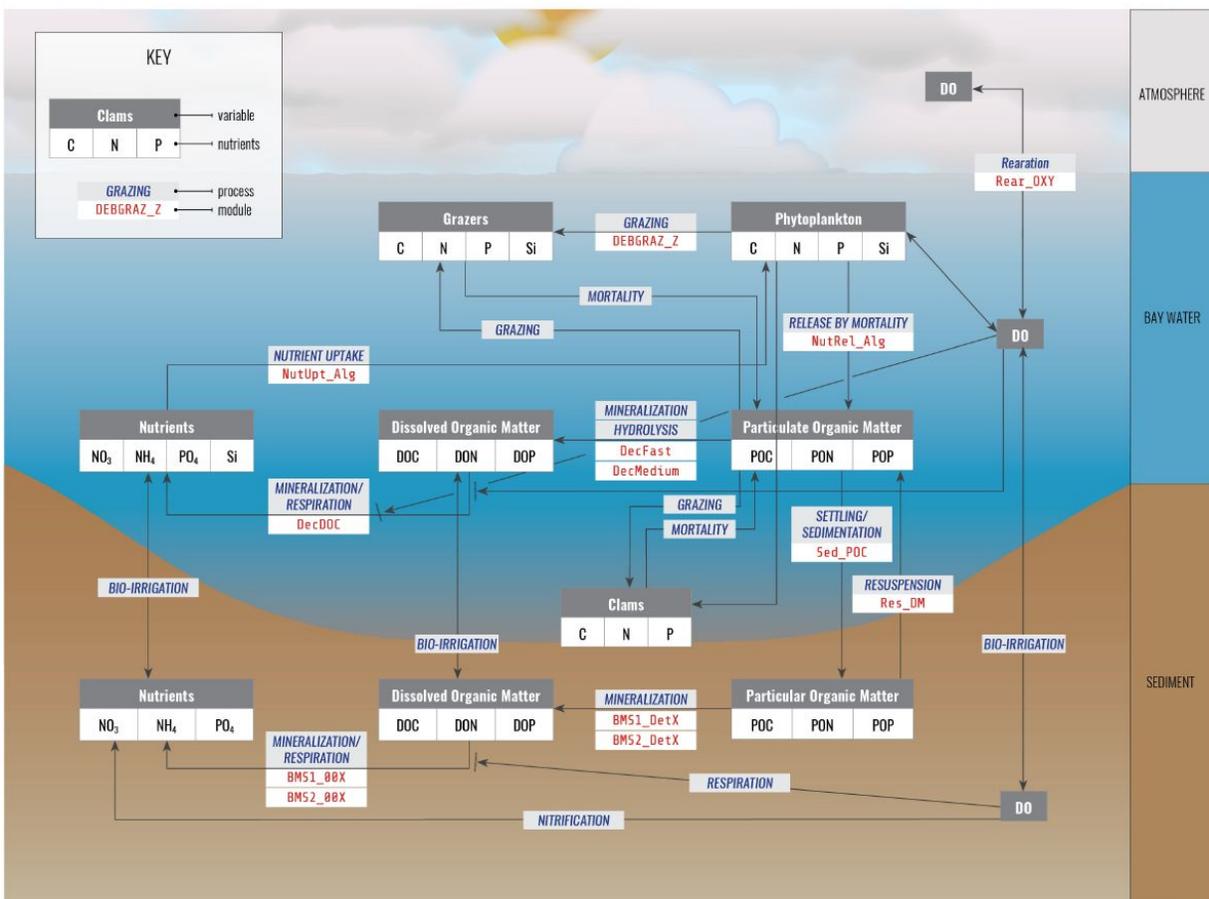

Figure 15 *Parameters and processes included in the current core model set-up*

Biogeochemistry: Nutrients, Phytoplankton, Grazing, Dissolved Oxygen

- As a starting place, during the first two years of the NMS Modeling Program, the majority of the water quality simulations used the high-resolution and well-calibrated hydrodynamic model results but a minimal set of reaction terms: nitrification, denitrification, an imposed sediment oxygen demand, and reaeration. We used that approach for initial tuning of nitrification/denitrification rate constants, and to develop preliminary nitrogen budgets for subembayments.
- FY18 work focused on incorporating a much more complete set of processes, including (Figure 15): phytoplankton (growth, nutrient assimilation, death); pelagic grazers (zooplankton); basic time-varying light field; mineralization of organic matter in the water column and release of nutrients; fluxes of nutrients from sediments.
- After tuning this more complex model, building on experience gained from the 'simplified' biogeochemical modeling work (including provisional rate constants), the model has been run for WY2013, and continues to undergo refinements (Figure 16). The model captures the relative trends in in DIN and chl-a in LSB over an 8 month period, including a large bloom event that drew down DIN. Given the early stage of model development the simulation also did reasonably well at predicting concentrations of chl-a, DIN, and the DIN forms NH4 and NO3 (Figure 2). However, this is only one feature during one year, and it is reasonable to expect that the current model will not perform well during other years, or when compared to higher-frequency data.
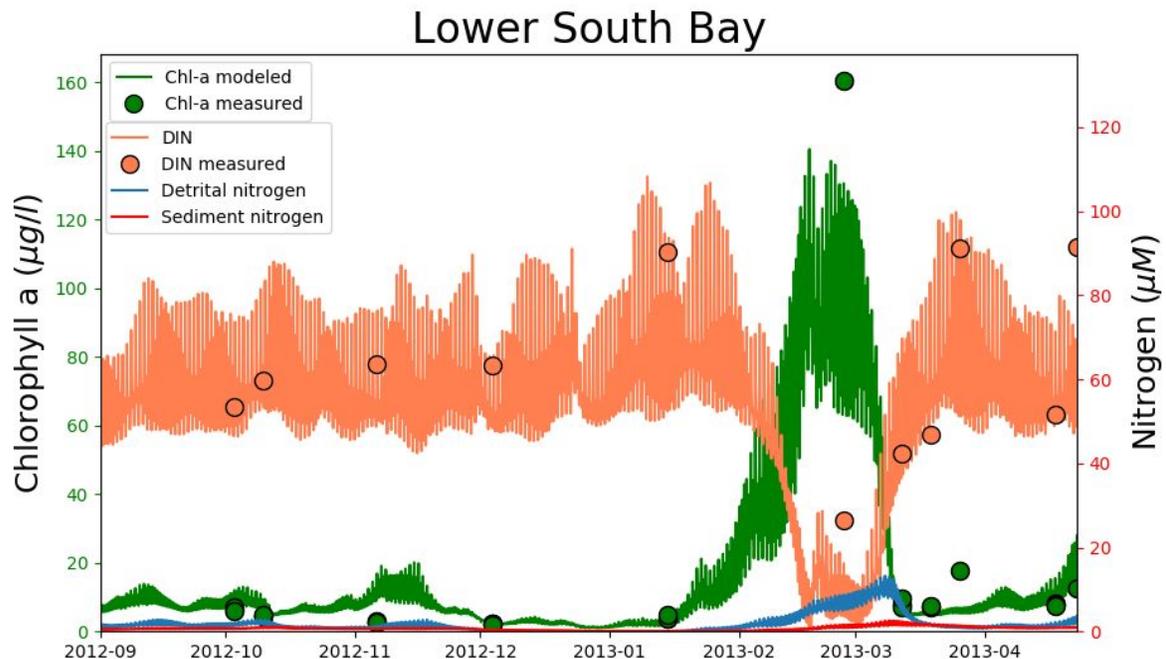
Figure 16 Measured and modeled concentrations of chlorophyll-a and DIN (nitrate (NO3) + ammonium (NH4)) in Lower South Bay (LSB), September 2012-April 2013. Measured data is from samples collected during USGS cruises in Lower South Bay (combining s34 and s36). Modeled values are hourly data, predicted using the current version of the NMS' coupled hydrodynamic/biogeochemical model. The modeled concentrations are predictions for a fixed location in LSB (s36, Figure 1), and the large, high-frequency variations result from a combination of LSB's strong tides and spatial heterogeneity in water quality. Model output and observations suggest that the observed substantial DIN decrease beginning mid-February resulted from a major phytoplankton bloom

Major Focus Areas in FY19: #1 and #2 will be the the primary focus of work.

1. ***Further develop and refine model by simulating a diverse set of biogeochemical features*:** Assessing the skill of the biogeochemical model requires modeling a range of flow conditions, hydrodynamics, and biological responses. WY2013 was a good starting point. During FY19, we will add 1-2 additional years, selected such that they allow for testing the model's ability to predict a different range of biogeochemical conditions or responses, and also to allow comparisons with more observational data. Two candidate years are WY2014 (drought year, and no major bloom event) and WY2017 (wet year, major bloom). WY2017 was a particularly interesting year, and one during which we have considerable observational data (Figure 17; all we will focus on testing the impact of flushing; whereas for WY2017, we will focus on testing the spatial variability of blooms, particularly, the difference between the channel and shoal regions.
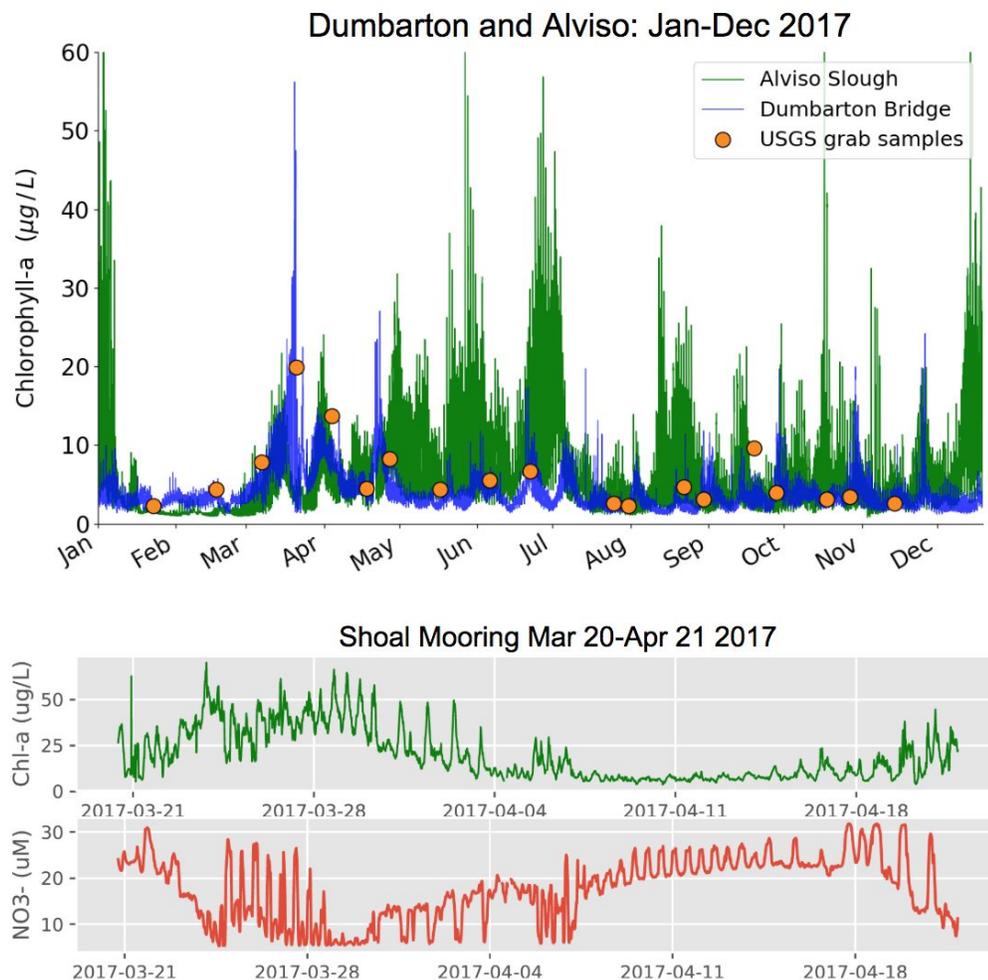
Figure 17 (Top) Example observational data in South Bay and Lower South Bay during WY2017. In addition to the major bloom event in Mar-Apr 2017 at Dumbarton Bridge, modest chl-a peaks were observable on highly-periodic basis throughout the year. Periodically-elevated chl-a levels were also evident in Alviso Slough. (Bottom) In addition, the mooring on the South Bay eastern shoal captured a sizable bloom and a coincident substantial drawdown in NO3.

