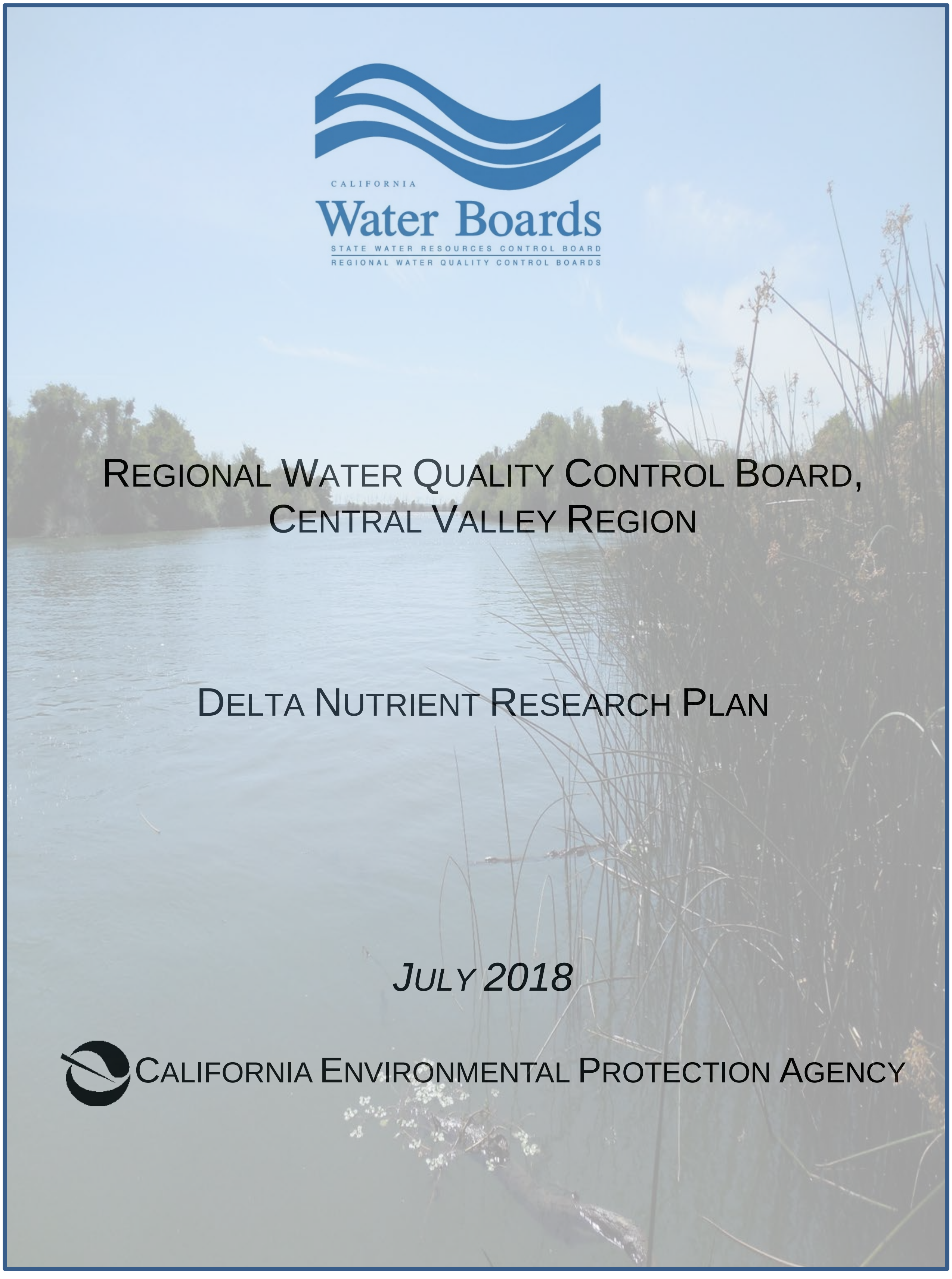

Regional Water Quality Control Board, Central Valley Region

Delta Nutrient Research Plan

July 2018

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D I S C L A I M E R

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DELTA NUTRIENT RESEARCH PLAN

JULY 2018

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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ACKNOWLEDGMENTS

Central Valley Water Board staff deeply appreciates the members of the Delta Nutrient Research Plan Stakeholder and Technical Advisory Group, Science Work Groups, and all others who gave of their expertise and time for this project. The authors are also grateful to Dr. Chris Foe, who began this project and gave it a firm foundation and strong vision.

This Delta Nutrient Research Plan was approved by the Central Valley Regional Water Quality Control Board. During a public meeting on 2 August 2018, the members of the Board unanimously adopted Resolution R5-2018-0059 approving the plan and directing staff to initiate actions described therein.

The cover photo of Miner Slough was taken by Steve Moore, State Water Resources Control Board Member, 04/23/2014

Executive Summary

The goal of the Delta Nutrient Research Plan is to develop and implement a study plan to determine whether numeric water quality objectives for nutrients are needed to address particular water quality issues in the Delta. These problems include: harmful algal blooms (HABs) and associated toxins and nuisance compounds, excess aquatic plant growth, low abundance of phytoplankton species that support the food web, and low dissolved oxygen in some waterways. Directives for development of the Delta Nutrient Research Plan are contained in the Delta Stewardship Council's 2013 Delta Plan and the Central Valley Water Board's 2014 Delta Strategic Work Plan.

The Central Valley Water Board worked with a Stakeholder and Technical Advisory Group (STAG) to develop this plan. Subject-matter experts authored white papers describing the state of science and noted that nutrients are among multiple, interactive drivers of the water quality problems named above. More work to understand nutrients' impacts is needed before nutrient water quality objectives can be considered. From the white papers, knowledge gap reports, and other literature, staff and the STAG compiled recommendations for monitoring, special studies, and modeling. Staff and stakeholders' ranking of research needs and status of current efforts are provided in this document.

Two overarching themes for additional nutrient research emerged:

- Deeper understanding is needed of the ways that physical and ecological factors interact and affect ecosystem responses to nutrients. These factors include light, temperature, hydrology, associations between macrophytes and phytoplankton, grazing effects of clams and zooplankton, and nutrient transformations by microorganisms. Data collections and assessments should be conducted with a holistic consideration of ecological, biogeochemical, and physical factors affecting nutrient responses.

- Numerical, processed-based models are necessary tools for understanding the complex relationships in the Delta and to test management scenarios. Model development should be accompanied by targeted data collection, interdisciplinary data synthesis, and robust data management.

In addition to the scientific information gaps, two additional types of information were recognized as important for evaluation of potential water quality objectives: identification of protective thresholds and policy options utilized in other arenas; and identification of management options and potential resulting changes in nutrient loads.

The Delta Nutrient Research Plan contains a framework and prioritized actions to develop the necessary information. Collaboration between agencies and entities conducting nutrient-related projects will be vital to completion of the activities identified in this plan. Since recommended research and modeling exceeds resources that are presently allocated or identified, staff will continue working with the STAG and others to identify sources of funding and partnerships for implementation actions.

In addition to developing partnerships and securing funding, near-term priorities for Delta Nutrient Research Plan implementation are:

- Completing existing and contracted work supporting the 2014 Delta Strategic Plan
    - Directed low dissolved oxygen assessment,
    - Contracted work for numeric model development, and
    - Herbicide toxicity evaluation on sensitive Delta algal species
- Prioritizing new projects for HAB monitoring and special studies;
- Integrating efforts with the Delta Regional Monitoring Program for both monitoring coordination and building bridges with other agencies;
- Initiating review of nutrient thresholds and policies and developing initial nutrient mass balance framework; and
- Developing a Science Action Plan to systematically fill research gaps through enhanced collaboration and funding opportunities.

The near-term projects prioritize efforts to address HABs due to the health risks represented. Following the general agreement that excess nutrients contribute to the severity (although not initiation) of HABs, it is anticipated that nutrient benchmarks and/or reduction goals will be developed while research is continuing toward potential nutrient triggers, targets and/or water quality objectives.

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1. Introduction

1.1. Problem Statement and Goals

The nutrients nitrogen (N) and phosphorus (P) contribute to water quality problems in the freshwater Sacramento-San Joaquin Delta. At a time, nutrient levels were associated only with periodic low oxygen levels in the Stockton Deep Water Ship Channel. However, the Central Valley Water Board now recognizes the need to examine the roles of nutrients in a broader context.

Water quality problems in the Delta related to nutrients include:

- Excess growth of harmful cyanobacteria (hereafter termed harmful algae blooms or HABs) and toxins and taste-and-odor compounds produced by cyanobacteria
- Excess growth of non-native aquatic plants (also termed aquatic macrophytes)
- Low dissolved oxygen in some Delta waterways, located mainly in the southern and eastern areas of the Delta.
- Low concentrations of phytoplankton which are important to the food web for native fish in the estuary (also referred to as low phytoplankton production)

Although nutrients contribute to water quality problems listed above, numeric nutrient objectives to help address the problems have not yet been identified. More information is needed about nutrients and other factors impacting these problems and their variations across the Delta. This research plan identifies research and modeling to fill gaps in our understanding of nutrients' effects and potential responses to changes in nutrient levels in the Delta and provides a strategy to both fill the data gaps and evaluate feasible management alternatives to control nutrient concentrations.

The primary geographic scope for examining nutrient-related impacts is the Sacramento-San Joaquin River Delta (Figure 1). Figure 2 provides a pictorial representation of nutrient issues. Concerns about low primary production span the north Delta and Suisun Bay. Nutrients from the Delta are also an issue with respect to HABs and taste and odor problems experienced in drinking water supply systems that utilize Delta water.

The goals of the Delta Nutrient Research Plan are to develop and implement a study plan to provide information which informs whether numeric water quality objectives for nutrients are necessary and appropriate to address identified problems in the Delta and to enable determination of appropriate objectives, if warranted.

Water quality objectives are "…levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses". (Water Code Section 13050(h)). "Beneficial uses" refers to uses of water that may be protected against degradation of quality. The beneficial uses of Delta water are identified in *The Water Quality Control Plan for the*

Sacramento River and San Joaquin River Basins (Basin Plan; CVRWQCB, 2016). The Delta's designated beneficial uses include warm and cold freshwater habitat, navigation, contact recreation, and municipal and domestic supply. Water quality objectives are achieved primarily through regulatory requirements placed on discharges to surface and groundwater. Implementation of management practices and restoration activities through Water Board and other agency programs may help achieve nutrient objectives. Existing water quality objectives that apply to the Delta are contained in the Basin Plan and the Bay-Delta Water Quality Control Plan (SWRCB, 2006).

The Basin Plan contains a narrative water quality objective that water not contain "biostimulatory substances which promote aquatic growths in concentration that cause nuisance or adversely affect beneficial uses". The Basin Plan contains a similarly-worded water quality objective that water not contain taste and odor-producing substances in concentrations that impart undesirable conditions or nuisance (CVRWQCB 2016). Consideration by the Central Valley Water Board of numeric nutrient objectives would be done in the context of these existing narrative objectives.

