# Delta RMP Special Study Proposal

## Merging High-Frequency Water Quality Data and Models to Gain Insights into the Factors Regulating Phytoplankton Blooms in the Delta in WY2016

Summary:
For this study, we propose to combine a hydrodynamic-biogeochemical model of the Delta in WY2016 with water quality measurements in order to understand what caused large phytoplankton blooms in this year. The approach will be to apply a biogeochemical model developed for WY2011 to WY2016 and then to compare the model predictions to measurements made throughout the Delta. Comparisons between the model and observations will provide insight into important mechanisms for phytoplankton productivity including physical and other influencing factors. The study will be a first step toward implementing priority research recommendations in the Delta Nutrient Research Plan. The study design leverages $24,000 of in-kind modeling resources from the Department of Water Resources and takes advantage of $900,000 of studies that are funded by other parties. Finally, this project implements a recommendation to increase data sharing among different models and monitoring programs.

Estimated Cost: $186,000

Oversight Group: Delta RMP Nutrients Technical Subcommittee

Proposed by: SFEI-ASC, USGS, DWR

## Background

Nutrient management is high-profile issue in the Delta. Nutrients are among the first-order factors that shape phytoplankton productivity, which is important for understanding pelagic organism decline. The Sacramento Regional County Sanitation District is already investing over $1 billion in wastewater treatment upgrades to manage nutrients. The Central Valley Regional Board recently completed a draft Delta Nutrient Research Plan which listed harmful algal blooms, increased aquatic macrophytes, and low dissolved oxygen as other water quality concerns associated with nutrients (Cooke et al., in review).

For this study, we are proposing a synthesis of monitoring and modeling tools to better understand the linkage between nutrients and the phytoplankton blooms that occurred in WY2016 taking into account physical and other factors. The approach is directly relevant to Research Recommendation MON1 from the Delta Nutrient Research Plan. This recommendation calls for monitoring to assess “physical, chemical, and biological factors affecting phytoplankton abundance and growth” (Cooke et al., in review). The combination of data synthesis and modeling proposed for this project will provide insight into all of these factors.

The proposed project is designed to take advantage of two existing efforts that are funded by other parties. The Regional Water Control Boards (RB2 and RB5), Sacramento Regional County Sanitation District, Delta Stewardship Council, and Central Contra Costa Sanitary District are funding a project to develop, calibrate, and validate a biogeochemistry model for the Delta-Suisun in WY2011 (a year with low productivity). SFCWA is funding a project to synthesize data related to phytoplankton blooms in the Delta in WY2016 (a year with higher productivity) and prior years. The total investment for these two projects is nearly $900,000.

The study design is to apply the WY2011 biogeochemical model to WY2016 to allow for comparison between model predictions and observations of phytoplankton during this year of lower rainfall and higher productivity (see Figures 1 and 2). The comparison between the model and observations will provide insight into important mechanisms for phytoplankton productivity. Finding a mutual set of model parameters that work for both ends of the spectrum in terms of productivity (i.e., years with low or high productivity) will also help to narrow down the choice of biogeochemical model parameters for the Delta, from which the WY2011 Delta-Suisun modeling effort can also benefit.

Finally, this project implements a recommendation from the white paper on modeling that was prepared for the Delta Nutrient Research Plan (Trowbridge et al, 2016). One concept from that report was that being able to share information between different modeling groups "would be economical, lead to more efficient model applications (shorter project timelines), and increase opportunities innovation because more resources would be available for modeling" (p.24-25). This study will put this concept into action by using hydrodynamics from DWR's SCHISM finite element platform and biogeochemistry from the Deltares Flexible Mesh finite volume platform. The project will develop code to facilitate future data sharing across these two platforms. Further, it will promote the sharing of information between modeling efforts, monitoring and research to help streamline the integration of new findings in biogeochemical models.