2. Complete work on empirically-based light-field estimates During FY19, this work will be completed and the data product will be available for use in biogeochemical modeling runs, including the new water years described in #1.

3. Sensitivity analysis to identify important data gaps: There are a large number of data gaps - rates, state variables -- that could be addressed to improve model skill. Some of those data gaps or uncertainties are undoubtedly more important than others. Objective criteria and quantitative analysis are needed to inform decisions about how to allocate limited funds for field work. With some well-designed 'modeling experiments' it would be possible to begin distinguishing between "high" and "low" importance. Depending on time and budget, work on sensitivity analysis will begin in FY19.

Deliverables:
- Technical report describing and comparing/contrasting biogeochemical model results or performance for WY2013 and 1-2 additional year(s). While a major focus will be on assessing model skill, the report will also include interpretations relevant to the management questions (e.g., factors regulating production and in particular interannual variations in bloom magnitude;, zones of highest production; etc.)
- Data product for space-time varying light field and technical memo documenting the approach and uncertainties and/or confidence in the results.
- Status report or brief technical report summarizing clear priorities that emerge through early analysis.

Budget Justification: 2 senior modelers at 0.5 FTE, and two junior modelers for a combined 0.7 FTE ($280k); external collaborator (30k)

C.4 and C.5 Science Program Coordination and Program Management
FY18 Estimated NMS Cost = $289,285 (C.4) + $107,221 (C.5)
Collaborators: SFEI

Science Program Coordination accounts for lead scientist's effort across all scientific activities of the NMS and for overall Program coordination. The distribution of work is estimated to be 60% hands-on science and/or managing directing projects and 40% program coordination (fundraising, stakeholder engagement, NMS and PS process). Program Management includes program management (including stakeholder engagement, interagency coordination, fundraising) and financial management ($102k) and travel ($5k).

PROJECTS

> **P.1 Algal toxins (phycotoxins) in bivalves: naturally occurring mussels as biomarkers of phycotoxin levels in San Francisco Bay**
>
> FY19 Estimated NMS Cost = $101,937
>
> Collaborators: SFEI, UCSC, USGS, SFSU-RTC

Goals:
- Quantify phycotoxin concentrations entering biota in Central and South Bay through measurements in naturally occurring mussels.
- Collect samples with sufficient frequency that concentrations in mussels can serve as semi-quantitative bioindicators of ambient toxin concentrations in the water column as a function of space and time, to address monitoring goals and inform mechanistic understanding of where and under what conditions toxins are being produced.

Mussels are filter-feeding organisms that accumulate phycotoxins, as well as anthropogenically-introduced toxins, in their soft tissue (e.g., Gibble et al., 2016; Peacock et al., 20180. Mussels will assimilate a toxin in proportion to its concentration in the water column. In general (at least for phycotoxins), mussels also decrease their toxin body-burden by metabolizing and excreting the toxin, such that the rise and fall of tissue toxin concentration tracks the toxin's concentration in the surrounding water. For that reason, mussels are commonly used as time-integrated bioindicators of toxin concentrations in the water column, and also provide information about phycotoxin exposure to higher trophic level organisms. Because some mussel strains can excrete certain phycotoxins fairly rapidly (e.g., domoic acid excretion half-life is on the order of days), the toxin burden in mussel tissue can change quickly as toxins concentrations decrease in surrounding waters. Therefore, sampling frequency is an important consideration when designing and interpreting data from mussel-toxin monitoring activities.

NMS-supported work on phycotoxins in bivalves began in 2014/2015, in collaboration with UCSC and USGS. Results from that work, described in a recent publication (Peacock et al. 2018) and previewed in earlier NMS Annual Reports (2015, 2016, and 2017), show that individual mussels often contained multiple marine phycotoxins (domoic acid, saxitoxin, diarrhetic shellfish toxins, Figure 16). Prior work, using tissue from same mussels, also reported frequent Microcystins detections (Gibble et al. 2016). At least one toxin was detected in 99% of mussels and all four toxins detected in 37% of samples. Of the four toxins studied, microcystin (and diarrhetic shellfish toxins (DST) exceeded regulatory limits in 20 and 5 individuals, respectively; domoic acid and saxitoxin were substantially lower than regulatory thresholds in all samples (Figure 16).
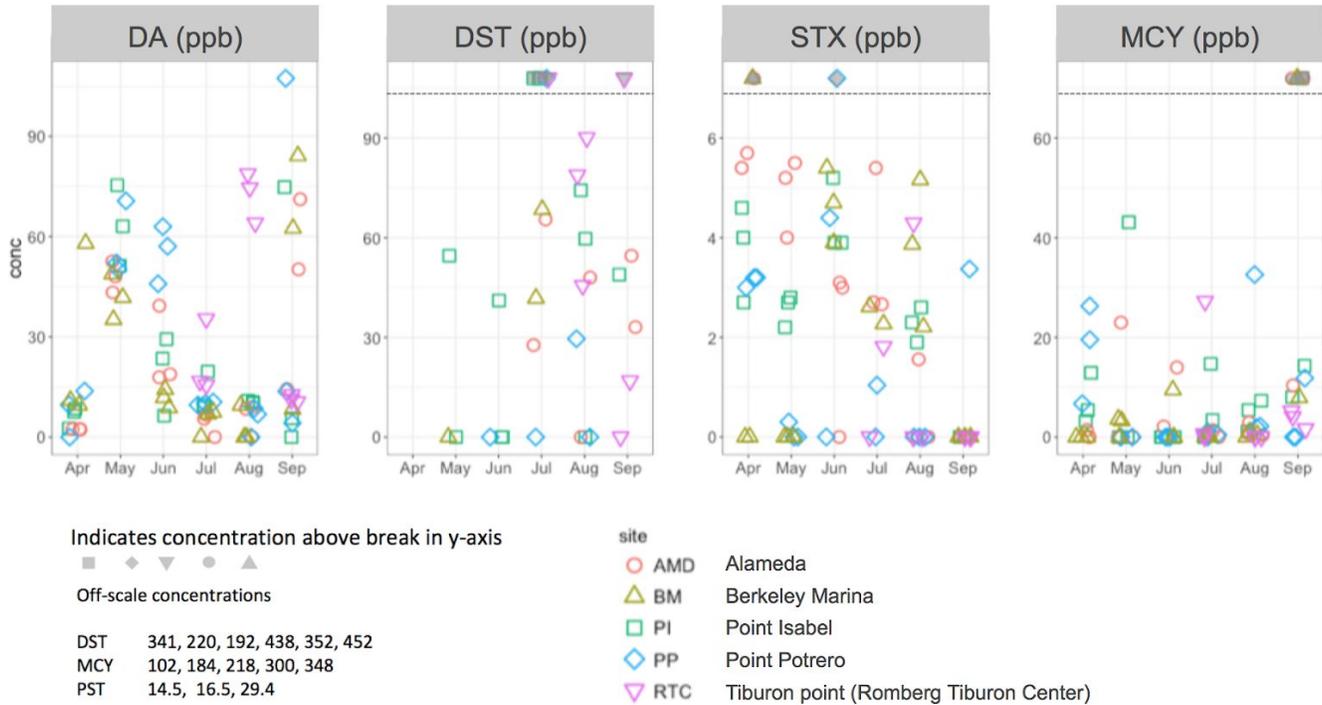
Figure 16 Adapted from data presented in Peacock et al. 2018. Domoic acid (DA), Diarrhetic Shellfish Toxin (DST), Microcystin (MCY) and Saxitoxin (STX) in mussel samples collected in Central Bay and northern South Bay from Apr-Sep 2015. Multiple toxins were present in mussels, with at least one toxin detected in 99% of mussels and all four toxins detected in 37% of samples. The y-axes are expanded to facilitate viewing data at the low end of the concentration range, with symbols above the dashed line (DST > 90; MCY > 70; STX > 7), with off-scale observations depicted as grey symbols and having the concentrations noted above left. Regulatory limits for these compounds are: DA: 20,000 ppb; MCY: 10 ppb 160 ppb for DST; and 800 ppb for STX. For DST and MCY, multiple samples exceeded regulatory limits. Maximum concentrations of DA and STX were ~200-fold and ~20-fold lower than these limits.

Over the past 2.5 yrs, the NMS has continued the mussel-toxin work as a pilot project, sampling naturally-occurring mussels biweekly from floating docks at an expanded network of sites distributed around SFB (Figure 16). This FY19 project is a continuation of the field and lab aspects of that work (data analysis and interpretation will be funded separately), continuing the collaboration with UCSC. To date, this component of the NMS program has proven to be an efficient and cost-effective approach that is yielding valuable information. Sample sites are accessible by car, and sampling can be completed in 1-1.5 days. Beginning late in FY17 we began collecting water quality data at each site (T, S, chl-a fluorescence, turbidity, etc.) and discrete samples for chl-a, which will prove useful both for interpreting toxin data and as condition monitoring in a very different habitats from other efforts (USGS, NMS).
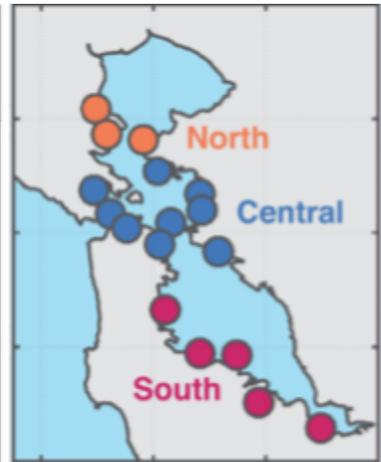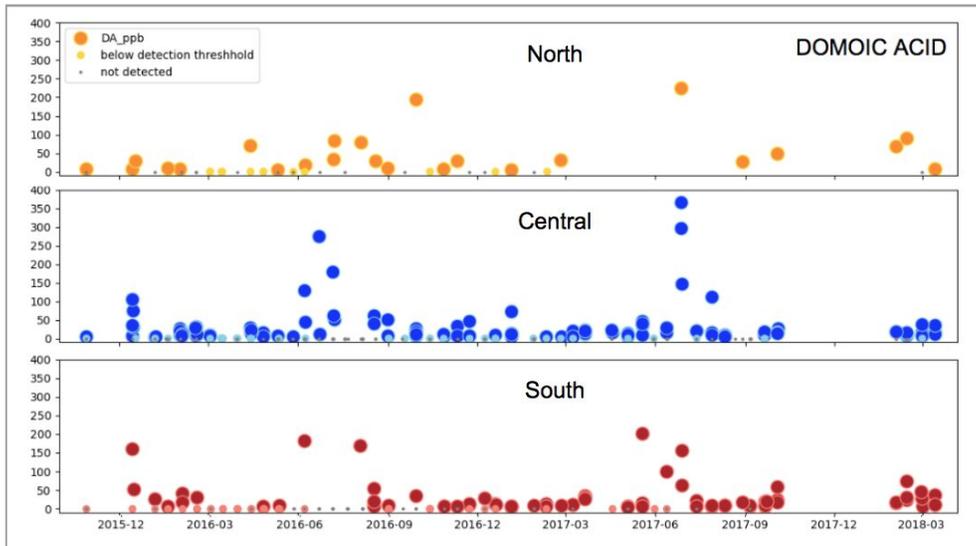
Figure 16 Phycotoxin concentrations in mussels collected biweekly in San Francisco Bay. Red horizontal lines denote regulatory thresholds (off-scale for domoic acid). Top: Domoic acid (ppb), threshold = 20,000 ppb. Middle: Saxitoxin (ppb), threshold = 800 ppb; Bottom: Microcystins (ppb), threshold = 10 ppb.
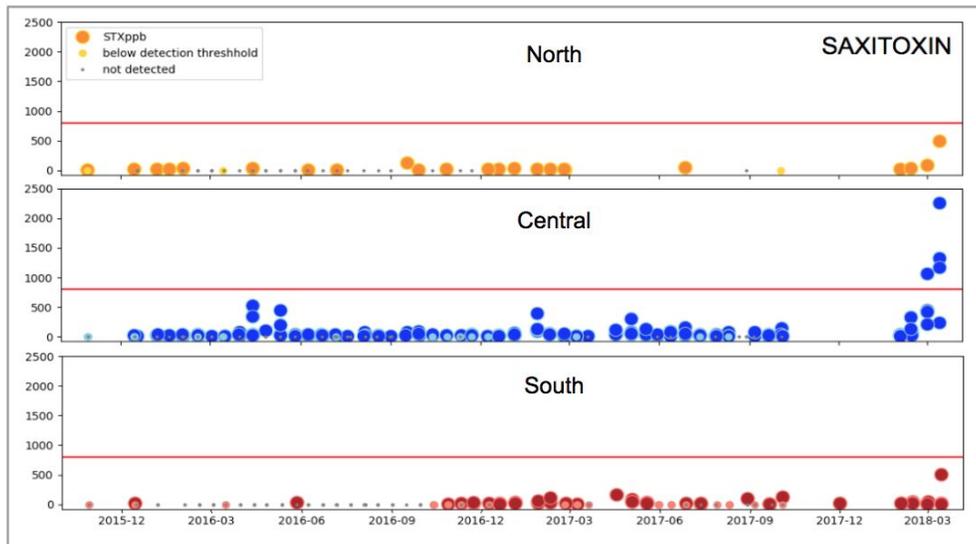
Within this time window, samples from remaining sites*dates have been prepped and are in the analysis queue (DA and STX: 10/2017-2/2018; MCY:7/2017-3/2018).
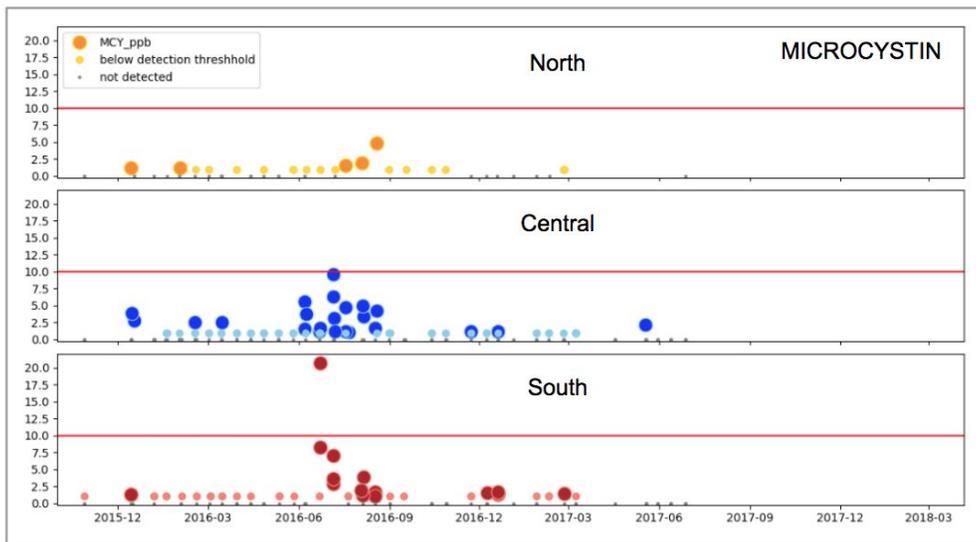
Note: Data from Peacock et al 2018 and Gibble et al 2016 are not included here.