1.2. Background

Directives for the development of the Delta Nutrient Research Plan (Delta NRP) are contained in strategic plans from the Delta Stewardship Council and the Central Valley Water Board. In 2009, the California Legislature passed the Delta Reform Act, which created the Delta Stewardship Council. The mission of the Council is to implement the coequal goals of the Reform Act of providing a more reliable water supply for California and protecting and restoring the Delta ecosystem, all in a manner that preserves the unique characteristics of the Delta. In 2013, the Delta Stewardship Council adopted the Delta Plan, a management and regulatory plan for achieving the co-equal goals. The Delta Plan contains a recommendation for the Central Valley Water Board to develop a study plan for the development of water quality objectives for nutrients in the Delta.

The Central Valley Water Board incorporated the Delta Plan recommendation into its own 2014 Delta Strategic Work Plan (CVRWQCB, 2014). The Central Valley Water Board's Delta Strategic Work Plan contains nine priority projects in the Delta. Included in the 2014 Delta Strategic Work Plan is direction to develop and implement a plan to determine whether nutrient objectives are needed to protect beneficial uses in the freshwater Delta.

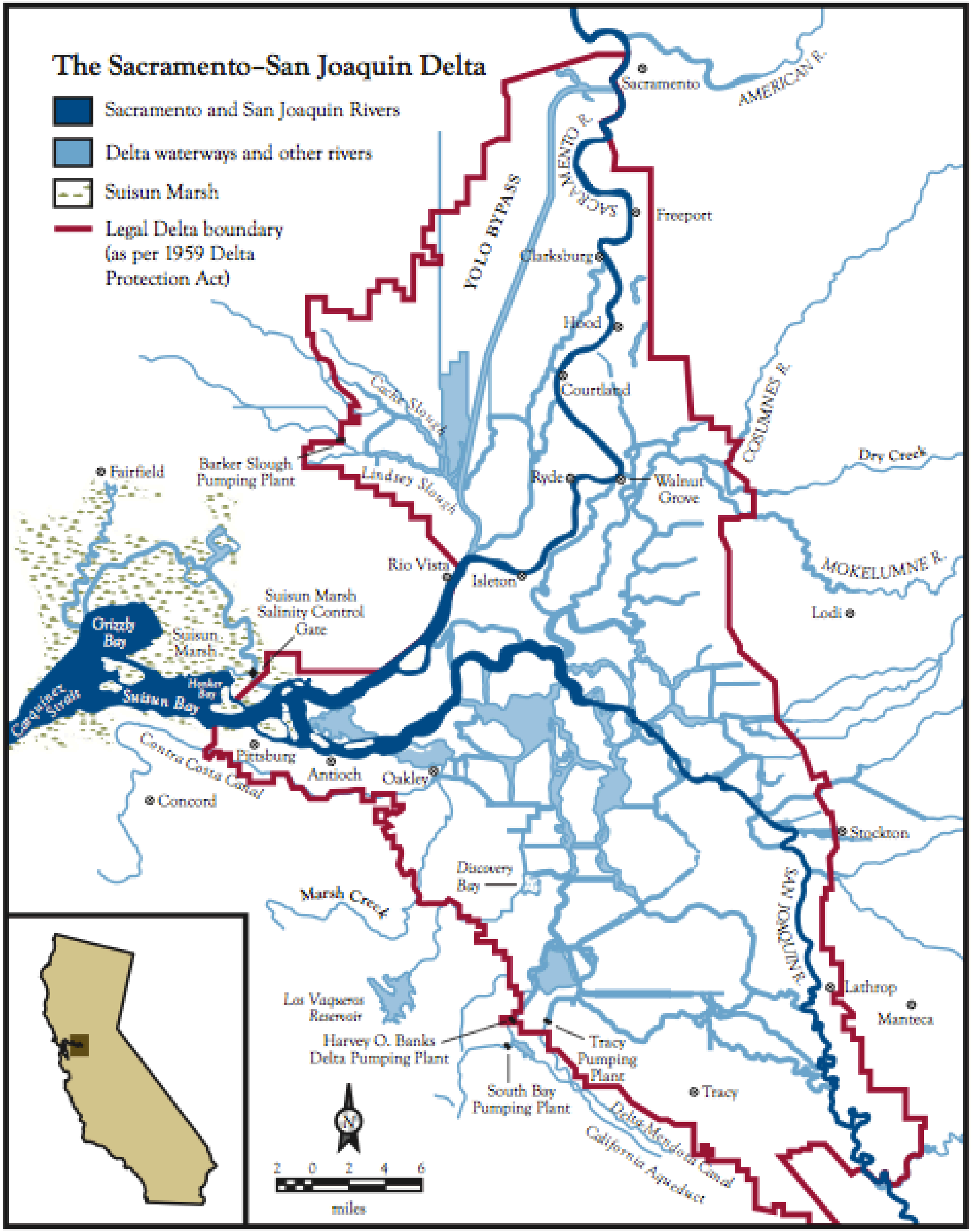

Figure 1. Sacramento-San Joaquin River Delta and Suisun Marsh
(Map: Department of Water Resources)

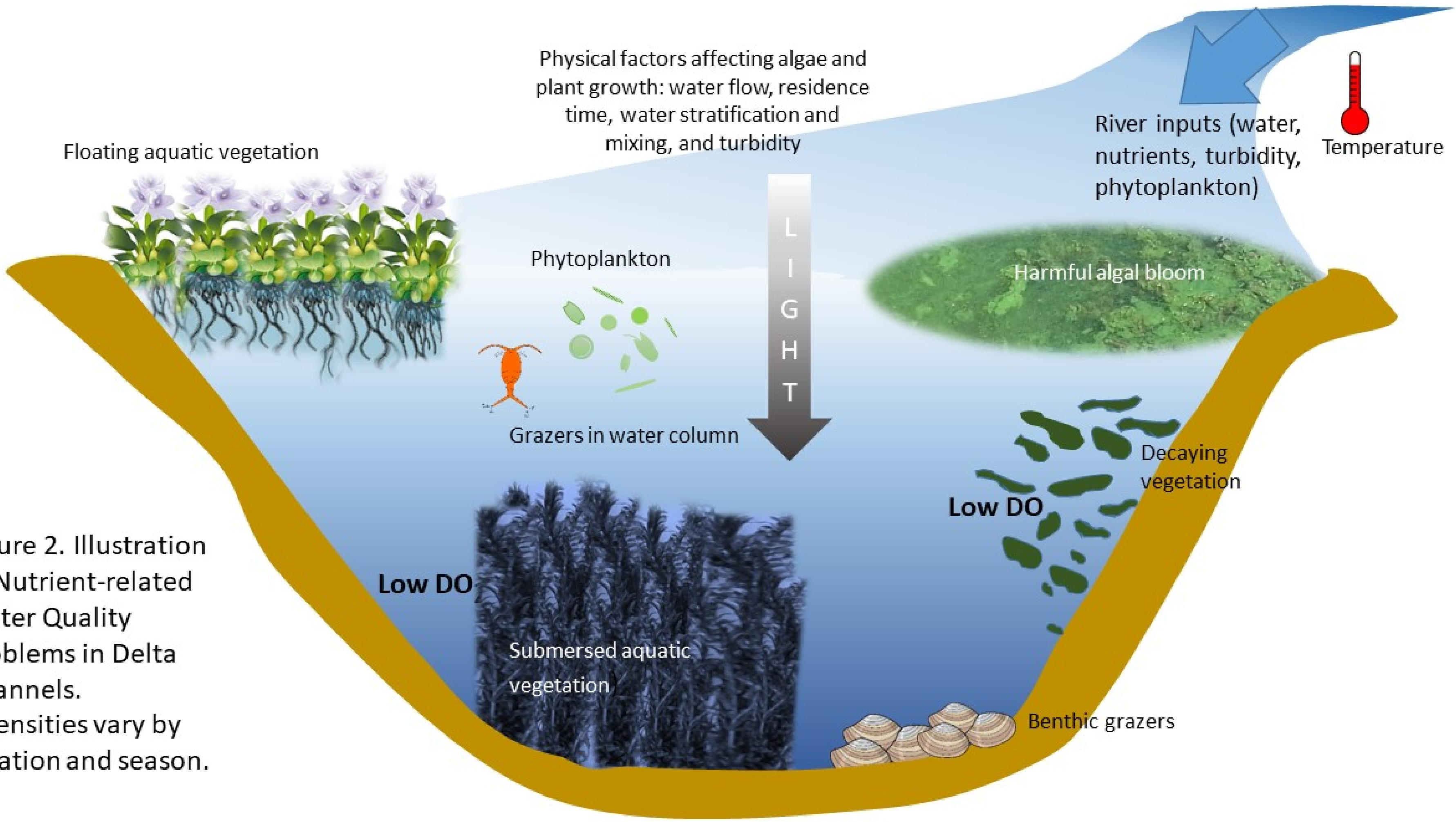

Figure 2. Illustration of Nutrient-related Water Quality Problems in Delta Channels. Intensities vary by location and season.

1.3. Management Questions

The Central Valley Water Board's aim for nutrient research is to produce information that will result in science-based nutrient management and protection of beneficial uses in the Delta. Research conducted under the umbrella of this plan will help answer nutrient management questions. Basic management questions that apply to all of the nutrient-related issues identified in the Delta are listed below.

Management Questions for Delta Nutrient Research

A. Is there a water quality problem?
B. Are nutrients contributing to the water quality problem?
C. Can nutrient management help address or ameliorate the problem?
D. Are particular hydrologic, biological, meteorological, or biogeochemical conditions needed for nutrient management to be effective?
E. How may anticipated future Delta conditions affect the nutrient-related problem?
F. What nutrient management measures are needed to protect beneficial uses now and in the future?

The Management Questions identified above encompass management questions identified by each science workgroup. Each Science Work Group identified management questions relevant to its topic (cyanobacteria, macrophytes, and nutrient forms and ratios) which are documented in the organizing documents for each white paper. The overarching and topic-specific management questions are presented together in Table 1.

Table 1. Management Questions for the Delta Nutrient Research Plan

Basic Management Question	**Related Topic Specific Questions**
Is there a water quality problem?	• What are the spatial and temporal trends in nutrient-related effects in the Delta o Diatom blooms and adequate phytoplankton production o Cyanobacteria blooms and toxins o Biomass of aquatic macrophytes o Low dissolved oxygen • What are the spatial and temporal trends in cyanobacteria blooms, toxins, and taste and odor-causing substances in downstream conveyance and storage facilities? • What are the gaps in our understanding of the problem, including status and trends?
Are nutrients contributing to the problem?	• What is the relative importance of nutrients versus other factors in promoting cyanobacteria dominance and/or cyanotoxin production in the San Francisco Bay-Delta? • How do nutrient concentrations, loads, and cycling affect the growth of aquatic macrophytes? • What are the main factors affecting potential nutrient-related effects and how does the relative importance of these factors vary with space and time? • What are the magnitudes of external sources and internal sources and sinks of nutrients in the Delta, including various nitrogen and phosphorus forms? • What are the important processes that transform nutrients in the Delta and what are the rates at which these processes occur? • Have within-Delta nutrient sources been adequately quantified? • How significant is recycling of N and P from decaying macrophytes and other organic matter In the Delta?
Can nutrient management help address or ameliorate the problem?	• Can nutrient management limit the occurrence or severity (frequency, magnitude, and/or toxin concentrations) of harmful algal blooms? • Can nutrient management reduce the severity (density of plants and/or spatial coverage) of macrophyte growth? • Can nutrient management increase abundance or nutritional quality of pelagic phytoplankton? • What are potential unintended consequences of nutrient management to address any of the water quality issues? • What is the level and type of changes in nutrients needed to affect change in HABs, macrophytes, or phytoplankton abundance?
Are particular hydrologic, biological, meteorological, or biogeochemical conditions needed for nutrient management to be effective?	• What combination of factors caused phytoplankton blooms in 2015 and 2016 in northern and western Delta? • Is nutrient management alone sufficient to limit cyanobacteria bloom frequency, magnitude and/or toxin levels? • Is nutrient management alone sufficient to control density and areal extent of macrophytes?