## Study Objectives and Applicable RMP Management Questions

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

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

| Delta RMP Management Question & Assessment Question | Study Objectives | Example Information Application |
|---|---|---|
| Management Question: Which sources and processes are most important to understand and quantify?<br><br>Assessment Questions: SPLP1- "Which sources, pathways, and processes contribute most to observed levels of nutrients?"<br><br>SPLP2 - "How are nutrients linked to water quality concerns such as harmful algal blooms, low dissolved oxygen, invasive aquatic macrophytes, low phytoplankton productivity, and drinking water issues?"<br>A. "Which factors in the Delta influence the effects of nutrients on the water quality concerns listed above?" | Set up and run a coupled hydrodynamic and biogeochemical model to simulate the nutrients and phytoplankton in the Delta in WY2016 by combining WY2016 hydrodynamics with a biogeochemical model developed for WY2011.<br><br>Compare the modeled results for nutrient concentrations and phytoplankton with the measured observations for WY2016.<br><br>Synthesize important differences between the model and observations to understand the processes that need to be improved in the model.<br><br>Analyze the modeled results for WY2016 to identify the major factors that caused the observed phytoplankton blooms in that year.<br><br>Demonstrate data sharing between different model platforms. | This project will accelerate biogeochemical model development in the Delta. If predictions match reality, then modelers will have confidence that the model parameterization is broadly applicable. If not, then modelers will have insights into what processes need to be improved in the model.<br><br>Managers and researchers will know more about process and factors (especially physical factors) that resulted in the large algae blooms in WY2016.<br><br>Data collection agencies and modelers will know more about which monitoring stations are useful for validating models.<br><br>Managers and modelers will gain experience and know the pros/cons of sharing data between model platforms. |

## Approach

Task 1: Obtain hydrodynamic model input and output files for the Delta in WY2016.

DWR will provide input and output files for WY2016 hydrodynamics from the SCHISM model. The hydrodynamics will be validated at multiple locations in the Delta for the following parameters: flow, water level, temperature and salinity. SFEI will work with Deltares to write code to translate the output files to match the requirement of Deltares DWAQ model input. This code is an investment because it can later be used to translate SCHISM output files for other water years.

This approach combines the extensive expertise from DWR on Delta hydrodynamic modeling as well as the power of Deltares Water Quality model (DWAQ) to predict sophisticated biogeochemical cycling processes in aquatic systems. Developing systems for sharing data across model platforms is consistent with the “community modeling” approach outlined in the Modeling Strategy White Paper (Trowbridge et al., 2016).

Due to the differences in the model platforms, there is a small amount of risk that the SCHISM model output cannot be translated to the Deltares DWAQ format. As a backup, if it is not possible to use the SCHISM model output, the funds can be redirected to a subcontractor to develop the WY2016 hydrodynamics for the Deltares Flexible Mesh model. Therefore, a first step for this task will be for DWR to provide the SCHISM model output for an earlier year (e.g., WY2011) so that Deltares can identify any major barriers right away.

Task 2: Prepare boundary condition and validation data for the WY2016 biogeochemical model

Measurements of nutrients and nutrient-related parameters in WY2016 are needed to evaluate the model predictions for this year. Fortunately, with funding from SFCWA, USGS is already compiling much of the data that are needed for the modeling. Therefore, for this task, USGS will provide the WY2016 data from USGS and DWR stations that they have compiled for their other project and SFEI will gather other relevant data not already in the USGS database. These data will be formatted to match the input needs for the model and reconciled among data sources, which is not part of the SFCWA effort.

The parameters of interest for discrete grab samples include: chlorophyll-a, ammonia, nitrate, phosphate, turbidity, and dissolved oxygen (and potentially others such as zooplankton biomass, benthic grazer data, silica, and organic nitrogen if available). These data will be formatted and incorporated into the database for Delta/Suisun Bay modeling.

The parameters of interest for high frequency, in-situ sensor data are: nitrate, turbidity, chlorophyll fluorescence, and dissolved oxygen. High frequency data collected by the USGS, DWR, USBR, and other agencies will be compiled. The quality of the high frequency data will be checked by comparing the measured high frequency data with the discrete sampling data at the same or nearby location or reviewing metadata on datasets that have already gone through this step.