Early observations based on currently-available data include:

- In general, DA, STX, and MCY were observed year-round and throughout all sampled regions of SFB.
- Consistent with the observations in Peacock et al. (2018) and Gibble et al. (2016), a subset of mussels contained multiple toxins. While maximum detected DA and STX concentrations observed in this longer record substantially exceeded those observed for May-Sep 2015, the MCY concentrations were substantially lower than May-Sep 2015.
- Four March 2018 Central Bay samples exceeded the regulatory threshold for STX. Through a developing partnership with CDPH, those samples had been analyzed within 24 hrs of collection (only for DA). Based on these observations CDPH issued a consumption advisory for Alameda and Contra Costa Counties.
- Spatial and seasonal variations:
  - Central Bay samples contained the highest concentrations for all three toxins.
  - STX in South Bay had more non-detects and overall lower concentrations than Central Bay
  - The results for DA are suggestive of a seasonal pattern. Additional data is needed to better assess this trend. For MCY, the limited data available presently points to increases during summer months, which is consistent with the strong temperature dependence of cyanobacteria's growth rate

The proposed FY19 workplan includes:

- Continue collecting naturally occurring mussels from ~10 stations on a biweekly basis.
- Measure basic water quality data at sampling sites using in situ sensors, and collect and analyze discreet samples for chl-a, and potentially for nutrients (budget permitting).
- Analyze mussels for multiple toxins: domoic acid, microcystin, saxitoxin, and potentially other toxins.
- Analysis and interpretation of FY15-FY18/FY19 data will be carried out as part of a separate project, either using carry-forward funds from FY18 or through a FY19 project that will be presented to the NMS SC at a subsequent meeting.

Deliverables: Data will be incorporated into the FY19 annual report. A more detailed technical report will also be prepared, funding permitting, using funds from a separate data analysis and synthesis project.

Budget Justification: Staff time (25% junior staff, 10% senior staff; $49,437); sample preparation and sample analysis ($30k); sampling/travel ($2500); technical support from collaborator ($15000; lab/analytical oversight, coordination, advising); discrete water quality data ($5000; chl-a, nutrients).

The FY19 budget is ~$35k less than allocated in FY18, due to less funding allocated for labor. Because of staffing changes, we substantially rescoped the project in terms of how components of the work will be completed. As a result, it is likely that we have not adequately accounted for all costs with this budget, in particular the cost of sample preparation, and will update the SC after evaluating the rescoped work plan and burn rate.

P.2 Investigating Effects of San Francisco Bay's Nutrient Exports to the Central CA Shelf
$200,000
Collaborators: UC Santa Cruz, SCCWRP, UCLA

Project Summary

San Francisco Bay (SFB) is a nutrient-enriched estuary that receives large anthropogenic nutrient loads from multiple sources (Figure 1A). The Bay Area's 37 publicly owned treatment works (POTWs), which treat wastewater from the region's 7.4mill people, discharge ~50,000 kg d^{-1} dissolved inorganic nitrogen (DIN) to SFB (Figure 1A). The POTW loads account for the vast majority of dry season DIN inputs, and are fairly constant year-round (±15%); however, recent analysis indicates POTW loads have increased substantially over the past decade (Figure 1B; SFEI, in prep). The Sacramento and San Joaquin Rivers carry water from California's Central Valley, delivering 90% of SFB's freshwater inputs to northern SFB along with large, seasonally-varying DIN loads (Figure 1A). Although SFB's waters are highly enriched in DIN, the system has not historically experienced eutrophication problems typical of other nutrient-enriched estuaries. Observations over the past decade have identified substantial interannual shifts in the SFB's response, or sensitivity, to nutrients (Cloern et al. 2007; SFEI, 2017). In response, regulators and stakeholders launched the SFB Nutrient Management Strategy (NMS) Science Program to carry out expanded monitoring and targeted investigations to inform management decisions related to SFB's 'carrying-capacity' for nutrients.

SFB's resistance to elevated nutrients stems from several factors (e.g., high turbidity, strong tidal mixing) that cap phytoplankton primary productivity and reduce DIN utilization within the system. While those factors tend to increase SFB's internal DIN carrying-capacity, they necessarily translate into greater DIN exports to the coastal ocean. Early coupled biogeochemical- hydrodynamic model simulations suggest that, while substantial fractions of SFB's DIN loads are 'lost' internally (denitrification), SFB serves as a large DIN point source to the coastal ocean via efflux through the Golden Gate (Figure 1C). Despite the large magnitude of these DIN loads, we currently know very little about their potential effects on ecological conditions along the coast.

This project will apply coupled atmospheric-physical-biogeochemical ocean models to investigate how SFB-derived DIN influences ecosystem conditions along the Central California Shelf (CCS). Work will focus on two sets of questions, the first emphasizing physical processes and the second addressing biogeochemical or ecological responses.

1. What geographic zones of the CCS are influenced by outflow from SFB? What factors regulate the SFB plume's trajectory, areal extent, and duration of influence?

2. What are the ecosystem structure resulting from natural coastal processes (e.g., upwelling, alongshore coastal transport, vertical mixing)? In impacted zones, what is the magnitude of the perturbation resulting from the outflow and SFB-sourced DIN? Over meaningful temporal averages (e.g., monthly or seasonal), what are the quantitative changes to primary production, phytoplankton concentrations, and community structure resulting from the outflow? What quantitative effects do these have on dissolved oxygen and acidity?

We will pursue this work through collaborating with an on-going (year 5) multi-institution project (UCLA, SCCWRP, UW, NOAA) that is applying coupled physical/biogeochemical models for the California Current system to predict the effects of ocean acidification and hypoxia (OAH) along the CA coast. That project, led by investigators at UCLA and SCCWRP and funded by the CA Ocean Protection Council and NOAA, has a specific emphasis on quantifying degree to which regional anthropogenic nutrient inputs influence OAH, via their influence on phytoplankton productivity. As a result, while the NMS and UCLA-SCCWRP projects differ somewhat in their specific goals or focus, the state-of-the-art models they are developing are ideal for addressing the NMS' management questions along the CCS.

In addition, the UCLA-SCCWRP project, which focused initially on the Southern California Bight, plans to begin shifting their geographic focus to CCS in 2019. The NMS-funded project is thus well timed (start late-2018/early-2019) to make meaningful contributions to the broader UCLA-SCCWRP project.
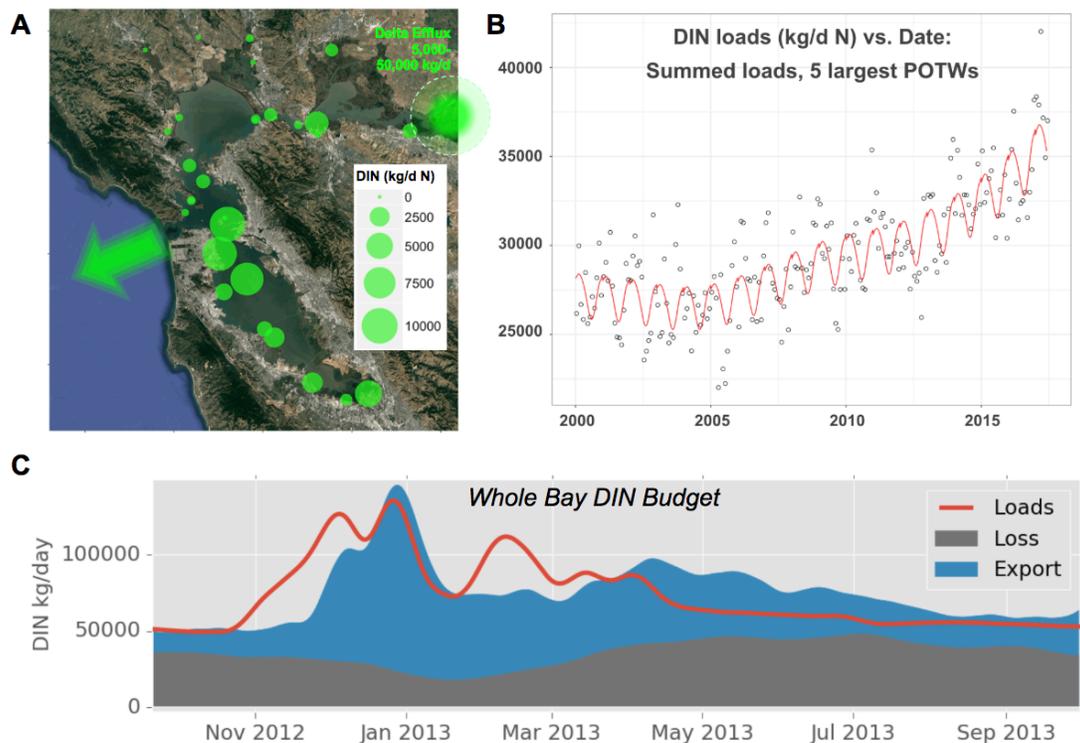

Figure 1 A. Locations and magnitudes (area of symbols) of major DIN loads to SFB. Delta efflux loads (northeast) vary seasonally (5,000-50,000 kg/d), as do predicted Exports to the coast (see C). **B.** Summed DIN loads from SFB's five largest POTWs vs time; ~40% increase, Jan 2005-Jun 2017. **C**. DIN Budget for SFB, WY2013, using the NMS v1.0 biogeochemical model. Instantaneous differences between the curves for Loads and Loss+Export indicate changes in DIN internal storage (i.e., changes in concentration).