Basic Management Question	Related Topic Specific Questions
	• What combinations of nutrient management and other management actions are likely to achieve equal levels of benefit with regard to macrophyte management?
How may anticipated future Delta conditions affect the nutrient-related problem?	• What are the most likely alterations in nutrient conditions due to o climate change, o Delta habitat restoration, and o changes in nitrogen forms and loads? • How will climate change affect frequency and magnitude of HAB, macrophytes, and phytoplankton abundance and species distributions?
What management of nutrients is needed to meet beneficial uses now and or in the future?	• What level of nutrient management would be needed to support control of harmful algal blooms and algal toxin production? • What level of nutrient management would be needed to support control of invasive aquatic macrophytes? • What nutrient levels are needed to support adequate primary production and a healthy food web, particularly for endangered fish species? • Are the necessary nutrient levels described above achievable through coordinated control of nutrient sources? • What loads of nutrients can the Delta assimilate without adversely affecting beneficial uses?

2. Process of Nutrient Research Plan Development

Steps in developing the Delta NRP included convening a stakeholder work group, engaging experts to prepare white papers describing the state of science and research recommendations, identifying prioritization criteria, prioritizing research recommendations, and revising a January 2018 draft version Delta NRP in response to public comments.

Staff began development of the Delta NRP by convening a stakeholder and technical advisory group (STAG) which met regularly to help shape the process and components of the plan. STAG members represent a range of interests involved in and potentially affected by water quality objectives and management of nutrients in the Delta, including permitted dischargers, water supply, resource management agencies, and environmental justice. Eighteen STAG meetings were held between September 2014 and May 2018. The STAG completed its formal Charter in July 2015. The STAG provided recommendations to Water Board staff on technical and policy aspects of the plan. The STAG also helped to identify members of science work groups and white paper authors. All STAG meetings were advertised and open to the public.

The core of the Delta NRP is recommendations for research to fill gaps in our understanding of the effects of nutrients. To establish the state of the science and identify information gaps, staff and the STAG commissioned a set of white papers on factors controlling harmful cyanobacteria blooms and invasive aquatic macrophytes, development of nutrient numerical models, and relationships of nitrogen forms and concentrations to phytoplankton growth and species composition. Science Work

Groups comprised of subject experts and interested parties formed for each of the topic areas. Participants are listed in Appendix 1. In addition, subcommittees of the STAG prepared papers on drinking water issues related to nutrients and anticipated changes to Delta nutrient loads based on new source controls scheduled to be complete in 2021.

Subject-matter experts were engaged to write the white papers. Processes for involving other researchers varied by topic. For cyanobacteria and macrophytes, each Science Work Group reviewed its corresponding white paper and developed a companion Knowledge Gaps document, which added specificity to broad data gaps named in the white paper. For modeling and drinking water, input from the corresponding Science Work Group was incorporated into white paper.

Development of the nutrients and phytoplankton white paper was challenging. There have been persistent disagreements about phytoplankton changes in the Delta and Suisun Bay and the importance of ammonium and nitrogen:phosphorus (N:P) ratios. In November 2016, the Delta NRP STAG and the San Francisco Bay Nutrient Management Strategy jointly hosted a public workshop in front of an external, independent panel. Following the public workshop, the external panel members wrote the nutrients and phytoplankton white paper (Ward and Paerl, 2017). Two research groups that did not participate in the workshop submitted a response to the white paper (Wilkerson et al., 2017). These comments were reviewed and considered. The final nutrients and phytoplankton white paper is a single document, with additional material contained in workshop presentations and comments on the white paper.

Information utilized in the development of the Delta NRP, including white papers and knowledge gap reports, meeting records, video of the Nutrients and Phytoplankton workshop, prioritization process development, comments and references are available on a set of Water Board webpages related to the plan, which are accessible here: (https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/index.shtml).

3. State of Science of Nutrient-Related Issues

Central Valley Water Board staff and stakeholders spent nearly two years reviewing information and producing topic-specific white papers and knowledge gap reports about nutrient-related concerns and a white paper on effective computer modeling. This section summarizes the state of science supported by the white papers. Section 4 discusses research recommendations identified in the white papers and knowledge gaps reports. Readers are encouraged to make use of the full documents. In addition to the white papers, knowledge gaps reports, and phytoplankton workshop materials, the Delta NRP draws on other summaries of nutrient impacts and representations of information needs (Meyer et al., 2009; National Research Council 2012; Dahm et al., 2016).

3.1 Blooms of Harmful Cyanobacteria

Cyanobacteria blooms in the Delta comprise a serious emerging problem that warrants more research (Berg and Sutula, 2015; Delta Cyanobacteria Science Work Group, 2015; Delta Drinking Water Work Group, 2017). *Microcystis* is the most common HAB species in the Delta and has been regularly observed in various locations since 1999 (Lehman et al., 2015). Other toxin-producing species and toxins have been detected in the Delta, but there is no comprehensive monitoring program to make a full assessment of risks to people, pets, and aquatic life. Cyanobacterial toxins affect drinking water systems that utilize Delta water.

The cyanobacteria white paper identifies five principal factors that regulate cyanobacteria blooms: water temperature, light availability, water residence time and stratification, availability of nutrients at growth-limiting levels, and salinity (Berg and Sutula, 2015).

On the role of nutrients in HABs, the white paper authors wrote:

> The initiation of Microcystis blooms around 1999 in the Delta was probably not associated with changes in nutrient concentrations or their ratios. However, as with all phytoplankton blooms, once initiated, cyanoHABs cannot persist without an ample supply of nutrients. It is important to keep in mind that while nutrient reduction may not limit the onset or frequency of bloom occurrence, it will limit bloom duration, intensity and possibly also geographical extent. If, in the future, nutrient concentrations were to decrease to the point where they start to limit phytoplankton biomass, then the magnitude of the nutrient pool, as well as seasonal changes in the magnitude, would impact cyanoHAB concentration, distribution and bloom duration (Berg and Sutula, 2015 pg. 46).

Because *Microcystis* grows relatively slowly, long water residence times are likely important in the location and timing of *Microcystis* blooms (Lehman et al., 2008; 2015; See Downing et al, 2016; Jabusch et al 2018; Kimmerer and Nobriga, 2008 for residence times). Increases in *Microcystis* abundance are correlated with low flow rates in the San Joaquin River and other parts of the Central Delta (Lehman et al, 2013).

Further research is necessary to evaluate whether *Microcystis* and other toxin-producing cyanobacteria could be constrained by nutrient reductions. Cyanobacteria can acquire nitrogen for growth from various forms in the water column, including ammonium, nitrate and urea. Cyanobacteria have a high metabolic demand for nitrogen, which is seen in a high cellular N:P ratio. In an assessment of water bodies outside the Delta, the *Microcystis* genus tends to dominate in waters with excess nitrogen (Paerl et al, 2016). In laboratory tests and in examinations of cells growing in the Delta, *Microcystis* readily utilized ammonium in the water column (Lee et al; 2015; Lehman et al, 2013, 2015). These observations suggest that reductions of nitrogen in the Delta to growth-limiting levels could lessen HABs. Decreases in ammonium and nitrogen loads that the Water Board has already required to be implemented are described further in section 3.6.

3.2 Invasive Aquatic Plants

There are more than 15 species of submersed and floating aquatic plants, both native and non-native, in the Delta. Brazilian waterweed (*Egeria densa)*, water hyacinth (*Eichornia crassipes)*, and Uruguay water primrose (*Ludwigia spp)*, which are non-natives, currently top the list as the most noxious. These species can grow in dense colonies, thereby affecting water quality by causing daily fluctuations in pH and dissolved oxygen, reducing flow and turbidity, and increasing water temperature. Macrophyte colonies also impede navigation and recreational activities. Brazilian waterweed and water hyacinth decrease turbidity and flow rates to such an extent that the changes support the weeds' own expansion.

The California Division of Boating and Waterways is authorized by State statue to operate programs of control for aquatic plants in the Delta. Control of submersed aquatic vegetation (SAV) is primarily by chemical treatment. The floating aquatic vegetation (FAV) control consists of chemical treatment supported by physical removal and biological control methods.

Analyses of data obtained via satellite and airborne surveys show that between 2008 and 2014, the area occupied by invasive aquatic vegetation increased from 7,100 to 11,360 acres (Ta et al., 2017). Factors that control growth of invasive aquatic plants are light, temperature, salinity, dissolved inorganic carbon, nutrients, flow and residence time (Boyer and Sutula, 2015). Authors of the macrophyte white paper concluded that there is an ample supply of nitrogen and phosphorus in the Delta to support macrophyte growth. As one illustration, biomass of invasive macrophytes has increased significantly in the past decade, while concentrations of nitrate, ammonium, phosphorus, and ratios of N:P have remained relatively constant.

> On the role of nutrients in macrophyte growth, the white paper authors and science work group concluded that management of nutrients alone is not expected to be sufficient to control macrophytes in the Delta. More study is needed to determine whether nutrient reductions could boost effectiveness of aquatic weed control measures currently in use. Significant information gaps regarding aquatic plants in the Delta include: comprehensive monitoring of various aquatic plant species over seasons and locations and responses of aquatic plant species to nutrient concentration changes (Boyer and Sutula, 2015; Delta Macrophyte Work Group, 2016).

3.3 Nutrients and Phytoplankton

Previous work on the effects of ammonium on phytoplankton growth and the potential importance of N:P ratios formed the back-drop of questions for this white paper. Nutrient inputs from Sacramento River support phytoplankton production across the North Delta and in Suisun Bay. The white paper authors concluded that the Delta science community needs a deeper understanding of the ways that physical factors, such as light and hydrology, affect the responses of the Delta ecosystem to nutrients (Ward and Paerl, 2017). They stressed that analyses should examine relationships between nutrients and phytoplankton in the context of physical and biological factors that also affect phytoplankton growth and concentrations. The authors advocated a more holistic examination of transformations and cycling of nitrogen, as well as phosphorus and organic carbon. Integration of nutrients and other drivers is needed to develop a quantitative understanding of phytoplankton responses to nutrients. Studies that examine biogeochemical processes will set the stage for modeling, which is needed to predict how future events, including climate change, will affect the ecosystem’s responses to nutrients.

3.4 Water Quality Modeling

Numeric, process-based water quality models are used to understand the complex, sometimes non-linear nutrient-related processes and to test scenarios of the future. All of the other white papers called for development and use of process-based modeling.