The geographic focus of this project is the whole Delta (see Figure 3 for a map of stations that will be included in the study). Much of the data needed, especially in the North Delta, including Cache Slough, and the Central Delta, are already being compiled by USGS through the SFCWA-funded study. For that study, data will be aggregated from the following sources: (a) USGS continuous monitoring stations and underway measurements; (b) DWR continuous monitoring stations; (c) discrete sampling and analysis programs of USGS, IEP, DWR, USBR and RTC; (d) other data as suggested by the community. Data types include temperature, conductivity, pH, turbidity, dissolved oxygen nutrients, chlorophyll fluorescence, chlorophyll concentration, dissolved organic matter fluorescence, phytoplankton abundance, zooplankton abundance, stage, discharge, velocity, precipitation, PAR, $K_d$ and others.

<u>Task 3: Apply the biogeochemical model that has been calibrated/validated for WY2011 to hydrodynamics in WY2016.</u>
A complete biogeochemical model[1] for WY2011 will be developed with funding from other sources by December 2018 (see timeline in Table 3). This model can be applied to WY2016 using the SCHISM hydrodynamic output (Task 1) and data prepared in Tasks 2. This application will not attempt to fully validate[2] the model for WY16 but rather provide some initial evaluation on the performance of the model by comparing the model results to what was observed (see Task 4).

<u>Task 4: Compare model predictions of biogeochemistry in WY2016 to observations.</u>
The water quality data compiled in Task 2 will be compared to the model predictions for WY2016 (Task 3). <u>*The comparisons will be made at stations in all areas of the Delta using a similar approach as the Delta-Suisun modeling project.*</u> In addition, the project will take advantage of the large quantity of new, high-frequency data that is available for the North Delta and Central Delta that is being synthesized for the SFCWA-funded project. The deliverable for this task will be a technical report with:

- Results from data quality checks and other QA/QC on the datasets
- Plots and statistics (e.g., correlation coefficients, root-mean-square-error, and bias) of the performance of the model compared to the observations for dissolved nutrient concentrations and chlorophyll concentrations at various locations throughout the Delta, such as:
    - Concentrations of dissolved nutrients and chlorophyll
    - Spatial distribution of dissolved nutrients and chlorophyll
    - Zones of bloom inception
    - Timing of bloom inception and senescence
- Plots of modeled results for WY2016
- Hypotheses to explain the differences between the biogeochemical model output and observed water quality. The explanations will consider mechanistic relationships between physical factors (such as flow), nutrients, grazers, and chlorophyll. The topics on this list can be investigated in more depth with

[1] Including all the modules for biogeochemical cycling (nutrient cycling, phytoplankton dynamics, benthic grazing, zooplankton, mineralization, and sediment fluxes, and empirical light field).
[2] Data from the boundary conditions will be used to initialize the model; data from interior Delta stations will be used to evaluate and validate the model performance.

scenario tests using a fully calibrated model in a second phase of the study.
- Insights from the model about processes and factors (especially physical factors) that resulted in the large algae blooms in WY2016 as well as inferred rates of nutrient transformation and uptake.
- The monitoring stations that appear to be especially useful for validating biogeochemical models.
- Lessons learned and the advantages and disadvantages of sharing data between model platforms.
- Code to translate the SCHISM hydrodynamics output files to match the requirement of Deltares DWAQ model input.

The final report for this study will benefit from, not overlap with, the related SFCWA-funded effort. The SFCWA-funded report (due in February 2019) will contain insights into factors that caused the WY2016 phytoplankton blooms based on statistical relationships between phytoplankton abundance and community structure with (a) nutrient concentrations, forms and ratios; (b) temperature; (c) light availability; (d) water source and history; (e) water velocity and wind (as a proxy for turbulence) and discharge; (e) estimated residence time; and (d) events such as stormflows, Yolo bypass outflows and water releases.  In practical terms, these insights will give direction on where to look and what to look for in terms of model validation and dominant processes (Tasks 3 and 4). Similarly, the mechanistic modeling work will provide insights into processes that could not be determined from the statistical analysis.  In this way, the two projects are complementary and synergistic.

For information on progress reporting, see the “Reporting” section later in this proposal.