Project Team(s), NMS funded project:
Lead PIs: Christopher A. Edwards (UCSC), James C. McWilliams (UCLA)
Co-Investigators: Faycal Kessouri (SCCWRP), Martha Sutula (SCCWRP), David Senn (SFEI)

Note: The project team for the UCLA-SCCWRP project includes other PIs, as discussed below.

Work Flow, Milestones, and Deliverables
Time-Frame: We envision Phase 1 being a 3-yr study, with funding currently being sought for Year 1.
Deliverables: Progress report at end of Year 1, and Technical Reports at ends of Years 2 and 3 (written as draft manuscripts, if relevant)

Year 1: Contribute to development and set-up of physical model for CCS, physical model validation
Year 2: Focus on CCS biogeochemistry and productivity, quantifying contributions
Year 3: Refine physics, biogeochem/productivity, application to OAH endpoints.

Budget: $183,000 for Year 1
Includes salary support for 1 Postdoc, 1 graduate student, 1 month summer salary support for C Edwards, $20,000 for travel (postdoc splitting time between UCLA and UCSC), and $4000 for equipment; and assuming an indirect rate of 10%.

NOTE: When approving the final budget, the NMS SC suggested including additional funds for NMS/SFEI staff to manage the project ($17,000), so the final approved budget is $200,000.

Expanded Project Description:

Project A (OPC, NOAA) Co-Principal Investigators: James C. McWilliams and Daniele Bianchi (UCLA), Faycal Kessouri, Martha Sutula (SCCWRP), Curtis Deutsch (UW), Richard Feely (NOAA PMEL)

Project B Team (NMS Funded): Lead PIs: Christopher A. Edwards (UCSC), James C. McWilliams (UCLA); Co-Investigators: Faycal Kessouri (SCCWRP), Martha Sutula (SCCWRP), David Senn (SFEI)

<u>**Goals & Scientific Questions**</u>: This project will apply coupled atmospheric-physical-biogeochemical ocean models to investigate the relative impact of natural versus anthropogenic forcing on nutrient mass balance, primary productivity, acidification and hypoxia on the Central California Shelf with historical hindcasts over multi-year simulations. Our work is driven by four key questions:

1. What is the uncertainty in model predictions of Central Coast physics, biogeochemistry, and lower ecosystem responses?
2. What is the effect of terrestrial and atmospheric sources of nutrients, organic matter and acidity on central coast shelf nutrient mass balance, productivity, carbonate chemistry, and oxygen and what is the spatial and temporal footprint of this impact over seasons and interannual climate cycles?
3. What is the geographic zone of the coast that is influenced by outflow from the San Francisco Bay estuary? Does the zone extend beyond Half Moon Bay and the Gulf of the Farallones? Under what conditions does it impact the region north (or south) of the Golden Gate? What is the fraction of time different regions are impacted?
4. What are the contributions of regional DIN sources (SFB exports, other freshwater exports, atmospheric), relative to ocean forcings, on nutrient mass balance, productivity, carbonate chemistry, and oxygen along the Central California shelf?

Background. The Central California Coast Shelf (CCS) of the California Current Ecosystem (CCE) is one of the most productive in the world, providing significant economic, cultural and recreational services to large populations living along the coast (Halpern et al., 2008). Climate change related effects are predicted to shift and intensify natural gradients and variability related to ocean acidification (OA), warming, and deoxygenation (Bakun et al. 2010; Turi et al., 2016; Gruber et al., 2012). In the CCS and Southern California Bight, mean declines in DO of 20-24% below the mixed layer from 1984–2006, and a 65-80 m shoaling of the hypoxic zone on the shelf have been documented (Bograd et al. 2008, McClatchie et al. 2010, Booth et al. 2014). The CCS is also experiencing some of the highest rates of acidification on the West Coast (Feely et al. 2008), at levels that are already impacting marine calcifying organisms (Bednarsek et al. in prep). These trends and fluctuations are projected to accelerate over the next decades (Gruber, 2016; Turi et al., 2016, Garcia-Reyes et al., 2016; Hauri et al., 2013). Local drivers have the potential to exacerbate OA and hypoxia (Duarte et al. 2013). One area of concern is CCS, where the discharges of primary or secondary treated wastewater from a population of 15 million people in San Francisco Bay (SFB) and agricultural discharges from the Salinas River Valley and the Bay-Delta represent an outwelling of anthropogenic nutrients to the coast. The West Coast Ocean Acidification and Hypoxia (OAH) Expert Panel recently urged the investigation of the degree to which anthropogenic inputs are currently influencing OAH along the California Coast, how their relative effect will change over time, and their influence on regional OAH hotspots of vulnerability (Chan et al. 2016) and been the focus of legislative directives aimed at crafting California's response to climate change (Legislative Assembly Bill 2139).

This investigation is the focus of a currently funded California Ocean Protection Council (OPC) and NOAA NOS/NCOS-funded project (Integrated Modeling of OAH to Support Ecosystem Prediction and Environmental Management in the California Current System; McWilliams and Deutsch, Lead PIs). The goal of this funded study, currently in its 6th year and with an interdisciplinary team of 15 scientists, is to model the physics, biogeochemistry, and lower trophic response to perturbations from climate

change, natural climate cycles, and anthropogenic carbon and nutrient inputs along the U.S. Pacific Coast. At the backbone of this effort is the Regional Ocean Model System (ROMs) with biogeochemical elements (BEC, Moore et al. 2002), a state-of-the-art modeling system is currently being used to investigate the relative influences of climate change, natural variability and local anthropogenic forcing on OAH trends, with direct applications to marine resource and local pollution management. ROMs has been successfully used for more than a decade for many locations including the CCS, and among our team are its principal creators and developers; BEC simulates the time-dependent global biogeochemical cycles of carbon (C), oxygen (O_2), phosphorus (P), nitrogen (N), and iron (Fe), driven by 3 functional groups of phytoplankton and 1 zooplankton. Phytoplankton groups include N-fixing diazotrophs, small phytoplankton, and diatoms. The ecosystem is linked to an ocean biogeochemistry module based on an expanded version of the OCMIP biotic model (Doney et al. 2004), with prognostic variables for carbon, alkalinity, iron, and DO. The model has been expanded the model to include explicit sinking particles, and a detailed nitrogen cycle (dissolved organic nitrogen, nitrate, nitrite and ammonium) for our work on oxygen minimum zones (e.g. (Deutsch et al. 2011, Deutsch et al. 2014. Validation of the U.S. West Coast 4-km domain indicates that the model reasonably captures broad patterns of dissolved nutrients, carbonate system, and oxygen in the CCE, as well as upwelling-driven phytoplankton blooms (Renault et al. 2016).

The model is further downscaled to 1-km nests for California and Oregon/Washington, then further downscaled a 300 m nest for specific investigations in the the Southern California Bight (SCB) and the CCS, areas of focus because of management interest in local pollution impact assessments (Howard et al, 2014, SFB NMS, SFB Regional Water Quality Control Board). Simulations are now being conducted within the SCB, where a stakeholder advisory group (SAG), including municipal dischargers, environmental non-profits, and water quality regulators, are actively engaged in a process to evaluate science supporting evidence for needed reductions of atmospheric and terrestrial point and non-point source loads to SCB coastal waters, based on impacts to OAH. Biological endpoints based on OA and hypoxia impacts to CCE marine organisms are proposed to interpret chemical model output (e.g. Bednarsek et al. in prep, Howard et al, in prep). During stakeholder meetings, dischargers have stressed that model validation and quantifying uncertainty in modeled predictions is a critical line of inquiry, as it impacts the degree to which we can make conclusions about local pollution impact.

NOAA- and OPC-funded ROMs-BEC simulations of the CCS will begin in spring 2019. These simulations are the starting point of a proposed collaboration between UCLA, UCSC, SCCWRP, and SFEI to further investigate impact of Central Coast and SFB outwelling on CCS nutrient budgets, productivity, and OAH. These investigations are timely, for two reasons. First, an existing SFB stakeholder workgroup, united under the SFB Nutrient Management Strategy (NMS, SFB NMS, SFB Regional Water Quality Control Board), have been supporting science to investigate the impact of anthropogenic nutrients on the SFB ecosystem. NMS-funded science has included an ongoing project to develop a coupled physical-biogeochemical and lower ecosystem model of SFB. A key component of this modeling project is to determine biogeochemical fluxes across the Golden Gate, because of their potential to decrease impact of anthropogenic nutrient loading on SFB, but at the same time, enhance productivity and exacerbate OAH in the coastal ocean. Modeling studies of the CCS need SFB model output to quantify fluxes to the coastal ocean, but also can provide key boundary conditions to force the SCB Delf3D physical and biogeochemical model.

Second, UCSC research programs in nested, coupled physical/biogeochemical modeling that examine fundamental dynamics of the CCE, including the CCS as a focal region. An example of this is a recently completed study by Fiechter et al. (2018, Figure 1), that examined how regional variations in alongshore wind stress and horizontal circulation patterns increase shelf nutrient supply between capes contribute meaningfully to primary productivity and ecosystem variability. The California OPC (Sutula et al. 2014) and the West Coast OAH Expert Panel (Chan et al. 2016) promotes a model ensemble approach, in which two or more models predict similar outcomes (e.g. nutrient transport, primary productivity, etc.) in order to better examine sources of model uncertainty in supporting

management actions. The use of UCSC and UCLA/UW approaches to coupled physical/biogeochemical modeling can provide improved insights the range of forcing mechanisms and processes that drive local currents at many scales and can help to constrain uncertainty.
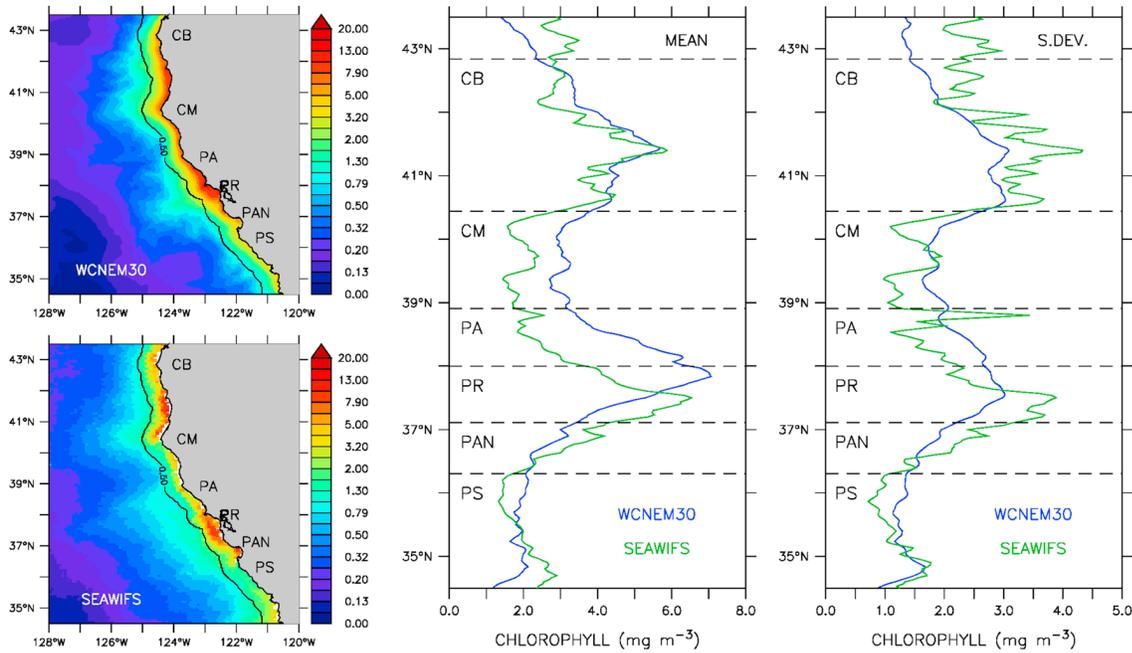

Figure 1: Left: Simulated (WCNEM30) and observed (SEAWIFS) surface chlorophyll concentrations (mg/m³) during May-July for 1998-2010. The left panel shows a 13-year May-July mean surface chlorophyll concentration from the model at a roughly 3 km resolution and from a satellite estimate of surface chlorophyll. The middle and right panels present the mean and standard deviation of surface chlorophyll (averaged within roughly 50km of the coast) as a function of latitude for both model and data. Both the model and data reveal significant alongshore changes in phytoplankton concentration associated with well-known geographic features in the coastline. From Fiechter et al. (2017).