To address the nutrient management questions in the Delta, modeling will need to include hydrodynamics, nutrient concentrations, water quality, primary productivity, benthic and pelagic grazing, sediment transport, and macrophyte-related processes (Trowbridge et al., 2016). The modeling white paper describes modeling goals, estimated costs and a phased approach that builds on existing, mostly hydrodynamic (flow) models. No one model can incorporate all processes, such as flow, sediment transport, algal growth, and nutrient cycling. The white paper describes links between models of hydrodynamics and of water quality and biotic components. The white paper authors recognized that model development will take time and recommended a two-stage process. In the first stage, model components for water quality processes would be added to existing hydrodynamic models and tested. In the second stage, model components would be refined to add complexity and algorithms obtained in the first stage transferred to more complex models.

3.5 Drinking Water Issues

The drinking water white paper identified problems and research gaps related to cyanobacteria blooms and macrophytes at drinking water intakes and in conveyance and reservoir systems that utilize water from the Delta (Delta Drinking Water Work Group, 2017). Excess macrophytes at water intake structures must be managed to prevent clogging. Blooms of toxin-producing cyanobacteria impact drinking water supplies and recreation in the reservoirs. Drinking water systems also can experience episodes of objectionable taste and odor issues caused by chemical compounds geosmin and 2-methylisoborneol (MIB). These chemicals are produced by cyanobacteria species that are different from those that produce toxins.

The research needs associated with nutrients and drinking water issues in the Delta overlap substantially with research needs identified for issues of HABs and invasive aquatic plants in the Delta. Opportunities for collaboration and data sharing with monitoring and study efforts focused on conveyance and storage facilities should be considered. Field and laboratory studies are needed to better understand how nutrients and other factors in the Delta affect the occurrence and abundance cyanobacteria that produce toxins and taste-and-odor compounds in downstream water conveyance and reservoir facilities.

3.6 Future Delta

The water quality issues described above are expected to continue in some form as the Delta changes. Over the backdrop of natural variations in precipitation and temperature, human management actions and climate change will continue to impact physical conditions (e.g., hydrology and water temperature) and water quality. The Delta is dramatically shaped by human activities of past and present. Alterations in land use water management, and aquatic species introductions have permanently changed Delta ecosystems.

Major changes anticipated for the Delta that will affect nutrient loads, concentrations, and N:P ratios include reductions in nutrient discharges from municipal wastewater treatment facilities. Three major projects planned for completion within the next decade are estimated to decrease loads of total nitrogen entering the Delta by about 13% (load data from Systech, 2011 and West Yost Associates, 2011). These major projects described below.

1. Significant upgrades to the Sacramento Regional County Sanitation District (Regional San) wastewater treatment facility (the EchoWater Project) are expected to reduce loads of ammonium and total nitrogen discharged from Regional San to the Sacramento River by 99 and 78 percent, respectively (loads calculated as daily averages; Krich-Brinton and Grovhoug, 2017). Nitrogen removal capabilities of Regional San's upgrades are planned to be complete in 2021.
2. A more than 90% decrease in ammonium and total nitrogen loads discharged to the San Joaquin River from the Cities of Modesto and Turlock is anticipated by 2020, as part of the North Valley Regional Recycled Water Program. As part of this program, most tertiary-treated wastewater from the Cities of Modesto and Turlock will be discharged into the Delta Mendota Canal instead of the San Joaquin River. Phosphorus loads discharged to the San Joaquin River will also decrease due to the Modesto and Turlock diversions.
3. Addition of denitrification treatment and other improvements at the Stockton Regional Wastewater Control Facility will decrease nitrogen inputs to the San Joaquin River within the Delta. A 25% decrease in total nitrogen loads discharged from the facility is anticipated by 2024.

Adding to the challenge of understanding and managing Delta water quality are the effects of human-induced climate change. Increases in temperatures, shifts in amounts and timing of precipitation, increases in magnitude of high-flow and flood events, increasing frequency of climatic extremes, and sea level rise are expected to impact hydrology and habitats within the Delta (Climate Action Team 2010; Cloern et al., 2011; Delta Stewardship Council 2018; Lehman et al., 2013). Likely consequences of climate change are changes in nutrient loads and algal blooms (Ward and Paerl, 2017). Alterations to precipitation patterns will change timing and magnitudes of nutrient loads entering the Delta via runoff. Increased water residence time and stratification, which are fostered in drought conditions, are drivers of harmful algal blooms. Higher water temperatures favor growth of some harmful bloom species, including *Microcystis*, relative to other phytoplankton taxa. We do not know if harmful algal blooms will be more severe or frequent in the future Delta. Scenarios related to climate change should be incorporated into modeling and management planning (Ward and Paerl, 2017).

4. Monitoring, Special Study, and Modeling Needs

At the core of this Delta NRP are recommendations for further work to better understand nutrients in the Delta. The white papers support the conclusion that while nutrients are not the primary factor in the problems described in Section 3, their contributions are significant and warrant further work before decisions can be made regarding potential nutrient water quality objectives. In addition to synthesizing recent literature, authors of the white papers and Science Work Groups identified specific information and data needs in three broad categories: monitoring, special studies and computer modeling (Tables 2a, 2b, and 2c, respectively). After compiling information needs, staff and stakeholders completed two additional steps: 1) prioritization of information needs; and 2) identification of projects currently helping to fill the gaps. Results of the prioritization process and existing efforts are also presented in Tables 2a, 2b and 2c and discussed further in Section 5.

Two overarching themes encompass the Delta nutrient research needs:

- Deeper understanding is needed of the ways that physical and ecological factors interact and affect ecosystem responses to nutrients. These factors include light, temperature, hydrology, associations between macrophytes and phytoplankton, grazing effects of clams and zooplankton, and nutrient transformations by microorganisms. Data collections and assessments should be conducted with a holistic consideration of ecological, biogeochemical, and physical factors affecting nutrient responses.

- Numerical, processed-based models are necessary tools for understanding the complex relationships in the Delta and to test management scenarios. Model development should be accompanied by targeted data collection, interdisciplinary data synthesis, and robust data management.

4.1 Summaries of Information Gaps for Nutrient-Related Issues and Current Activities

4.1.1. Process-Based Computer Models

Computer models are needed to better understand the roles of nutrients and potential outcomes of management. The Delta ecosystem is highly complex. Some ecosystem responses to nutrients are nonlinear and therefore not apparent when using graphical depictions of data and simple statistical tools. Testing predictions of nutrient–related ecosystem responses under scenarios of possible future nutrient management, water management, climate, and other conditions requires models. Modeling will need to include hydrodynamics; hydrology; sediment transport; nutrient concentrations, cycling, and transformations; light availability; temperature; growth of phytoplankton and other primary producers; grazing by clams, other benthic species, and zooplankton; and macrophyte growth and contributions to nutrient cycling. Terminology that includes all of the above is "biogeochemical modeling" of nutrients. The modeling white paper developed to support the Delta NRP provides details to guide efforts for model development, including coordination, planning, and new data collection (Trowbridge et al., 2016). Model development is an iterative process, in which model results are tested against field data and expected results, followed by refinement and expansion of models.

Recommendations for modeling components and uses are provided at the end of Table 2. The Central Valley Water Board will continue working with modelers and stakeholders to identify additional hypotheses and scenarios to help answer management questions. The cyanobacteria and macrophyte white papers named some specific model purposes and scenarios (Berg and Sutula, 2015; Boyer and Sutula, 2015). Hydrologic conditions to be modeled include proposed changes to Delta inflow and outflow volumes and timing (e.g., State Water Resources Control Board update to the Bay-Delta Plan) and proposed changes to Delta water management and export locations. Modeling efforts will also aim to predict effects of climate change on nutrient-related water quality problems. Anticipated climate change impacts in the Delta include increases in temperature, alteration in precipitation patterns, occurrence of peak flows earlier in the year, possible increase in water residence times at times of the year and during drought, and increased frequency of extreme weather events (Ward and Paerl, 2017). These changes could affect timing and quantities of nutrient inputs to the Delta, rates of microbial cycling and release of nutrients, frequency of flow and temperature conditions that favor harmful algal blooms, and alter phytoplankton species compositions.

Development of process-based models for nutrients in the Delta and San Francisco Bay is underway. Central Contra Costa Sanitary District, Regional San, and the Delta Science Program have provided initial funding to develop a biogeochemical nutrient model for the Delta and Suisun Bay. The effort is utilizing hydrodynamic inputs developed and validated as part of the CASCaDE Project (Knowles and Lucas, 2015) for water year 2011 (high flow, low phytoplankton production).

Funding from the Water Boards and the Delta Regional Monitoring Program to expand nutrient modeling capabilities will be available beginning in Fall 2018. Tasks of future work include developing hydrodynamic inputs to simulate other flow conditions and water years and continuing to increase the breadth and detail of processes modeled. Development and application of process-based nutrient and primary production models are objectives of both the Delta NRP implementation and the Bay Nutrient Management Strategy Science Plan (SFB NMS, 2016).

For modeling efforts to be successful, there must be a process that promotes cross-disciplinary coordination and effective exchanges between those involved in monitoring, modeling, research, management, and users of modeled information. Some exchange between modelers and monitoring teams already occurs during gathering and review of data for biogeochemical model development. Coordination is particularly needed when selecting scenarios to be run (requires understanding of management questions) and design of monitoring and studies (consider whether it satisfies modeling needs). The Central Valley Water Board will work with the current modeling project teams, Delta Regional Monitoring Program, and others to foster coordination to support the Delta modeling. The California Water and Environmental Modeling Forum (CWEMF), a non-profit organization dedicated to increasing the usefulness of models, is a logical resource for some of the necessary coordination through its workshops and annual meeting. Potential, future involvement by the Delta Stewardship Council in linking modeling efforts across disciplines would also help advance the development of biogeochemical models. Supporting the development, integration, and use of numeric models is a priority action of the Delta Stewardship Council Delta Science Program (Delta Stewardship Council, Delta Science Program, 2017).

4.1.2. Harmful Algal Blooms and Controlling Factors

There is an urgent need to gather and evaluate data to define the extent of the harmful algal blooms and algal toxin problems in the Delta, understand causes, and develop predictive capabilities. Research for these aims involves both surveillance to detect harmful algal blooms and toxins in Delta waters and gathering data on multiple parameters through the duration of blooms to identify potential drivers. See Table 2, monitoring recommendations MON2, MON3 and special study recommendation SS1. There is no comprehensive surveillance to detect HABs in the Delta currently occurring or committed for the near future. Design of effective HAB monitoring should consider available tools, including satellite images and detection of genes for particular cyanobacteria species and toxins. Coordination of surveillance and special studies should be planned, such that when a bloom is detected or likely, researchers can deploy crews and instruments to monitor factors controlling the bloom and toxin release.

HABs are a Water Board management priority because of risks to human health through water contact and drinking water, wildlife health, and the adverse impacts on non-contact Delta uses of recreation and aesthetics. More research is necessary to understand the potential for limiting harmful algal blooms by nutrient management.

HAB episodes in the South Delta, Discovery Bay, the downtown Stockton waterfront, Old River, San Joaquin River and the Big Break shoreline in the West Delta have resulted in advisories to avoid contact with water. Studies of factors contributing to blooms should include these locations.

Drinking water conveyance and reservoir systems that use Delta water also experience cyanobacteria blooms. The Department of Water Resources and water districts that draw water from the Delta monitor HABs and toxins at drinking water intakes and in water delivery systems outside of the Delta. More coordination between the monitoring and special studies conducted by drinking water programs, the California Cyanobacteria and Harmful Algal Bloom (CCHAB) Network and the Water Board would increase the pool of data for syntheses and analysis of causative factors. For the CCHAB Network, the State Water Board developed monitoring and data reporting guidance (Anderson-Abbs, et al., 2016).