## Proposed Deliverables and Timeline

**Table 2.** Deliverables

| **Deliverable** | **Due Date** |
|---|---|
| Task 1: Obtain and format WY2016 Hydrodynamics input and output files | December 31, 2018 |
| Tasks 2 and 3: Progress reports (written) and verbal updates to Delta RMP Nutrient Subcommittee members and other stakeholders at quarterly meetings for the Delta-Suisun modeling project. | July 2018<br>January 2019<br>July 2019<br>January 2020 |
| Task 4: Final Technical Report/Manuscript | March 31, 2020 (draft)<br>June 30, 2020 (final) |

**Table 3**. Timeline

| | 2018 | | | | | | | | | | | | 2019 | | | | | | | | | | | | 2020 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J |
| Task 1 - Hydrodynamics | | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | |
| Task 2 - Model Set Up | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Task 3 - Model Application | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Task 4 - Reporting | | | | | | | X | | | | | | X | | | | | | X | | | | | | X | | X | | | X |
| **Related Studies** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SFCWA Study | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Data aggregation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Data analysis | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reporting | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Delta-Suisun WY2011 Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stage 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stage 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stage 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stage 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stage 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

X = Deliverable due
= Activity

<u>Delta-Suisun Modeling Stages</u>
Stage 2: Building a complete biogeochemical modeling framework that includes nitrogen cycling, phytoplankton dynamics, grazing behavior, mineralization, and benthic processes.
Stage 3: Test runs with Stage 2 model. Identifying dominant processes. Refining input data and model structure.
Stage 4: Improve model performance by tuning biogeochemical coefficients.
Stage 5: Adding dissolved oxygen. Scenario testing to answer management questions.
Stage 6: Final reporting.

## 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 | Funding for Contractors | Total Funding Requested | In-Kind Contributions |
|---|---|---|---|---|---|
| Task 1 - Hydrodynamics | $0 | $5,000 | $35,000 | $40,000 | $24,000 |
| Tasks 2 & 3 - Biogeochemical Model Set Up and Application | $20,000 | $66,000 | $0 | $86,000 | $0 |
| Task 4 - Report | $20,000 | $30,000 | $10,000 | $60,000 | $0 |
| **Total Funding Requested** | **$40,000** | **$101,000** | **$45,000** | **$186,000** | |
| **Leveraged In-Kind Contributions** | | | | | **$24,000** |

<u>Budget Justification</u>

Task 1

- DWR will provide the WY2016 hydrodynamics model in-kind.
- The funding requested is for a $35,000 subcontract with Deltares to write code to convert DWR's SCHISM model output to the Deltares Flexible Mesh (DFM) format and $5,000 SFEI-ASC labor (40 hours of SFEI-ASC modeler time) to handle data transfers and contribute to the coding.

Tasks 2 & 3

- For SFEI-ASC: The funding requested is for 3 months of SFEI modeler time ($51,000) and 1 month of Environmental Analyst time ($15,000) to initialize and run the biogeochemical model for WY2016. This step will also include generating plots of model output versus observations.
- For USGS: The funding requested includes $20,000 to support participation in meetings to plan and evaluate integration of high-frequency data with model output, trouble shoot WY2016 data transfer issues, and assist with additional data compilation.

Task 4

- The final report will be a collaboration between SFEI, USGS, and DWR. SFEI-ASC will be the lead author.
- For SFEI: $30,000 is requested for 130 hours of SFEI-ASC technical staff time and 75 hours of Program Manager/Senior Scientist time.
- For USGS: $20,000 is requested for analysis of modeled versus monitored data, and co-authorship of the final report including time to present the findings to Delta RMP committees and respond to up to two rounds of comments. Funding

will also support USGS participation in two project meetings: (1) Meeting to compare monitored and modeled results and plan final steps; and (2) Meeting to finalize main conclusions for final report.

- An additional $10,000 is requested for honoraria for consultants and external reviewers of the final report. The specific expertise needed to evaluate the results of this study is not known at this time. These funds would make it possible to bring in experts in phytoplankton, zooplankton, benthic grazers, or another discipline on an as-needed basis. In addition, the funds could be used for expert reviewers of the final report. Potential reviewers could be: Stephen Monismith from Stanford University, Jim Cloern from USGS, Fei Chai from University of Maine, Wim Kimmerer from San Francisco State University, and Lisa Lucas from USGS. Obtaining an in-kind peer-review through CWEMF will also be pursued. Plans for the use of these funds will be discussed with the Delta RMP Nutrients Subcommittee in advance.