Proposed Work:

We propose a model ensemble study to understand the evolution and fate of terrestrial outflow, including pollution sources, along the CCS and its subsequent BGC impacts. The study would use ROMS in a nested configuration. The modeled area will be a broad swath of the central California coast, including Monterey Bay and San Francisco Bay, using a model grid with at least 300 m resolution. To leverage the OPC- and NOAA-funded efforts focuses on broader assessments of local pollution sources, including Salinas River Valley ag inputs to Monterey Bay, this project proposed for NMS funding will focus on outflow from the SFB estuary, identifying impacted coastal regions which may vary seasonally as well as on short time-scales associated with changing atmospheric or oceanic conditions. The objective would be to compare realistic coastal BGC and lower ecosystem models that can investigate whether pollution sources from SFB influences coastal ecosystem dynamics relative to natural processes associated with the ocean dynamical response to local and remote physical forcing.

We will investigate dynamics of the coastal ecosystem, quantifying the relative significance of naturally occurring processes with those influenced by the plume. Ecosystem impact by outflow properties will

be assessed through changes in primary production, phytoplankton standing stock and phytoplankton community structure, as well as other metrics. To asses model uncertainty associated with model construction (e.g., number of phytoplankton functional types) and mathematical representation of biological processes (e.g., nutrient uptake), two independent BGC and lower ecosystem models will be applied, and their results compared.

The added benefit of a next higher nest (having perhaps 75 m resolution) will be considered in terms of dynamical processes represented and overall model fidelity (see additional background on physics and biogeochemistry, Appendix 1). Simulations will extend for at least two model years, allowing statistical analysis and characterization of plume evolution and dispersal under a wide range of conditions. SFB would not be resolved explicitly, but volume and property fluxes would be specified at the mouth of the bay based on observations or independent modeling studies that focus on bay-ocean exchange. The time-period would be historical, a multi-year integration that has characteristic bay-ocean exchange and typical California Current System dynamics.

Responsibilities:
Modeling activities will be shared between the UCLA, UCSC, and SCCWRP groups, with science support (interpretation and management translation) from SFEI, UW, and NOAA PMEL. UCLA researchers will be responsible for carrying out the physical ROMS calculations, including construction of nests, attainment of a relevant, multi-year atmospheric forcing. The UCLA and SCCWRP group will calculate biogeochemical fields using the BEC model, described above, which will be applied in an online configuration, simultaneously with the physics. The team have assembled a first cut of atmospheric and terrestrial forcing data for the CCS 300-m domain, including SFB outflow, CCS rivers and coastal outfalls, atmospheric wet and dry deposition, and atmospheric ambient CO_2 (Kessouri et al. in prep), and will run 300-m resolution scenarios in the spring 2019, with and without atmospheric and terrestrial forcing, to assess total impact on nutrient budget, productivity, and OAH on the CCS. The significant computational expense of running the coupled model system will restrict this configuration to only a few additional tests. The UCSC group will calculate complementary BGC integrations offline (i.e., independent of the physical circulation, but using the stored physical circulation fields as input), applying versions of either the NEMURO or Darwin biogeochemical models. The NEMURO model (Kishi et al., 2007), has been extensively used in the CCS (e.g., Fiechter et al., 2014, Song et al., 2016, Mattern et al., 2017), and it is computationally quite efficient with a small number of total state variables. The Darwin model is a much more complex model, with more phytoplankton functional types. It has a long history in global models (Follows et al. 2007, Ward et al. 2014) as well as in the CCS (Goebel et al., 2010). Sensitivity calculations that consider different nutrient loading conditions within the outflow plume will be carried out with the offline configuration.

A joint post-doctoral research associate, co-supervised by UCSC and UCLA, will work collaboratively to diagnose model output and verify that outflow plume dynamics are well-represented and reasonably consistent with available observations, such as remotely sensed satellite-derived information, HF RADAR surface current estimates. UCSC personnel will work collaboratively with UCLA and SCCWRP group members, with regular skype calls and travel, enabling cross-fertilization of ideas, technology transfer when appropriate, and ensuring best practices in model development and analysis.

 SFEI and SCCWRP will engage the NMS steering committee and technical/scientific advisory workgroups to vet the overall project approach, identify best available data for terrestrial and atmospheric forcing as well ambient ocean observations, and discuss model validation and interpretation throughout the project periods.

Timeframe: We envision a multi-year effort. Year 1 would include formalizing atmospheric and terrestrial forcing data for the CCS, setting up and running the physical model and biogeochemical model (UCLA, SCCWRP), gathering and analyzing data sets for evaluation and beginning physical and biogeochemical model evaluation and validation (UCSC, SCCWRP and UCLA). Year 2 would include necessary refinements of the physical and BEC model (UCLA), possible downscaling near the San Francisco Coast, and its evaluation (UCSC, UCLA and SCCWRP). Year 3 would pursue sensitivity studies in which anthropogenic forcing is modified to investigate source attribution and ecosystem response relative to natural processes is determined, with both parties involved in either online or online contexts (UCLA, SCCWRP and UCSC).

Deliverables: As noted above, project deliverables included progress reports or technical reports at the ends of Years 1-3, with the technical reports written as journal manuscripts if relevant. We anticipate that three publications will result from this study. One will report on the validation and preliminary pollution impact of collective atmospheric and terrestrial sources on the CCS (questions 1 and 2 above). The second is the physical evolution and fate of the SF Bay outflow plume, addressing question 3 above. The third publication will examine question 4 above, focusing on biogeochemical impacts resulting from plume outflow. Additional publications relating to these calculations and analysis are likely.

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P.3 Intercalibration Study for Chlorophyll Fluorescence Sensors in the Bay-Delta, Phase II
FY19 Estimated NMS Cost = $42,400 (jointly funded with the Delta RMP)
Collaborators: SFEI-ASC, USGS, DWR, and USBR

Summary:
Chlorophyll is an important water quality parameter for assessing the effects of nutrients and for fisheries management in the Bay-Delta. This study is the second phase of a multi-year effort to improve the accuracy, precision, and comparability of chlorophyll data collected in the Bay-Delta. Phase I planning has shown that variability in the methods used for measurement chlorophyll across the Bay-Delta is significant and that reducing this variance is of interest to a wide variety of monitoring agencies. In FY18/19, we propose to tackle a portion of the problem with a series of tasks to help understand and reduce the variance in the measurements of chlorophyll by in-situ sensors and laboratory methods. The proposed tasks include: (1) assessing methods used by different monitoring programs; (2) performing field intercalibration exercises between programs; (3) organizing a laboratory intercalibration study; and (4) preparing a summary report through technical workgroup discussion. Funding is requested for SFEI-ASC and USGS to lead the study. The study leverages $105,000 of in-kind support from the Department of Water Resources and the US Bureau of Reclamation.

Full project description available at the end of this document

Nutrient Management Strategy Special Study Proposal

Intercalibration Study for Chlorophyll Fluorescence Sensors in the Bay-Delta, Phase II

Summary:
Chlorophyll is an important water quality parameter for assessing the effects of nutrients and for fisheries management in the Bay-Delta. This study is the second phase of a multi-year effort to improve the accuracy, precision, and comparability of chlorophyll data collected in the Bay-Delta. Phase I planning has shown that variability in the methods used for measurement chlorophyll across the Bay-Delta is significant and that reducing this variance is of interest to a wide variety of monitoring agencies. In FY18/19, we propose to tackle a portion of the problem with a series of tasks to help understand and reduce the variance in the measurements of chlorophyll by in-situ sensors and laboratory methods. The proposed tasks include: (1) assessing methods used by different monitoring programs; (2) performing field intercalibration exercises between programs; (3) organizing a laboratory intercalibration study; and (4) preparing a summary report through technical workgroup discussion. Funding is requested for SFEI-ASC and USGS to lead the study. The study leverages $105,000 of in-kind support from the Department of Water Resources and the US Bureau of Reclamation.

Estimated Cost: $84,800 Total

-$42,400 Funding approved by Delta RMP SC on 5/11/18

$42,400 NMS Funds Requested

Oversight Group: NMS Nutrient Technical Workgroup, Delta RMP Nutrients Subcommittee

Proposed by: SFEI-ASC, USGS, DWR, and USBR

Background

Accurate, precise measurements of phytoplankton biomass are critical to inform important management questions about productivity, nutrient management, and fisheries. Chlorophyll concentration is a widely-accepted proxy for phytoplankton biomass. There are presently more than 50 moored chlorophyll sensors using in-situ fluorescence in the Bay-Delta, belonging to networks maintained by the U.S. Geological Survey (USGS), Department of Water Resources (DWR), and others (Figures 1, 2, and 3). Prior to now there has been no effort to ensure that the groups making these measurements are using calibrations, sampling methods, and data processing techniques that ensure comparable results. Ensuring data comparability will save money and time, and will provide managers with better, high-resolution data for the entire estuary.

Therefore, to increase the utility and improve our return on the considerable effort to produce these data, the Delta Regional Monitoring Program and the San Francisco Bay Nutrient Management Strategy Science Program are jointly funding a project with the goal of improving the comparability of the chlorophyll data collected by different programs across the region. While a seemingly simple task, achieving this goal requires overcoming several technical barriers to apply common approaches for sensor acceptance and performance criteria, sensor calibration, performance validation, data collection, data quality assurance, data management, and data access.

In FY17/18, the Delta RMP and the Nutrient Management Strategy each contributed $15,000 for SFEI-ASC to organize the stakeholders, conduct some initial analyses, and to develop a detailed workplan for FY18/19.

The stakeholder outreach process revealed a broad interest from many agencies in:
- Standardizing, improving processes
- Having data from different programs be interoperable
- Improving relationship between in-situ and lab chlorophyll-a
- Coordination
- Improving data accessibility

The survey of 13 monitoring programs found that a variety of methods are being used by the different programs especially in the areas of sensor settings, calibration procedures, sensor cleaning, and QA/post-processing. The method differences were significant enough to make comparing data from different programs difficult. For example, some of the programs conduct 2-point calibrations, others perform a single point test at zero, and others do no calibration check. The laboratories performing extracted chlorophyll-a analyses use two fundamentally different methods (spectrophotometry and fluorometry).

Finally, analysis of measurements from the different programs data showed a large amount of variability in chlorophyll fluorescence response (differences as much as a factor of two) between regions of the Bay-Delta and between programs (Figure 4). Variability of this magnitude impedes synthesis of data from across the Bay-Delta without using site-specific calibrations.

Overall, the effort in FY17/18 has shown that variability in the methods used for measurement chlorophyll across the Bay-Delta is significant and that reducing this variance is of interest to a wide variety of monitoring agencies. A conceptual model for variability in the chlorophyll fluorescence (Figure 5) provides a way to break this challenging problem into smaller tasks. In FY18/19, we propose to tackle a portion of the problem with a series of tasks to help understand and reduce the variance in the measurements of chlorophyll by in-situ sensors and laboratory methods.