4.1.3. Aquatic Macrophytes, Treatments, and Ecosystem Impacts

Information is lacking to understand the interactions between invasive aquatic macrophytes and macrophyte chemical treatments on nutrient cycling and phytoplankton growth and species composition. See Table 2 monitoring and special study recommendations MON4 and SS2, respectively. Filling this information gap involves data collection in the field and under controlled conditions to confirm field observations. Presence and decay of dense colonies of aquatic macrophytes alter growth of phytoplankton by affecting water clarity and light intensity, flow rates, and nutrient availability. In addition to physical effects of aquatic plants themselves, chemical treatment of macrophytes may result in selective promotion of cyanobacteria. Chemical treatment is the principal tool available to the Division of Boating and Waterways to control aquatic macrophytes to maintain capacities for navigation.

Particularly needed are investigations of macrophyte growth and nutrient uptake as functions of nutrient concentrations in water and sediment. Such research would lead to understanding of the potential extent and conditions under which nutrient reductions may reduce aquatic macrophyte growth. The first step involves studies under controlled conditions of macrophyte growth rates, nutrient uptake rates, and nutrient tissue concentration under conditions of varying nutrient concentrations in sediment and water. Laboratory work should be followed by field studies in the Delta to confirm nutrient-macrophyte relationships over a range of ambient nutrient concentrations.

A research forum and several current projects are making steps toward achieving the macrophyte-related work. In 2016, the Interagency Ecological Program formed an Aquatic Vegetation Project Work Team to promote coordination and information sharing. Funded through the US Dept. Agriculture, the Delta Regional Area-wide Aquatic Weed Project (DRAAWP), involves teams researching various aspects of aquatic weeds, including plant growth, development of a mapping tool based on satellite images, biological control and economic impacts of management. The Delta Smelt Resiliency Strategy calls for treatment of aquatic weeds in North Delta habitats to benefit delta smelt. A team of researchers from UC Davis, Dept. Fish and Wildlife and DWR is in the midst of a 2-year study of the effects of chemical treatments on delta smelt habitats and food web in the North Delta (California Natural Resources Agency, 2016). This study is useful for optimizing aquatic weed management for delta smelt.

In laboratory and controlled field studies, cyanobacteria have shown greater tolerance to the herbicide glyphosate than other phytoplankton species (Forlani, 2008; Harris and Smith, 2016). The Central Valley Water Board is funding a small study to test the toxicity of individual herbicides and fungicides to Delta phytoplankton species. This testing is useful as early implementation of the Delta NRP. However, more study of the effects of glyphosate and other herbicides on phytoplankton species in the Delta is needed.

4.1.4. Low Dissolved Oxygen

Two projects in the 2014 Delta Strategic Plan are directed at low dissolved oxygen in Delta waterways: the Delta NRP and the Old and Middle Rivers dissolved oxygen project. Regional Board staff is currently engaged in evaluating data and information needs to address low dissolved oxygen (DO) impairments in Old and Middle Rivers and Grant Line Canal in the South Delta. The Delta NRP STAG did not commission a white paper on low DO. Rather, the STAG proceeded with white papers on other nutrient-related issues while Regional Board staff is assessing the Old and Middle Rivers DO issue.

Additional effort focused on low DO in Delta waterways is needed because aquatic life indicators and relationships of factors causing low DO have not been identified for Delta locations. Eleven additional waterways that are partially or completely within the Delta are identified on the Clean Water Action Section 303(d) List as impaired due to low DO. Work is still needed to examine and address low DO in these waterways. The first step for these waterways is to gather data to confirm the impairments. Monitoring should include DO conditions and beneficial use impacts in waterways identified as impaired and in comparative Delta sloughs and off-channel locations. Water bodies of concern for low DO include Old and Middle Rivers (southern Delta sections); Grant Line Canal; lower Mokelumne River; Pixley, Mosher, and Five Mile Sloughs; Bear Creek (San Joaquin County) and Kellogg Creek.

Subsequent steps are data evaluation to identify contributing factors and analyses of management options. Addressing low dissolved oxygen may include refining water quality objectives for dissolved oxygen in the Delta. Example approaches to DO objectives include projects in Suisun Marsh (Flippin et al., 2017) and the Klamath River (North Coast Regional Water Quality Control Board, 2010). Factors contributing to DO impairments in Delta sloughs and small waterways include low volumes of freshwater inputs, elevated nutrient concentrations, high organic loads, extended water residence times, stratification of the water column, and dense colonies of aquatic plants.

4.1.5. Low Phytoplankton Production

An objective of implementing the Delta NRP is to understand relationships between nutrients, biological, physical factors, and their combined effects on nutrient use and phytoplankton growth. Important physical factors include flow, water residence time, mixing, turbidity, irradiance, channel geomorphology, and temperature. In Table 2, monitoring recommendation #1 (MON1) describes the broad approach to monitoring and data collection needed for a holistic understanding of nutrient impacts. Conceptual models, statistical analyses, and computer models are all needed to generate this understanding.

The Delta Stewardship Council is funding the initiative “Operation Baseline” to address uncertainty about how changes in nitrogen inputs to the Delta resulting from the Regional San wastewater treatment plant upgrades will impact the Delta. Operation Baseline includes pilot studies that are geared toward developing new analytical tools and approaches while simultaneously collecting pre-upgrade data. The pilot studies are designed to develop new approaches to measuring nutrient concentrations and transformation rates, and to link these to effects on the lower food web. The Delta Stewardship Council is also supporting development of a conceptual model identifying likely effects of the Regional San upgrade. As a collaborative effort involving several research teams, Operation Baseline is supporting holistic data collection and integration across disciplines. Studies to better understand the ecosystem response before, during, and after major changes in nutrient loads from point sources is a Delta Science Action Agenda priority science action (Delta Stewardship Council, Delta Science Program 2017).

Other studies or pilot tests within particular areas or hydrologic conditions are encouraged. Focused studies are useful to evaluate hypotheses about nutrient-phytoplankton relationships and inform adaptive management programs. Short-term (5-day) nutrient addition experiments in the Delta Mendota Canal, for example, documented the response of phytoplankton abundance and species composition to changes in the forms and concentrations of nitrogen and phosphorous under a constant N:P ratio (Van Nieuwenhuyse et al., 2011). USGS also performed a focused study to understand potential effects of ammonium-rich wastewater effluent on phytoplankton health the lower Sacramento River (Kraus et al. 2017). The study traced parcels of water, with wastewater effluent presence or absent, down the Sacramento River over five days, measuring changes in nutrient concentrations and phytoplankton species composition and abundance. There may be other locations in or near the Delta amenable to similar types of pilot projects, which conduct controlled nutrient manipulation experiments in the watershed and measure for chemical and biological responses.

In general, nutrient monitoring and special studies in the Delta should consider how data collection and/or analyses can be integrated with physical, chemical, and biological factors. This evaluation is essential to understand interactions of these factors with nutrients in producing phytoplankton responses.

In addition to phytoplankton, other biological compartments of benthic algae, plants, and bacteria, are involved in nutrient cycling contribute to the lower food web. To fully understand effects of nutrients on ecosystem productivity, growth rates and nutrient fate in these other biological compartments should be quantified. This is particularly useful to track the effects of habitat restoration, as the food web contributions by phytoplankton and other carbon sources vary by habitat and are hypothesized to have changed over time (Cloern et al., 2016).

4.1.6. Nutrient Trend Evaluations and Mass Balances

A mass balance is a useful and relatively simple tool for integrating data and identifying missing components. Data compilation efforts for use in mass balances are useful for computer modeling and vice-versa. Through the process of identifying the components and data quality needed for a mass balance, data gaps for can be identified. In addition to acting as a useful step toward computer-based modeling, nutrient mass balances both within the Delta and in the Sacramento River and San Joaquin River watersheds would also provide tools to realistically evaluate potential management alternatives to control nutrient loading.

A well-developed nitrogen mass balance exists within the Delta boundaries (Novick et al 2015). A similar phosphorus mass balance for the Delta is needed. Also, mass balances for areas within the Delta that are highly impacted by cyanobacteria and macrophytes would help in understanding potential relationships to nutrient sources. Two areas that are prime candidates for detailed mass balances to identify sources and nutrient use within the Delta are Discovery Bay and South Delta channels between the San Joaquin River and Clifton Court Forebay (including Old and Middle Rivers and Grant Line Canal).

Table 2a. Research Recommendations for Monitoring

Research Recommendations	Prioritization								Research In Process or Funded?
Monitoring (MON#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
MON1: Surveillance of cyanobacteria blooms in the Delta for 3-5 years to understand where, when and under what conditions blooms occur. Include major cyanobacteria species, range of habitats, particularly natural and restored wetlands, drinking water intakes and recreational areas.	**16**	3	3	2	3	1	3	1	Partially. Some Central Delta and main river stations are monitored regularly and other, selected locations monitored by various agencies when blooms appear. DWR monitors visually for Microcystis in the lower San Joaquin River and at several other fixed stations in main channels, monthly in summer-fall. DWR Municipal Water Quality Investigations Program and water suppliers monitor at intakes, including HAB taxonomy and toxins. UC Davis & CDFW received Prop 1 funds to identify phytoplankton genera at these stations 2017-2019. The California Water Quality Monitoring Council and SWAMP maintain a portal for real-time HAB data display. However, monitoring data are not easily accessible from one source or database. Lacking regular surveillance for multiple toxin-producing species across the Delta.
MON2: Monitoring and assessment of data on physical, chemical and biological factors affecting phytoplankton abundance and growth. Include nutrients, phytoplankton growth and species composition, microbial processes related to nutrient release, biological controls of phytoplankton (e.g., grazing), and physical factors, including hydrology, turbidity, turbulence, irradiance, and temperature. Include examination of previous light and nutrient conditions as they affect nutrient uptake by phytoplankton.	**15**	3	3	3	2	1	2	1	No. Monitoring generally hasn't included full suite of biological, physical, and chemical parameters. Existing data have been analyzed sufficiently to generate conceptual models (e.g. Dahm et al, 2016 Fig 4). Some studies have probed specific relationships between physical and biological factors using experimental design or multivariate statistical analyses. Data collection across the Delta and among a range of habitats is still needed. Evaluation of data collected in MON2 will require advanced statistical analyses (Beck et al., 2018) and process-based modeling. Related: IEP Science Strategy identifies gap in understanding multiple factors affecting phytoplankton and pelagic primary production (IEP, 2016).