*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.

- DWR will contribute the WY2016 hydrodynamic model output from SCHISM as well as input files with an approximate value of $24,000.

While not strictly “leveraging”, the project will use outputs from two other highly-complementary and well-timed studies as an effective launch pad to maximize the impact of this work.

- Delta-Suisun Modeling with funding from Regional Boards (RB2 and RB5), Central Contra Costa Sanitary District, Sacramento Regional County Sanitary District, and Delta Science Program ($800,000 in total).
- WY2016 Algal Bloom Analysis with funding from the State and Federal Contractors Water Agency ($83,700).

## Optional Tasks for Future Funding

The proposed project will initiate the process of gaining understanding on the mechanisms behind phytoplankton productivity in the Delta. For FY19/20, a second phase of the study could be conducted to:

- Fully validate the WY16 biogeoechemistry model.
- Perform alternative hypothetical scenario runs to isolate the contribution from each forcing factor on causing the bloom event in 2016.

## Reporting

The final report will be prepared in a format such that it can be submitted for publication as a manuscript. This manuscript will be reviewed by the Delta RMP committees following the protocols in the Delta RMP Communications Plan. If the manuscript is delayed, a stand-alone technical report will be prepared for the Delta RMP.

Progress reports (written and verbal) will be provided at semi-annual meetings for the Delta-Suisun modeling project. The Delta RMP Nutrients Subcommittee will be invited to these meetings. Similarly, participants from other, related studies (Operation Baseline, SFCWA study, Delta Smelt Resiliency Study) will be invited to these meetings.

The project will be overseen by the Delta RMP Nutrients Subcommittee so there will be regular updates on progress in that forum.

## References

Cooke, J., C. Joab, and Z. Lu. In review. Delta Nutrient Research Plan, Draft Report. Central Valley Regional Water Quality Control Board, Rancho Cordova, CA. January 2018.

Trowbridge, P.R, M. Deas, E. Ateljevich, E. Danner, J. Domagalski, C. Enright, W. Fleenor, C. Foe, M. Guerin, D. Senn, and L. Thompson. 2016. Recommendations for a Modeling Framework to Answer Nutrient Management Questions in the Sacramento-San Joaquin Delta. Report prepared for: Central Valley Regional Water Quality Control Board, Rancho Cordova, CA. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. Published online: https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2016_0301_final_modwp_w_appb.pdf.