This proposal was developed and reviewed by a workgroup with representatives from SFEI-ASC, USGS, DWR, US Bureau of Reclamation (USBR), and the Central Valley Regional Water Quality Control Board.
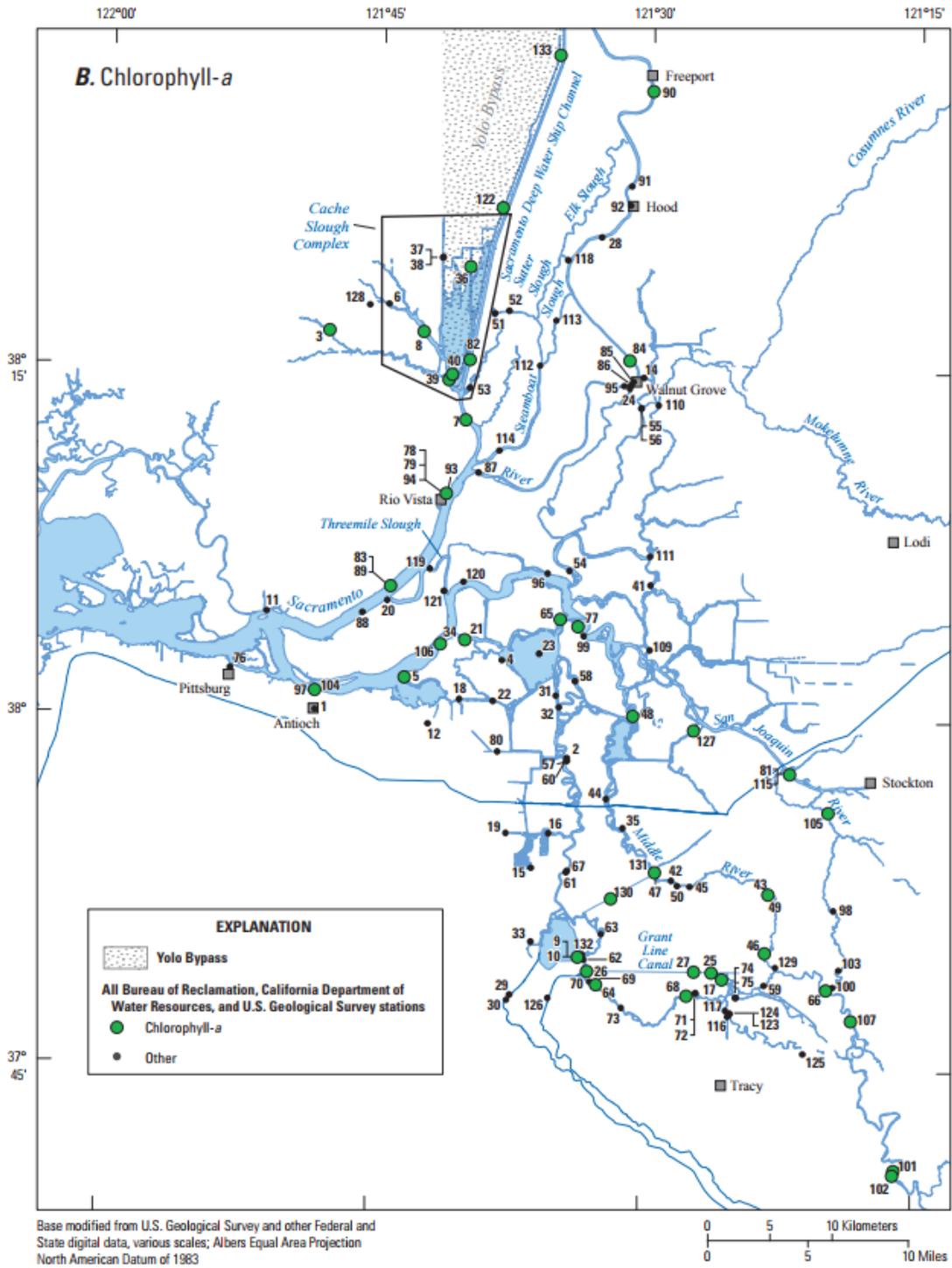
Figure 1: Chlorophyll fluorescence sensors in the Delta (from Bergamaschi et al., 2017)

3
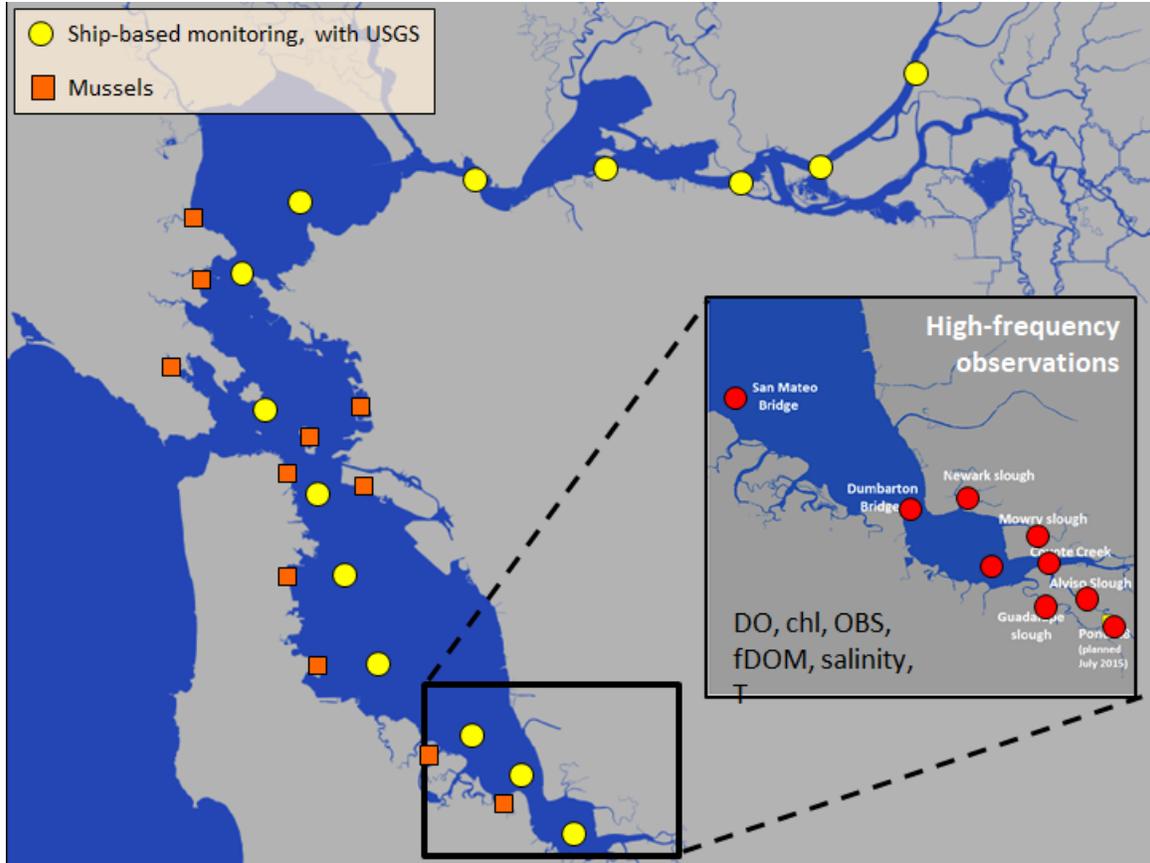
Figure 2: Chlorophyll fluorescence monitoring stations in the Bay. Continuous monitoring with moored sensors is performed at the red stations. Discrete measurements with sensors are made at ship-based monitoring sites (yellow) and mussel sites (orange). The graphic does not show all stations where chlorophyll fluorescence is monitored in the Delta, the Bay, and the coastal ocean.
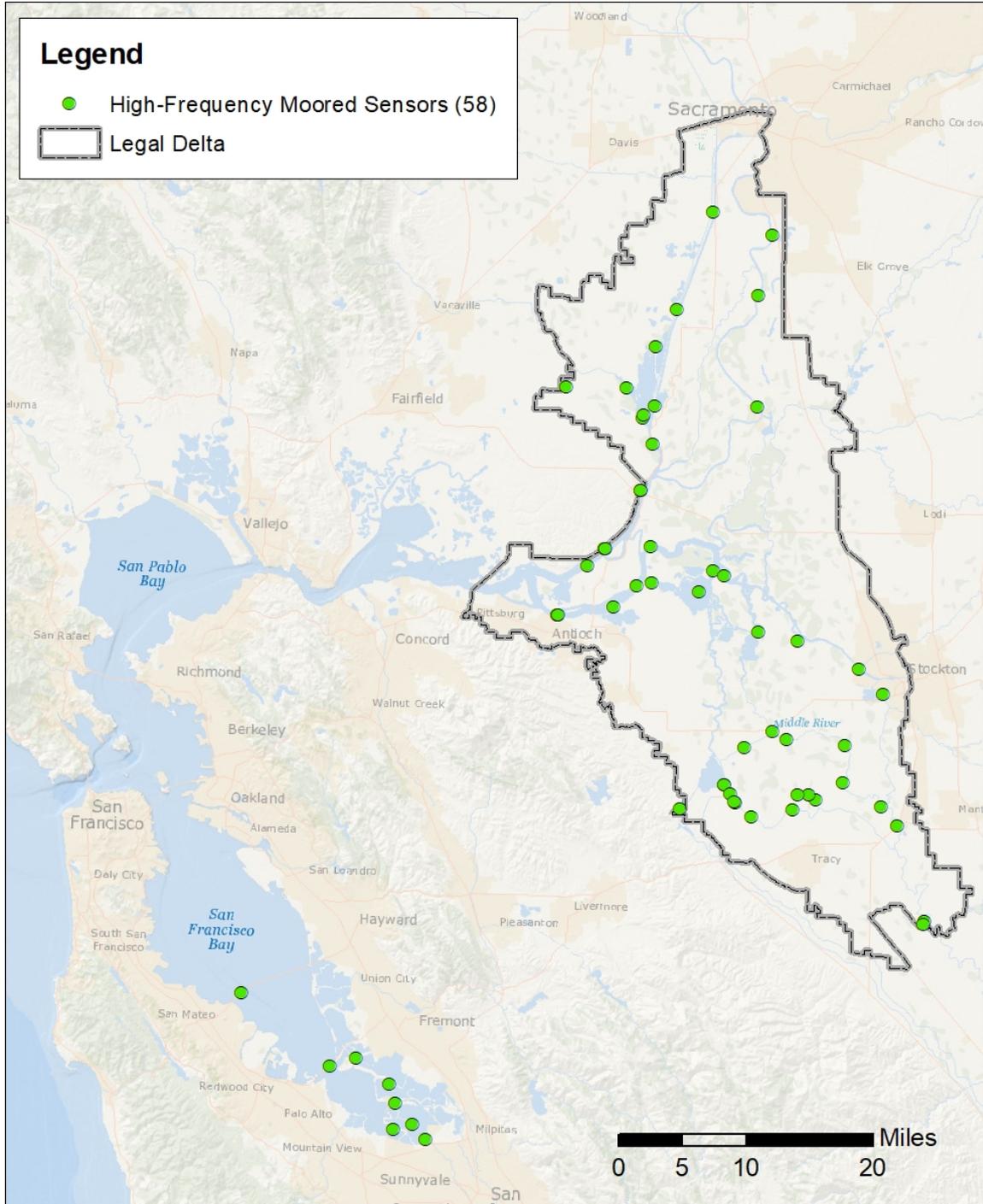
Figure 3: Stations with high-frequency moored sensors for chlorophyll that are managed by organizations that have agreed to participate in this study. Additional organizations will be invited to join the study.