Table 2a. Research Recommendations for Monitoring

Research Recommendations	Prioritization								Research In Process or Funded?
Monitoring (MON#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
MON3: Surveillance of harmful algal toxins in water to assess risks. Include monitoring of particulate and dissolved toxins in a range of habitats, particularly natural and restored wetlands, drinking water intakes and recreational areas. Quantify algal toxins in surface water and scum.	**15**	3	2	2	3	1	3	1	No. Toxins monitored as needed by Water Boards, DWR Municipal Water Quality Investigations and Environmental Monitoring Programs, county public health departments and water suppliers to assess risks to public health. DWR and water suppliers monitor for algal toxins at drinking water intakes and in Central Valley Project and Water Project facilities. Some special studies have published toxin detections. California Water Quality Monitoring Council and SWAMP maintain the freshwater HAB portal for display and archiving of voluntarily reported HAB episodes. Lacking widespread testing for multiple toxins or associated gene sequences and detailed data sharing for use in studies beyond testing for public health.
MON4: Comprehensive, multi-year monitoring program of macrophytes in a variety of Delta habitats to determine status and trends in seasonal and annual biomass of aquatic floating and submersed invasive macrophyte species. Record observations of new species.	**14**	3	1	2	3	1	3	1	Partially. Monitoring involves analysis and mapping of remote sensor data (hyperspectral images collected by satellite or other airborne means) plus ground surveys (Ta et al., 2017). Mapping of FAV and SAV in the Delta has been done for 2004-2008 and 2014-2017 for 1-2 dates per year. Support needed to continue acquisition of images and analyze them. Monitoring would be improved by increasing the number of dates for which images are processed per year. Lacking a publicly available platform for collecting, integrating and displaying remote sensor and on-the-ground data.
MON5: Monitoring of nutrients to fill temporal and spatial gaps in nutrient monitoring efforts (Supports SS11; some similar tools as for SS10)	**13**	2	2	3	2	1	2	1	No. Gaps exist in existing networks and projects. Spatial gaps include shallow water, high-residence time habitats and some areas of the Central and South Delta with HAB and macrophyte problems not represented by current monitoring (Jabush et al, 2016). Temporal gaps exist when monitoring is not frequent enough to detect biochemical processes and changes in nutrient concentrations (Bergamaschi et al, 2017).
MON6: Monitoring of harmful algal toxins in biota for use in assessing risk to people and wildlife. Measure harmful algal toxins in fish tissue, bivalves, and/or sensitive wildlife.	**11**	2	2	1	3	0	2	1	No. Monitoring of toxins in biota in the Delta has been proposed, but not yet funded. California Cyanobacteria and Harmful Algal Bloom Network has convened a subcommittee to examine risks to wildlife and identified initial tasks of gathering data.

Table 2b. Research Recommendations for Special Studies									
Research Recommendations	**Prioritization**								**Research In Process or Funded?**
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS1: Field study to determine roles of nutrients and other drivers in controlling growth rate, maximum biomass, and toxin production of HABs. Sample multiple events in bloom and non-bloom (control) areas and monitor all potential drivers, including possible effects of herbicides and grazing. Collect data on nutrient forms and concentrations during bloom. Coordination recommendation: maximize data collected within 3-5 years by using the routine monitoring (detection of blooms) to identify time and locations for special study (follow bloom & factors affecting size and duration).	**17**	3	3	3	3	1	3	1	No. Data collection during full arc of growth and decline of HAB for cyanobacteria and possible physical and biochemical drivers of the bloom for a series of HABs has not been done.
SS2: Examine nutrient transformation and transport and responses by primary producers, including phytoplankton, microalgae, vascular plants, bacteria, and detritus, in range of Delta habitats. Use information to understand connections between peripheral habitats (wetlands, floodplains, and macrophyte beds) and phytoplankton in open water.	**16**	3	3	3	3	2	1	1	Partially. USGS is using high frequency sensors at fixed stations and on boat cruises to track gradients in phytoplankton and associated parameters (e.g., light, residence time, nutrients, chlorophyll). Lacking studies in full suite of habitats from shallow, non-navigable wetland habitats and nutrient source evaluations.
SS3: Special study (field and/or controlled) to understand factors that control submersed and floating aquatic macrophytes. Monitor in representative Delta habitats of instantaneous, annual, and inter-annual production rates of aquatic macrophytes and of the potential drivers of production.	**15**	3	3	3	3	0	2	1	Partially. Delta Region Areawide Aquatic Weed Project includes study of growth of three invasive macrophyte species under various field conditions and across seasonal cycles.

Table 2b. Research Recommendations for Special Studies									
Research Recommendations	**Prioritization**								**Research In Process or Funded?**
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS4: Controlled studies to examine growth rates of invasive aquatic macrophytes under conditions including ranges of nutrient levels in water and sediment. Simultaneously collect and analyze tissue to determine whether there is a predictable relationship between tissue growth, nutrient uptake rates & nutrient concentrations.	**15**	3	3	3	3	0	2	1	Partially. Several Delta Region Areawide Aquatic Weed Project studies include studies of aquatic plant growth under various conditions, but are not specifically designed to identify nutrient-growth relationships.
SS5: Controlled studies and data syntheses to confirm key drivers of cyanoHABs identified in field studies and to refine rate measurements for use in modeling. (Follows SS1)	**15**	3	2	3	3	1	2	1	No. Key drivers are known in general. Specific study goals are to be identified and will be determined, in part, by process-based model needs.
SS6: Study to evaluate potential for environmental conditions, including herbicides and grazing pressure, to selectively enhance growth of cyanobacteria.	**14**	3	2	3	2	1	2	1	No.
SS7: Study of potential for changes in nutrients or physical drivers to reduce frequency and magnitude of harmful cyanobacteria blooms and toxins. (Follows SS1)	**14**	3	2	2	3	1	2	1	No.

Table 2b. Research Recommendations for Special Studies									
Research Recommendations	**Prioritization**								**Research In Process or Funded?**
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS8: Controlled study to examine effects of environmentally-relevant concentrations of herbicides, fungicides, and mixtures thereof on aquatic macrophytes, harmful algal species, and phytoplankton species composition.	**14**	3	3	1	3	1	2	1	Partially. Central Valley Water Board is managing a contract to test toxicity of several herbicides and fungicides to Delta phytoplankton species. Work on the multi-agency Delta Smelt Resiliency Strategy in 2017-2018 includes evaluating effects of aquatic weed spraying at sites in the Northern and Western Delta on the delta smelt food web, including phytoplankton. Toxicity studies planned to date are limited and do not include herbicide mixtures or examining effects of multiple stressors. Studies outside the Delta are relevant, so periodic updating of literature reviews is needed.
SS9: Study of the effects of grazers (including grazing by bivalve, zooplankton, and protists) on phytoplankton biomass, productivity, and composition to understand where, when and under what conditions grazers can have the most significant impacts on phytoplankton growth and composition as well as relationships between nutrients and grazing.	**14**	3	2	3	3	1	1	1	Partially. Effects of past bivalve introductions on phytoplankton biomass, particularly in Suisun Bay, are known. Lacking information on magnitude of effects of zooplankton and protist grazing, extent of bivalve grazing in some waterways, effects of grazing on phytoplankton species composition, and potential of nutrient management to ameliorate effects of grazers.

Table 2b. Research Recommendations for Special Studies

Research Recommendations	Prioritization								Research In Process or Funded?
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS10: Special study of nitrification and other nitrogen transformation processes in benthic and pelagic zones and fluxes between these zones.	**14**	2	3	3	2	1	2	1	Partially. Comparisons of aqueous concentrations of nitrogen forms between monitoring points indicate transformation rates (e.g., Kraus et al., 2017). Lacking understanding of contributions from sediment, which is needed for computer modeling.
SS11: Development of quantitative estimates of nitrogen and phosphorus inputs, sinks, and outputs in breadth of hydrologic conditions and seasons	**13**	3	2	2	3	1	1	1	Partially. Mass balances for nitrogen in the entire Delta and subareas for data through 2011 have been completed (Novick et al., 2015). Lacking estimates for phosphorus and improved estimates of Delta internal sources and sinks for N and P.
SS12: Monitoring of aquatic plant biomass (MON4), nutrient content, and instantaneous and net tissue growth rates of aquatic plants (SS3) to estimate production and cycling rates for both nutrients and carbon. Compare these values with similar estimates for pelagic and benthic algae to determine the relative importance of aquatic vegetation processes in the Delta.	**12**	3	0	2	3	1	2	1	No. Preliminary calculations in Dahm et al., 2016. SS12 is important for understanding potential for success of various management actions.
SS13: Data collection and evaluation to determine whether predictive relationships exist between cyanobacteria (bloom occurrence and toxin concentrations) and continuous sensors or other readily available data (e.g., nitrogen forms, chlorophyll, other pigments).	**11**	2	1	2	3	0	2	1	No.

Table 2b. Research Recommendations for Special Studies

Research Recommendations	Prioritization								Research In Process or Funded?
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS14: Field studies of nutrient concentrations at increasing distance from and into aquatic macrophyte beds. Combine with results from SS8 to determine seasons and locations in the Delta when nutrient concentrations might be restricting growth. If prioritization is needed, target floating aquatic species for initial effort.	**11**	3	0	2	3	0	2	1	No. Macrophyte growth studies within Delta Region Areawide Aquatic Weed Project may provide some information.
SS15: Survey of HAB occurrence and toxins in water conveyance and reservoir system downstream of the Delta and evaluate with respect to Delta nutrient sources, cycling, and other Delta conditions to understand potential for Delta factors to manage problems in drinking water systems.	**10**	0	2	1	2	1	3	1	No.
SS16: Survey phytoplankton species with a focus on benthic phytoplankton, to expand knowledge of cyanobacteria associated with taste and odor problems, other impacts of benthic phytoplankton species, and factors driving their growth. Research needed in Delta and downstream in water conveyance and reservoir system.	**10**	1	2	1	2	0	3	1	Partially. Dept. Water Resources Municipal Water Quality Investigations program and drinking water purveyors lead data collection of HAB, toxin and taste and odor episodes that affect drinking water systems. Lacking examination of potential associations between these data and Delta nutrient and environmental conditions.
SS17: If field and controlled studies indicate that nutrient management could help reduce macrophyte growth, then conduct studies to determine whether macrophyte controls (mechanical, herbicide and biological) would be enhanced at lower nutrient levels.	**10**	3	1	2	2	0	2	0	No.
SS18: Use controlled studies and data evaluation to examine potential for changes in nutrients or physical drivers to reduce the frequency and magnitude of benthic and planktonic cyanobacteria causing taste and odor problems. (Follows SS15).	**8**	1	1	1	2	0	3	0	Partially by managers of drinking water reservoirs. Not currently investigated for the Delta.