# WY11 vs WY16: Lower Flow

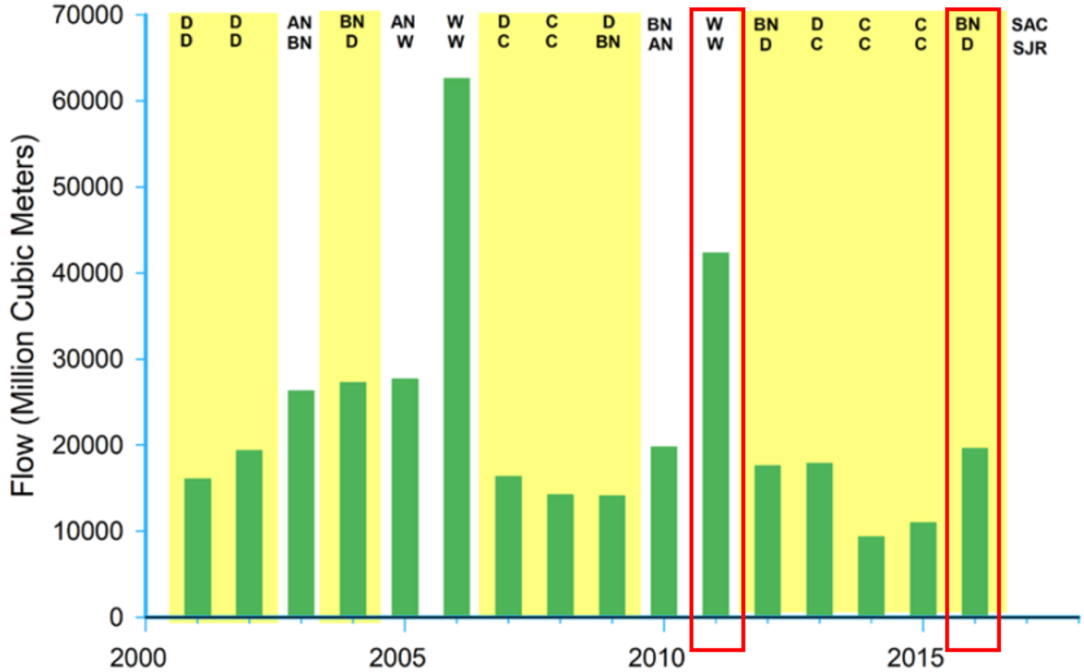


Figure 1: Total flow into the Delta. WY2011 and WY2016 are indicated with red boxes. WY2011 was characterized as a "wet" year. WY2016 was characterized as a "below normal" or "dry" year.

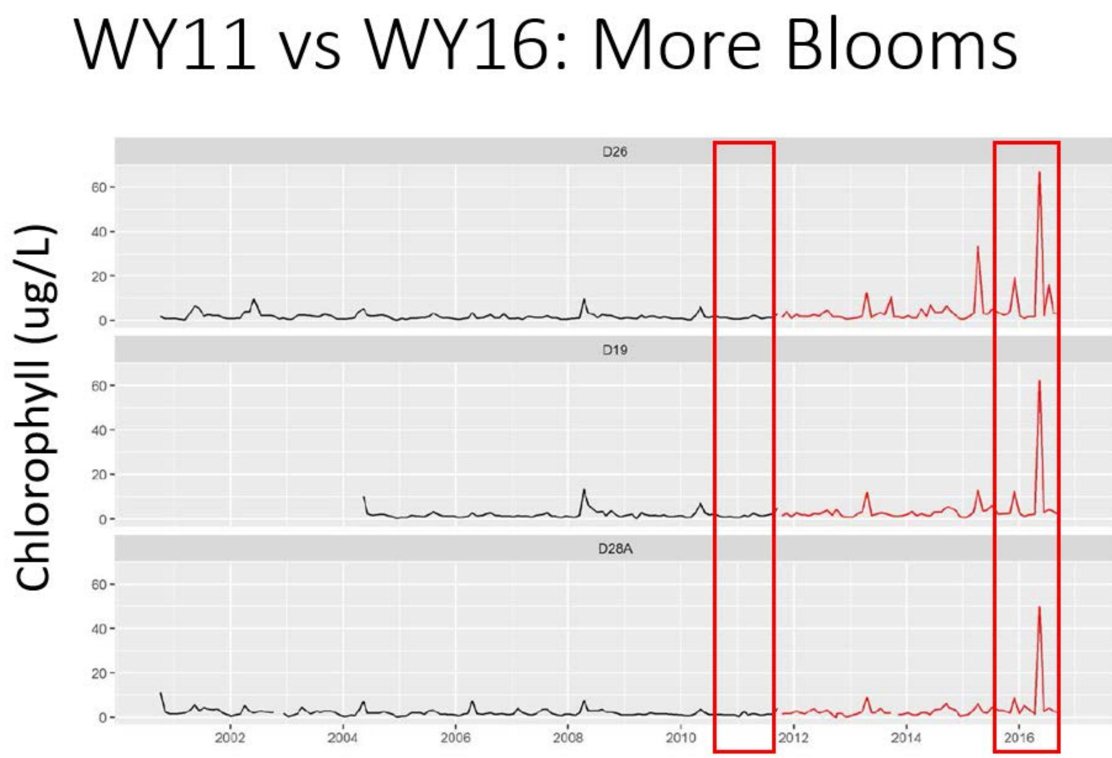


Figure 2: Timeseries of chlorophyll-a concentrations at DWR Environmental Monitoring Program stations in the Central Delta. WY2011 and WY2015 are indicated with with red boxes. WY2016 had significantly higher chlorophyll-a concentrations, indicative of algae blooms, than WY2011.