RFU-Chla Ratio Varies With Program and Station

Ratio of Discrete Chl-a Lab Measurement in µg/L to Sonde Fluorescence in RFU
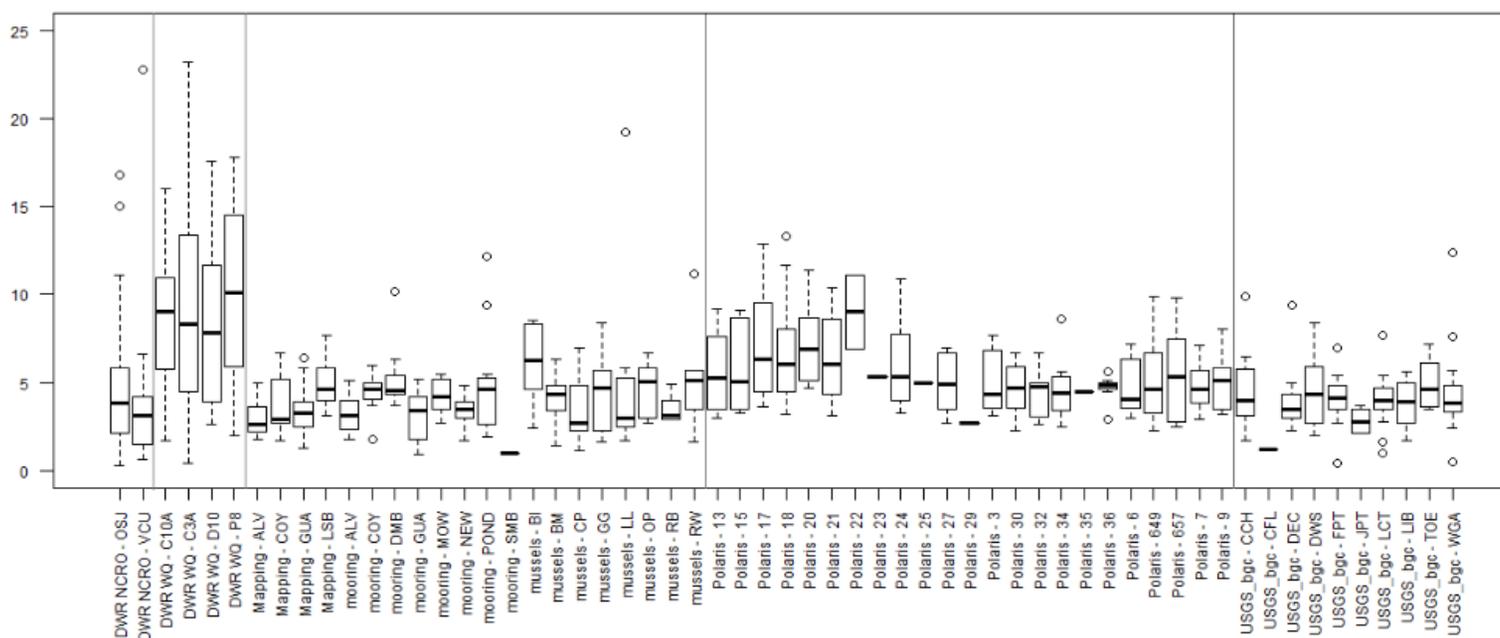
Figure 4: Ratio of sonde relative fluorescence units (RFU) from YSI EXO sondes to extracted chlorophyll measured in the laboratory across multiple programs and multiple locations in the Bay-Delta. The variance shown on this figure is from a combination of factors (see Figure 4). Natural variability among sites is evident when comparing different sites monitored by the same program. There can be natural differences between stations due to differences in salinity, tidal influence, and phytoplankton community. However, this graphic illustrates that some of the variance observed could be due to different protocols used by different programs.

Conceptual Model

In-Situ Chl-a Measurements
- Sensor type
- Sensor settings
- Deployment type
- QC practices
- ...

Uncertainty in relationships from
- fDOM
- Turbidity
- Algal species
- Life stage
- Light quenching
- ...

Lab Chl-a Measurements
- Lab method
- QC practices
- Field collection methods
- ...

Algal Biomass
- Taxonomy method
- Sampling method
- Regional extrapolation
- ...
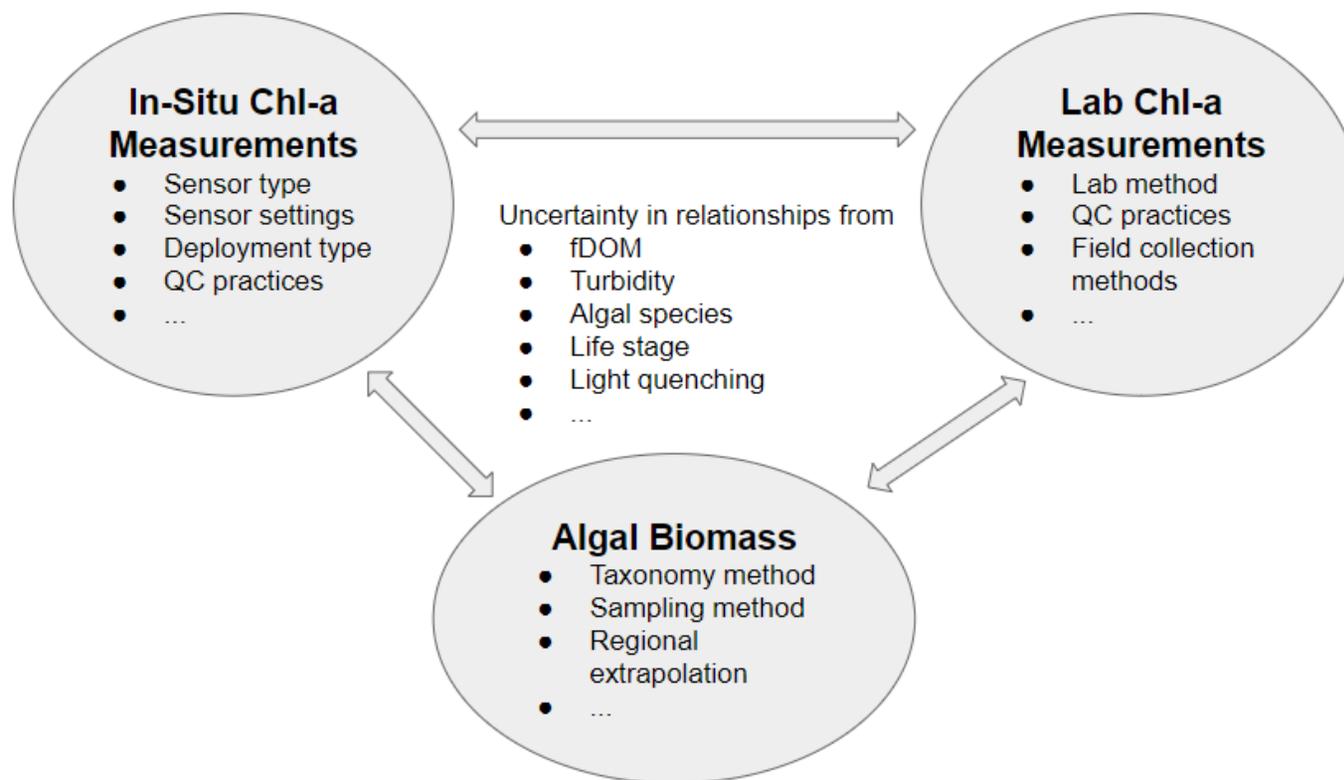
Figure 5: Conceptual model developed in FY17/18 for variance in extracted chlorophyll-a, in-situ chlorophyll fluorescence, algal biomass, and the relationships between these related parameters.

Study Objectives and Applicable RMP Management Questions

The objectives of the project and how the information will be used relative to the Delta RMP's management and assessment questions are shown in Table 1.

Table 1. Study objectives and questions relevant to Delta RMP management questions

Delta RMP Management Questions & Assessment Questions	Study Objectives	Example Information Application
Management Question: Is there a problem or are there signs of a problem? Assessment Question: How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally? (S&T1) This study is relevant to these questions because it will improve our ability to discern spatial and temporal trends in chlorophyll using data from multiple programs operating in the Bay-Delta.	Assess the differences in methods used by each program to measure chlorophyll. Determine whether differences in methods between programs result in significant variability in sensor and lab results for chlorophyll.	Water quality and resource managers will know the comparability of chlorophyll-a data from the major monitoring programs in the Bay-Delta. Data collection agencies will know which methods are important to address to improve the accuracy and precision of sensor and lab chlorophyll-a data in the Bay-Delta.

Approach

Task 1: Assessment methods used to measure in-situ chlorophyll fluorescence by different monitoring programs in the Bay-Delta

A small group of experts from the major programs (USGS, DWR, USBR, and SFEI-ASC) will summarize current practices for chlorophyll fluorescence measurements. At a minimum, the assessment will cover the following topic areas:

- Types of sensors and sonde equipment used
- Sensor settings
- Calibration
- Deployment and retrieval protocols
- Sensor servicing and cleaning
- Quality assurance
- Post-processing and data correction
- Reporting

The assessment will only cover <u>current methods</u> in use by programs; it will not survey past methods. Understanding the comparability of past methods to current methods is a priority for some agencies (e.g., DWR that has been monitoring since the 1980s) but it is beyond the scope of this effort.

A brief literature review will be conducted to ensure that this regional effort is informed by national and other relevant guidance. This review will not be exhaustive. It will focus on reports such as recent guidance/protocols for chlorophyll fluorescence sensors, previous intercalibration exercises with chlorophyll fluorescence sensors, and key foundational literature.

The deliverable for this task will be a short report on the results of the assessment, highlighting differences in methods for in-situ chlorophyll fluorescence between the major monitoring programs in the Bay-Delta, and the literature review. The report will become part of the final report for the overall project to be completed by the workgroup (Task 5)

For a schedule, the first step of this task will be prioritized to occur in July 2018. DWR has plans to deploy multiple new chlorophyll fluorescence sensors in the summer of 2018. Having initial information from the first step of this task will be helpful for setting up these sensors to be compatible with other major programs. The rest of the task will be completed during the first six months of the project.

Task 2: Coordinate intercalibration exercises that can be used to show the effects of different methods on sensor results

USGS will organize a series of field tests to measure chlorophyll fluorescence using different equipment and methods. Participants in these field tests will include at a minimum USGS, SFEI-ASC, DWR and USBR. The deliverable for this task will be a presentation to the workgroup.

Proposed Field Tests
- Side-by-side deployments by all programs that want to participate. Deployments would be in two locations that span a range of chlorophyll fluorescence and fDOM conditions (Mossdale and Montezuma Slough tentatively). Deployments would be during the summer and fall bloom period in 2018. A minimum of 4-6 weeks of side-by-side data will be collected. All sondes would be installed at the same depth in a common location and, at a minimum, will collect data on water temperature, specific conductance, dissolved oxygen, pH, turbidity, and chlorophyll fluorescence (and BGA and fDOM, if possible). The sondes will be serviced at whatever frequency each program normally uses. At the conclusion of the first side-by-side deployment, the organizers will decide if additional side-by-side deployments or a reproducibility study (described below) should be performed next.

Other Possible Field Studies
- Reproducibility study. This type of study tests for how much variance is due to operator, sonde type, or program protocols. Each program will send up to three technicians with their own calibrated sondes out on a boat together (USGS vessel). The boat will stop at a variety of sites. At each site, each technician will measure chlorophyll fluorescence (averaged over a duration of 10 minutes to reduce noise). Statistical analysis will be used to estimate the 95% confidence intervals (error bars) within and between technicians and programs.

Task 3: Intercalibration study for laboratory chlorophyll-a measurements
Laboratory measurements of extracted chlorophyll-a are used to calibrate and validate in-situ chlorophyll fluorescence measurements. Therefore, any effort to improve comparability in chlorophyll data needs to address variance in both in-situ and laboratory measurements. The proposed intercalibration study would show whether the laboratories in the region report similar results when given a split sample of the same water. Significant differences in the results between labs would trigger troubleshooting by chemists to find and fix the source of the variance.

A. Inventory of the methods used by the major laboratories measuring chlorophyll-a in the Bay-Delta and secure their participation.
   a. The known laboratories for major programs are DWR's Bryte Lab, USGS National Lab, SFSU Romberg Tiburon Center, and UC Davis. All laboratories will be allowed to be anonymous for the purposes of the study.
   b. A standardized survey instrument will be used to capture information on the field and analytical methods used and quality assurance procedures.