Table 2b. Research Recommendations for Special Studies									
Research Recommendations	**Prioritization**								**Research In Process or Funded?**
Special Study (SS#)	**Total score**	Management Q.	Early step	Model use	Applies broadly	Multiple issues	Leveraging	3-5 yr timeline	
SS19: Special study (field and/or controlled) to identify the relationship between aquatic macrophyte species and biomass and uses by other aquatic organisms, including fish and invertebrates.	**7**	0	1	0	2	0	3	1	Partially. Implementation of the Delta Smelt Resiliency Strategy includes multi-agency investigation of aquatic weed and treatment effects on delta smelt food web http://resources.ca.gov/delta-smelt-resiliency-strategy/)

Table 2c. Recommendations for Modeling
MOD1: Develop computer-based, biogeochemical model(s) for the Delta that includes hydrodynamics; nutrient and organic carbon water quality; productivity and nutrient cycling by phytoplankton, vascular plants, non-phytoplankton microalgae, and bacteria; benthic and pelagic grazing, sediment transport, and macrophyte-related processes.
MOD2: Develop biogeochemical model and use it to assess relative importance of nutrients and other drivers of aquatic macrophyte growth and to test predictions of effects of possible nutrient and water management changes.
MOD3: Develop biogeochemical model(s) and use to assess relative importance of nutrients and other drivers of HAB growth and controls of maximum bloom size.
MOD4: Use biogeochemical model to help identify factor(s) is (are) limiting or enhancing the occurrence of the nutrient-related effects, including in different seasons and locations in the Delta where the effect has been observed.
MOD5: Perform sensitivity analyses to understand how changes in limiting factor(s) may influence the magnitude of response to nutrient load reductions or increases.
MOD6: Use an ecosystem model to predict the effectiveness of management measures to control the initiation, magnitude, and duration of HABs, including at specific Delta locations where HABs affect non-contact recreation.
MOD7: Use an ecosystem model to predict the changes in frequency and magnitude of harmful algal blooms in the Delta as a result of climate change and water management changes.
MOD8: Use biogeochemical models to determine if mechanical, herbicide, and biological control practices could be modified for a greater level of efficacy.
MOD9: Use ecosystem model to examine whether turbidity, flow rates, and mixing can be controlled by flow management, habitat restoration, or turbidity inputs. (recommended for understanding options for harmful algal bloom management)
MOD10: Use modeling to examine whether non-nutrient drivers of algal blooms (e.g., turbidity, residence time, limited flushing of biomass, stratification) can be controlled by management of flow routes and volumes, suspended sediment inputs, and habitat restoration.
MOD11: Establish collaborative relationships between agencies for data management sharing of expertise, and amassing additional funds to meet modeling goals.
Note: Recommendations for modeling were not ranked by priority or importance because the nutrient modeling effort must include multiple, interrelated parameters and processes.

5. Delta Nutrient Research Plan

5.1 Strategy and Framework

In the past three years, staff and stakeholders have focused their attention and activities on identifying the information gaps in our understanding of the impacts of nutrients in the Delta. The Delta NRP's monitoring, special study, and modeling recommendations, captured in Tables 2a, 2b and 2c, are written to fill gaps in our knowledge of the processes and scales of nutrient impacts. Additional types of information are needed, however, to develop an approach to management of nutrient-related problems in the Delta and to consider numeric water quality objectives. The three components in the Water Boards' process for evaluating potential management and water quality objectives are:

a) Scientific research and modeling to understand nutrient mechanisms and impacts;
b) Identification of protective thresholds and policy options; and
c) Identification of management options and potential changes in nutrient loads.

These components are inter-related (Figure 3). For example, evaluating nutrient trends and mass balances is a special study recommendation (Section 4.1.6 and Table 2b, #11) to support model development and use and understanding of nutrient processes. Nutrient trends and load estimates are also needed in order to evaluate the potentials for change due to management actions on top of other landscape and climactic changes. In other words, what is the feasibility of effectively changing nutrients loading through regulation of different sources? Also, depending on the potential impact, is it worth making the change?

During STAG meetings in Spring 2018, staff and stakeholders began discussing the steps required to incorporate these components into the Delta NRP. Due to the extensive and varied types of research needs identified, an initial step was to develop a prioritization process as discussed in Section 5.2. The prioritization process further identified the need to capitalize on current activities such as existing monitoring efforts, initiate long-term, multi-layered activities such as development of a robust modeling tool, initiate a review of protective thresholds, management options and policies utilized in other settings, and develop a Science Action Plan that further refines activities needed to insure necessary research is funded and appropriate nutrient management controls implemented. Section 5.3 discusses these activities in more detail for both the near and long-term.

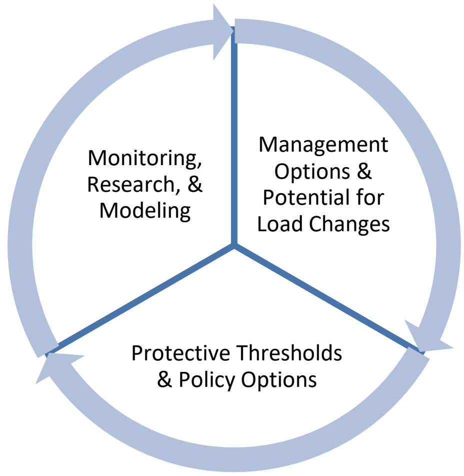

Figure 3. Components of Delta Nutrient Research Plan Implementation

5.2. Prioritization of Research Recommendations

Staff and stakeholders created a decision-making process to prioritize research recommendations (NRP Prioritization Work Group, 2017) and applied it to the recommendations for monitoring and special studies (Tables 2a and 2b). The prioritization process consists of the Delta NRP Management Questions, prioritization criteria, and a system for applying the prioritization criteria. Because the modeling white paper concluded with one recommendation, to develop and apply biogeochemical models, staff and stakeholders did not apply the prioritization process to the modeling effort.

Prioritization Criteria for Research Recommendation

1. Does the research recommendation address a management question?
2. Will the recommended research fill an early need for information or is it first on a path to subsequent research?
3. Will information generated provide important input to proposed models?
4. Does the research recommendation have broad application within the Delta?
5. Does the research recommendation address multiple water quality issues?
6. Does the candidate research offer opportunities for collaboration or leveraging of research by other agencies or projects?
7. Could the recommended research be accomplished within 3-5 years (not including acquisition of funds)?

Scores of 0, 1, 2, or 3 points, representing No, Low, Medium, or High support for the criteria question, were assigned to five of the prioritization criteria questions. Questions #5 and #7 are yes or no questions and were assigned scores of 1 or 0, respectively.

The STAG also identified criteria and questions relevant to ranking future research proposals (e.g., are we able to forecast the research will have a positive cost-benefit?) and assessing feasibility of nutrient management (e.g., what changes in ambient concentrations are possible?). These additional criteria were recorded for use in during implementation.

Each research recommendation in Tables 2a-c is valuable and can be used as support for future work. The prioritization process served to highlight those research recommendations that would fill modeling needs as well as special study or monitoring gaps, address multiple water quality issues, and/or apply broadly in the Delta.

The Water Board itself places a high priority on filling information gaps to better understand and manage HABs. Delta HABs pose a significant health risk and adversely impact direct water contact, recreation and drinking water. Although the STAG's prioritization was not directed by the Water Board's top concerns, information gaps related to HABs are ranked highly in Tables 2a and 2b. Also, the total of existing HAB-related efforts by all agencies in the Delta falls far short of needed monitoring and special studies identified. In comparison, a greater proportion of the research needed for issues of low phytoplankton production and aquatic macrophytes are underway or under consideration. These ongoing efforts involve several other entities and are described in the last column of Tables 2a and 2b.

5.3 Near-term Activities

The Delta NRP contains phased activities to move toward a better understanding of nutrient conditions and processes and determination if nutrient water quality objectives are appropriate to address current issues related to HABs, macrophytes, low dissolved oxygen and phytoplankton species abundance. Initial activities have been identified with near-term projects focused on completing existing efforts, strengthening coordination, prioritizing efforts related to HABs, developing a Science Action Plan to fill research data needs, and evaluating thresholds, management actions and policies. In general, the initial path forward consists of:

- Completing existing and contracted work supporting the 2014 Delta Strategic Plan
    - Directed low dissolved oxygen assessment,
    - Contracted work for numeric model development, and
    - Herbicide toxicity evaluation of sensitive Delta algal species
- Prioritizing new projects for HAB monitoring and special studies;
- Integrating efforts with the Delta Regional Monitoring Program for both monitoring coordination and building bridges with other agencies;
- Initiating review of nutrient thresholds and policies and developing initial nutrient mass balance framework; and
- Developing a Science Action Plan to systematically fill research gaps through enhanced collaboration and funding opportunities.

Near-term activities are discussed briefly below and summarized in Table 3.

5.3.1 Complete Existing and Contracted Work

Contract to Develop Hydrodynamic-linked Biogeochemical Model: A Water Board-funded contract with the San Francisco Estuary Institute to further develop Delta modeling will begin in Fall 2018. This contracted effort will build on modeling work supported by the Delta Science Program, Central Contra Costa Sanitary District, Sacramento Regional County Sanitation District, Department of Water Resources and the Delta Regional Monitoring

Program. The model development will link Suisun Bay models to the Delta and provide initial testing of potential future scenarios within the Delta. The project is coordinated with the San Francisco Bay Regional Water Board. A status report for previous work is available at:

http://sfbaynutrients.sfei.org/books/reports-and-work-products

Additional funding and time will be required to fully model relationships between nutrient forms and their movement in water, sediment, and the food web.

Supports: Modeling Recommendations

Contract End Date: 2021

Address Low Dissolved Oxygen in Old and Middle Rivers: Central Valley Water Board anticipates releasing a white paper in 2018, with an evaluation of low dissolved oxygen conditions in the South Delta, specifically within the area encompassed by Old and Middle Rivers. The project is a nutrient related priority identified in the Central Valley Water Board's 2014 Delta Strategic Plan. The Department of Water Resources (DWR) is developing a report to evaluate the effects of the South Delta Temporary Barriers Project on water quality.

Supports: Monitoring of physical, chemical and environmental factors and their impact on eutrophic conditions, HABs, and low dissolved oxygen levels.

End Dates: 2018—Old and Middle River White Paper; 2020—DWR Evaluation of South Delta Temporary Barriers Project

Contract to Test Herbicide Toxicity on Native Delta Phytoplankton Species: A contract is in place with the University of California, Davis to evaluate the sensitivity of native Delta phytoplankton to a select set of herbicides and fungicides, including those used in aquatic weed control. The work is being conducted on phytoplankton cultured within the laboratory. This project is a nutrient-related priority identified in the Central Valley Water Board's 2014 Delta Strategic Plan. It complements work on the multi-agency Delta Smelt Resiliency Strategy in 2017-2018 that includes evaluating effects of aquatic weed spraying at all sites in the Northern and Western Delta on the Delta smelt food web. The current project is limited in scope and does not address effects of multiple stressors.

Supports: Determination of drivers impacting phytoplankton species diversity

End Date: 2021

5.3.2 Projects Related to HAB Monitoring and Special Studies

Seek Funding for HAB Related Projects: In June 2018, Central Valley Water Board staff teamed with a suite of HAB researchers (including the San Francisco Bay Nutrient Management Strategy Group and members of the California CyanoHAB Network) to submit a proposal to the California Department of Fish and Wildlife for Prop 1 funds for monitoring microcystins in water and benthic organisms. Staff also developed a proposal and is seeking funding to assess the state of nutrients and HABS in Discovery Bay.

Supports: Improved understanding of HABs and toxin risks to people and wildlife. The Discovery Bay project also supports examination of links between HABS and nutrients in a specific area.