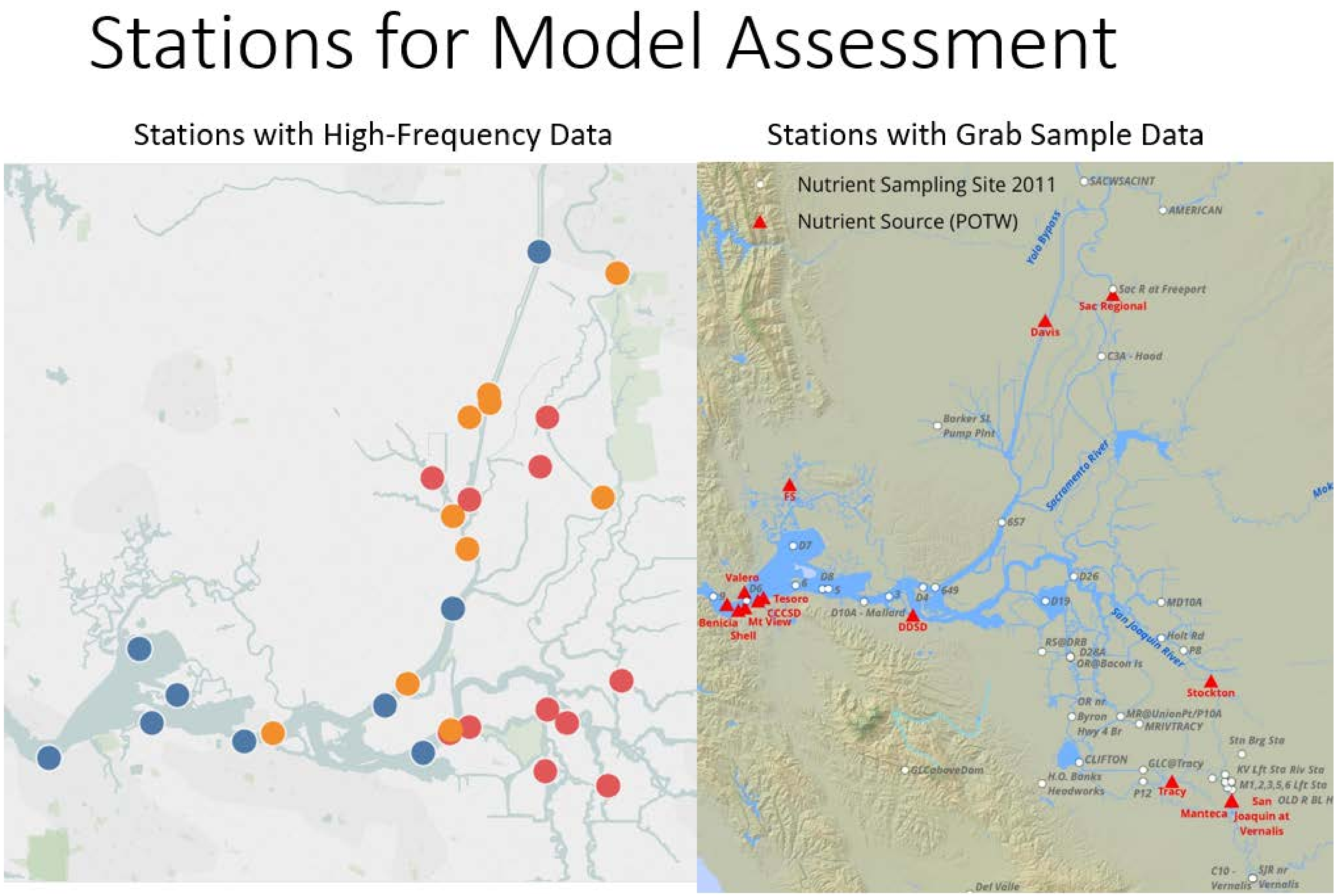


Figure 3: Stations with data that will be used for the modeling analysis. Model verification plots will be made for a subset of these stations covering all areas of the Delta.

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.