B. Implement a "pre-coordination" round of analysis by participating laboratories.
   a. For intercalibration study, the field samples will be collected by USGS during an opportunistic cruise.
   b. Samples will be collected during the summer growth period (July-Oct) at stations where chlorophyll-a concentrations are expected to exceed 5 ug/L.

      c. A total three sampling rounds will be conducted. For each sampling round, one large sample will be collected by peristaltic pump from 1 meter below the surface. This large sample will be delivered to DWR to be split between the participating laboratories using a churn splitter. Each laboratory will receive triplicates of the sample in whatever format they usually require (e.g., a filter, a whole water sample, or something else). Each participating laboratory will receive three replicates of each sample.

      d. For quality assurance, laboratories will also receive samples spiked with known concentrations of an algal culture. This process of "standard addition" will provide information on the accuracy of the methods used.

C. <u>Analyze and report the results of the "pre-coordination" sampling round</u>.

      a. Results of the study will be evaluated by comparing the mean and range of the triplicate samples from each laboratory. For a statistical evaluation of all the data across the three sampling days, the overall mean of all chlorophyll-a measurements from the same day will be subtracted from each individual result from the same day as a measure of deviation from the expected result. One-Way ANOVA will be used to determine whether there are any laboratories with statistically significant differences in the deviations.

      b. Quality Assurance. The measurement quality objectives for chlorophyll-a results by a single lab is presumed to be +/-30%. The goal of the study is to have the between-laboratory variance in this same range. A power analysis indicates that a sample size of 8 for each laboratory is needed to detect 50% differences between laboratories (e.g., for lab means of 10, 10, 10, and 5 ug/L with assumed error of 3 ug/L). Therefore, collecting 3 rounds of triplicate samples (9 samples total for each lab) will have sufficient sample size to detect between laboratory differences of management interest.

D. <u>Organize coordination meeting with laboratories</u>. Hold a meeting with representatives from the participating laboratories to discuss the results and coordinate regarding methods.

E. <u>Prepare final report</u>. The final report will summarize the results of the test, lessons learned, and recommendations.

Task 4: Convene a workgroup to summarize findings and recommendations

A workgroup of key practitioners will meet quarterly in FY18/19 to review the findings from the field and laboratory intercalibration studies. The workgroup meetings in FY17/18 have been highly productive and valued by the participants as a forum to learn from each other and to discuss important issues. The workgroup will review outcomes from the Tasks 1-3 and be responsible for developing a short report with conclusions and recommendations for next steps. Participants in the workgroup will include USGS-WSC, DWR, USBR, and SFEI/ASC at a minimum. At least one person who also sits on the Delta RMP Nutrients Subcommittee will be part of the workgroup. Participation will be open to any other interested parties.

The deliverable for this task will be a summary report with recommendations for next steps taking into account results from Tasks 1-4. The report will be submitted to the Delta RMP committees but is expected to be shared widely among Bay-Delta monitoring program once it is published.

Proposed Deliverables and Timeline

Table 2. Deliverables

Deliverable	Due Date
Task 1: Assessment of in-situ chlorophyll methods in use	Dec. 31, 2018 (final)
Task 2: Presentation to workgroup on field intercalibration exercises	Dec. 31, 2018
Task 3: Report on laboratory intercalibration study	March. 31, 2019
Task 4: Summary report with recommendations for next steps	April 30, 2019 (draft) June 30, 2019 (final)

Table 3. Timeline

Task	2018						2019					
	J	A	S	O	N	D	J	F	M	A	M	J
Task 1 - Assessment of Methods						X						
Task 2 - Field IC Exercises						X						
Task 3 - Lab IC study									X			
Task 4 - Workgroup Meetings			X			X			X			X
Task 4 - Summary Report										X		X

X = Deliverable due
= Activity

Budget

Table 4 shows the estimated costs for this proposed special study.

Table 4. Proposed Budget

Task	Funding Requested for USGS	Funding Requested for SFEI-ASC	Total Funding Requested	In-Kind Contributions (details in justification)
Task 1 - Assessment of Methods	$5,000	$0	$5,000	DWR, USBR
Task 2 - Field IC Exercises	$6,750	$5,250	$12,000	DWR, USBR
Task 3 - Lab IC Study	$4,300	$13,500	$17,800	DWR, USBR
Task 4 - Workgroup Meetings	$10,000	$20,000	$30,000	DWR, USBR
Task 4 – Summary Report	$10,000	$10,000	$20,000	DWR, USBR
Total Funding Requested	**$36,050**	**$48,750**	**$84,800**	
Leveraged In-Kind Contributions				**$104,927**

Budget Justification

Project Costs

Task 1
- USGS will manage this task and prepare a summary report. The cost for this effort is $5,000 (60 hours, mostly project manager time).

Task 2
- USGS will manage the field data collection for this task. The cost for this effort is: $5,750 (56 hours, mostly technician time) + $1,000 for boat, vehicle, and fuel expenses.
- SFEI-ASC will analyze the data from the field exercises and prepare a presentation with the results. The cost for this effort is $5,250 (48 hours of effort, mostly technician time).

Task 3
- SFEI-ASC will coordinate the laboratory intercalibration study and prepare a short summary report with the results. The cost for this effort is $10,000 (70 hours of effort, mostly technician time).
- Up to $3,500 of direct costs are budgeted for sample shipping, supplies, and lab fees. If laboratories agree to participate for free, costs will be reduced.

- USGS will collect the field samples for the field study and be responsible for shipments to the laboratories. The cost for their participation is $3,300 (40 hours mostly project manager time) +$1,000 for boat, vehicle, and fuel expenses.

Task 4
- SFEI-ASC will organize and facilitate 4 quarterly meetings of the workgroup. Assuming 20 hours to prepare and run each meeting (80 hours) plus 40 hours for project management for a total cost of $20,000.
- SFEI-ASC will also contribute to, edit, and ensure completion of the final report (40 hours) for a total cost of $10,000.
- USGS will participate in 4 quarterly meetings and be the lead author in the final report. Total funding required for these tasks is $20,000 (combination of senior scientist and project manager time). This total cost has been split as $10,000 for the workgroup meetings and $10,000 for the report.

Leveraged Funds and In-Kind Contributions

Leveraged funds are cash contributions from another source that pay for a part of the scope of work. In-kind contributions are staff time or resources (e.g., boat time, lab analyses) that are contributed to the project to complete the scope of work.

- The DWR Office of Water Quality and Estuarine Ecology has authorized 6 staff to participate in the study, which is an in-kind contribution of $33,939.
- The DWR North Central Regional Office has authorized 2 staff to participate in the study, which is an in-kind contribution of $19,400.
- The DWR Bryte Lab will analyze 9 water samples for Task 4. Each analysis has a value of $150/sample. Therefore, this service is an in-kind contribution of $1,350.
- The USBR Bay Delta Office has authorized 2 staff to participate in this study and purchase of needed equipment/supplies. This is an in-kind contribution of $20,238.

USGS is also funding a laboratory study on "Developing corrections for observed biases on in situ chlorophyll fluorometers used in real time monitoring". This study is directly related to the objectives of this study. Therefore, its value of $30,000 is also considered leveraged funds.

In FY17/18, the Nutrient Management Strategy for San Francisco Bay contributed $15,000 to Phase I of this effort. This program will likely be willing to contribute a similar amount in FY18/19 but the amount and the type of tasks it will choose to fund are not yet known. The Steering Committee will decide on budgets for FY18/19 in June.

Reporting

The final deliverable from this project will be a technical report to the Delta RMP with the results from FY18/19 tasks and recommendations for future work. The lead author for

the study will be USGS but the report will be *published* by SFEI-ASC. Representatives from other participating organizations will be co-authors. The report will be prepared in the form of a manuscript to facilitate publication of some or all of the findings in the peer-reviewed literature.

Optional Tasks for Future Funding

Achieving the high level goals of this study is expected to take several years. Accordingly, the proposed tasks for FY18/19 do not cover the full range of effort that is needed. The FY18/19 tasks will be useful to understand the scope of the problem, not necessarily to diagnose its causes. The project team anticipates the following tasks will be needed in FY19/20 plus recommendations that come out of the FY18/19 tasks. Furthermore, maintaining consistency and compatibility of water quality monitoring methods in the Delta must be an ongoing effort if it is to succeed. We envision an annual "Bay-Delta Monitoring Training Academy" where technicians can maintain proficiency in standard methods and share innovations.

Extension of Task 2: Coordinate intercalibration exercises that can be used to show the effects of different methods on sensor results
- Share equipment between programs, e.g., exchange of sensors and calibration check standards.
- Embed field crews from different programs to help identify where field methods differ and to share knowledge.
- Purchase 3 probes (sequential serial numbers) for all programs to check for variance in identical sensors and to remove variance from sensors of different ages.

Extension of Task 3: Intercalibration study for laboratory chlorophyll-a measurements
- Implement a "post-coordination" round of analysis by participating laboratories. The approach for this study would be the same as for the "pre-coordination" round. The samples will be collected in April and May 2019. The purpose of the post-coordination sampling round is to show improved correspondence between laboratories after coordination.

Analyze existing data to understand the magnitude of factors affecting chlorophyll fluorescence measurements
- For this task, existing data will be analyzed to understand the magnitude of the impact of other factors on chlorophyll fluorescence measurements. The effects that will be investigated are deployment depth, non-photochemical quenching, fDOM, and turbidity. The deliverable for this task will be a presentation to the workgroup.
- To understand if there is a large offset in chlorophyll fluorescence depending on the depth of the sensor, analyze profile data at sonde locations collected by USBR in the Deep Water Ship Channel (5 years of data). This dataset spans the range of vertical mixing conditions that are likely to be encountered in the Delta. The question to be addressed is: Do measurements of chlorophyll fluorescence at the surface or at the bottom need to be adjusted to be representative of the

overall water column in Bay-Delta channels? At all sites? At certain types of sites?

- To understand if non-photochemical quenching (NPQ) is an important factor, analyze data collected during the day and the night (including grab samples for laboratory analysis from USBR) within the same 24-hour period and with tidal correction. The question to be addressed is: Does NPQ cause enough of an effect in the Bay-Delta that chlorophyll fluorescence data needs to be correct for this factor? If there is an important effect, one solution is to only use data collected at night.
- Analyze historic datasets where fDOM and turbidity have been measured to determine the size of the effect that these water quality parameters have on the measurement of chlorophyll fluorescence. It has already been established that these parameters do affect chlorophyll fluorescence measurements. In some cases, fDOM sensors have direct interference with fluorometers. However, the magnitude of this effect and recommendations for correcting for it need to be determined. The question to be addressed is: How large of an effect do fDOM and turbidity have on chlorophyll fluorescence measurements in the Bay-Delta? Laboratory experiments are needed to investigate direct "cross talk" between fluorometers and fDOM sensors. That type of experiment is not proposed for this study.

Develop standardized methods for in-situ fluorometers
- Standardized methods would improve the consistency of data collection across the Bay-Delta. If the methods assessment (Task 1) and side-by-side deployments (Task 2) indicate the need for standardization and the major monitoring programs are willing to change their protocols, then a methods manual could be developed.

Training for water quality monitoring technicians
- Hold a training for larger audience of technicians to disseminate the lessons learned and common field protocols.

Analyze and collect data to relate chlorophyll fluorescence data to phytoplankton biomass
- A long-term goal is to be able to use chlorophyll measurements to make accurate assessments of phytoplankton biomass to inform important management questions about productivity, nutrient management, and fisheries. The FY18/19 workplan is focused on improving the comparability of just the chlorophyll measurements. In order to be ready for the next phase of the study, data to relate chlorophyll to actual phytoplankton biomass should be analyzed. Some data are already being collected as part of other studies (e.g., picoplankton and taxonomy at some USGS stations). Additional data may need to be collected in other locations to round out the dataset. Adding more sensors to some moored stations to create "superstations" where the relationships between these sensors and chlorophyll fluorescence is another option. Interpretation of phytoplankton taxonomy data will require expanding the expertise in the workgroup to cover this discipline.

References

Bergamaschi, B.A., Downing, B.D., Kraus, T.E.C., and Pellerin, B.A., 2017, Designing a high-frequency nutrient and biogeochemical monitoring network for the Sacramento–San Joaquin Delta, northern California: U.S. Geological Survey Scientific Investigations Report 2017–5058, 40 p., https://doi.org/10.3133/sir20175058.