End Date: Dependent on funding decisions

Complete Delta HAB Data Synthesis: Central Valley Water Board staff will work with other agencies with HAB data and develop a framework for recording detailed information, including bloom location, bloom duration, genetic and toxin data, and ancillary parameters where available. Information on blooms will be linked to a GIS database layer for the Delta to identify high frequency bloom locations as well as apparent unimpacted areas. The information will be compiled in a summary report to support development of new HAB monitoring and special studies.
Supports: Future development of HAB specific studies
End Date: December 2018

5.3.3 Integrate Efforts with Delta Regional Monitoring Program (Delta RMP)

Coordinate with Delta RMP Nutrient Technical Advisory Committee: Initiate joint meetings between the STAG and the Delta RMP Nutrient Technical Advisory Committee to facilitate development of monitoring efforts supportive of both programs. See also 5.4.1. under Collaboration.
Supports: Coordinated monitoring efforts
End Date: ongoing

5.3.4 Review of Potential Thresholds and Policies and Initial Mass Balance

Review Potential Thresholds and Policies: Review and summarize regulatory approaches used to manage nutrient impacts in other areas (non-Delta) including areas outside of California. The initial focus will be on nutrient thresholds and policies developed to address HABs including documentation of any benchmarks utilized.
Supports: Development of alternative regulatory approaches and potential targets, triggers and/or water quality objectives
End Date: June 2019—Draft report focused on HABs

Nutrient Mass Balance: Summarize current status, information sources, and information needs to develop nutrient loading estimates and mass balances both within the Delta and within watersheds draining to the Delta. Based on the information gathered, develop a proposal to fund efforts to fill remaining data gaps. The effort will build on the nitrogen mass balance developed within the Delta boundaries (Novick et al 2015). Two focus areas for detailed mass balances to identify sources and nutrient use are within the Delta are Discovery Bay and South Delta channels between the San Joaquin River and Clifton Court Forebay (including Old and Middle Rivers and Grant Line Canal). Both areas experience high occurrence and duration of HABs.
Supports:

- **a)** Data compilation and identification of data gaps for computer modeling
- **b)** Provides tools to realistically evaluate potential management alternatives to control nutrient loading

End Date: June 2019—Summary Report and Proposal to Fill Data Gaps

5.3.5 Develop Science Action Plan

Science Action Plan: Central Valley Water Board staff will work with the STAG and other interested parties to identify tasks, funding needs, partnerships and priorities to systematically fill research gaps identified in Tables 2a and 2b and support modeling aims identified in Table 2c and present them in a Science Action Plan for Delta nutrients. The Science Action Plan will also identify a framework to evaluate potential metrics and thresholds that correspond to beneficial use protection as well as to evaluate potential management options. Goals of the Science Action Plan are to refine activities needed to insure necessary research is funded and appropriate nutrient management controls implemented.
Supports: Determination of whether future nutrient triggers, targets and/or objectives would effectively reduce impact from HABs, aquatic macrophytes, low dissolved oxygen and low desirable phytoplankton production.
End Date: 2019

5.4 Collaboration

Monitoring, special studies, and modeling recommended to fill information gaps exceed resources that are presently labeled for the work. Collaboration between agencies and entities conducting nutrient-related projects is vital to completion of the research identified in the Delta NRP. Staff will continue work with the STAG and others to identify additional funding and support implementation of the NRP. Implementation actions are described in more detail in Table 3.

Following are specific actions enhanced coordination and collaboration in the next 1-5 years:

- Continue work with a stakeholder and technical advisory group (STAG) to oversee implementation of the Delta NRP. Tasks include tracking the stability of long-term monitoring programs, identifying opportunities to leverage other efforts, and evaluating the progress of filling nutrient information gaps.
- Identify areas of overlap in management questions guiding other Delta programs and initiatives. Important directives that identify shared interest in nutrient-related issues are the Interagency Ecological Program (IEP) Science Strategy (IEP, 2016), the Delta Science Plan (Delta Stewardship Council, Delta Science Program, 2016), and the Delta Science Action Agenda (Delta Stewardship Council, Delta Science Program, 2017).
- Coordinate with long-term water quality monitoring programs in the Delta, including the Department of Water Resources' Environmental Monitoring and Municipal Water Quality Investigations Programs and the US Geological Survey network of high frequency monitoring stations.
- Seek funding and collaborations to implement remaining research and modeling in Table 2. Staff will work with STAG and others to develop process for review of projects and proposals.
- Identify opportunities to leverage existing monitoring, special study, and modeling efforts.
- Expand monitoring and data sharing for HABs through partnerships with CCHAB Network and others.

- Identify partnerships and resources to further develop numeric modeling capabilities and opportunities for exchanges between data providers, model developers, and users of modeled information.

The Delta NRP should serve as a focal point and impetus for improving coordination among various nutrient-related science efforts in the Delta. Water Board staff will need to expend the effort to support these activities and create partnerships.

Entities funding nutrient monitoring and research in the Delta include the Delta Science Program, Regional San, Interagency Ecological Program, and State and Federal Water Contractors. These entities have independently initiated several major projects. Identification of shared goals and implementation of projects collaboratively with the Delta NRP would speed the progress of nutrient science in the Delta.

Collaboration with other entities can start with recognizing shared management questions and information needs. The Interagency Ecological Program's Science Strategy identifies areas where science is most needed to inform management in the near-term (IEP, 2016). The five areas include understanding lower food webs in the estuary and impacts of non-native species, including aquatic macrophytes. These IEP science themes have important overlap with Delta NRP issues and research recommendations. Likewise, the Delta Science Action Agenda 2017-2021 contains priority science actions that directly correlate with Delta NRP research recommendations (Delta Stewardship Council, Delta Science Program, 2017). Science Action Agenda priority actions include: build capacity for collaborative synthesis, improve data access and exchange, implement studies to better understand ecosystem responses of changes to major Delta discharges and advance integrated modeling. Other programs having significant coordination with the Delta NRP and implementation are described below.

5.4.1 Delta Regional Monitoring Program (Delta RMP)

The Delta Regional Monitoring Program (Delta RMP)'s nutrient efforts are conducted in conjunction with the Delta NRP. Nutrients are one of four priorities funded for study by the Delta RMP. The Delta RMP identifies the Delta NRP as its "management driver" for nutrient-related projects. Beginning in 2015, the RMP's focus for nutrients work has been filling gaps in understanding of status and trends of nutrients. Products include a review of existing nutrient-related monitoring (DRMP, 2016), a set of three reports on high-frequency nutrient monitoring (Bergamaschi et al., 2017; Downing et al., 2017; Kraus et al., 2017), synthesis of nutrients and chlorophyll data at major fixed stations (SFEI 2017a) and analysis of gaps in the existing nutrient monitoring network based on water source profile and residence time (Jabusch et al, 2018b).

The Delta RMP's nutrient efforts currently bring together Water Board staff, stakeholders interested in and potentially affected by nutrient management decisions, and researchers. The Delta RMP's nutrients technical subcommittee meets approximately quarterly to develop study designs and review products. There is potential to increase collaboration between the Delta NRP STAG, Delta RMP, and the San Francisco Bay Nutrient Management Strategy.

Improving collaboration would leverage resources and deepen the capabilities to understanding of nutrient effects from fresh through salt water in the Estuary.

5.4.2 San Francisco Bay Nutrient Management Strategy

The San Francisco Bay Water Board initiated its program to evaluate the role of nutrients throughout San Francisco Bay in 2012. The 2013 Delta Plan recognized the need for this work and included a recommendation that the San Francisco Bay Water Board develop and implement a study plan for nutrient water quality objectives in Suisun Bay. The San Francisco Bay Nutrient Management Strategy is being implemented as a long term planning effort under a nutrient watershed NPDES permit adopted in 2014. Coordination between Delta and San Francisco Bay nutrient efforts will continue. Shared efforts are particularly relevant to understanding processes from the North Delta through Suisun Bay and in development of biogeochemical models, for which whole-systems approaches are beneficial.

Table 3. Summary of Near-Term Delta Nutrient Research Plan Activities

Activity	Timeline	Product
Complete Existing and Contracted Work		
--Contract to Develop and Apply Hydrodynamic-linked Biogeochemical Model	2018 to 2021	2019 & 2020 – Annual progress reports describing development and testing of hydrodynamic and biogeochemical components 2021 – Final report on application of model to scenarios selected
--Address Low Dissolved Oxygen in Old and Middle Rivers • Central Valley Water Board Review • Department of Water Resources' Evaluation of Temporary Barriers	2018 2020	2018—White Paper on potential causes and available management approaches to address 2020—Report by Dept. Water Resources on effects of temporary barriers on low DO
--Contract to Test Herbicide Toxicity on Native Delta Phytoplankton Species	2021	UC Davis report on sensitivity of native phytoplankton species to herbicides and fungicides, including those used in aquatic weed control
HAB Monitoring and Special Studies		
--Seek Funding for Special Studies • Microcystins in clams and other biota • Assessment of nutrients and HABs in Discovery Bay	2019 or later, depending on funding	Data on HABs and nutrients
--Delta HAB Data Synthesis • Central Valley Water Board staff lead in coordination with entities evaluating Delta HABs	2018	• GIS data layer to identify high frequency bloom locations and unimpacted areas • Framework to record HAB related information on location, duration, genetic/toxin data, etc. • Recommendations for HAB monitoring and studies
Integrate Efforts with Delta Regional Monitoring Program (Delta RMP)		
--Coordination with Delta RMP Nutrient SubCommittee	Ongoing	• Improved, mutually beneficial monitoring and study designs
Review Potential Thresholds and Policies and Initial Mass Balance		
--Review Potential Thresholds and Policies in areas outside of the Delta	2019	• Draft report summarizing nutrient benchmarks and policies utilized to address issues of concern with initial focus on HABs
--Nutrient Mass Balance • Within Delta: o Expand current mass balance to include phosphorus; and o Focused studies in areas subject to HABs • Basins draining to the Delta: initial identification of sources, loads and data gaps	2018 To 2023	• 2018: initial evaluation of available information and data gaps • 2019: funding proposals to fill data gaps • 2019-2023: mass balance to support management decisions and modeling efforts • 2019-2021: identification of potential source controls for case study areas experiencing HABs
Science Action Plan		
--Collaborative development of plan to identify tasks, funding needs, partnerships and priorities to systematically fill information gaps in order to determine whether nutrient triggers, targets and/or water quality objectives needed to address Delta issues	2019	• Framework that refines needed activities to insure necessary research is funded and appropriate nutrient management controls implemented

6. Intersections with Other Water Board Efforts

6.1 Biostimulatory Substances Objectives and Program to Implement Biological Integrity

The State Water Resources Control Board (State Water Board) is proposing to adopt statewide water quality objectives for biostimulatory substances and a program of implementation to implement biological integrity. The State Water Board is currently working on the first phase applicable to wadeable streams. The second phase will focus on lakes and the third phase will focus on estuaries, enclosed bays, and non-wadeable rivers. “Biostimulatory substances” refers to contaminants that promote excess aquatic plant or algae growth, particularly nutrients. An assessment of biological integrity uses measurements of aquatic species and ecosystem health to determine whether waterways achieve desired conditions.

The Delta NRP is consistent with the approach of the State Water Board’s Biostimulatory Substances Objective and Biological Integrity Project. Identifying indicators of biological health across the Delta in terms of abundance, distribution and species phytoplankton and macrophyte species is a task to be done in parallel with research under the Delta NRP. The Central Valley Water Board will consider tools developed for the State Water Board projects and share information from the Delta. Identifying indicators of optimal ecosystem function in the Delta is complicated by the complexity of the changes in landscapes, hydrology, and invasive species that have permanently altered the Delta’s biological responses.

The State Water Board assembled an external panel of internationally-recognized nutrient experts to review the results of the proposed Statewide nutrient numeric endpoint program. State Board staff has offered services of its external expert panel to review Delta NRP efforts, dependent upon the timing of the biostimulatory and biological integrity efforts and the availability of the external panel members.

6.2 Water Quality Objectives for Ammonium

The Central Valley Water Board is evaluating the need to adopt numeric water quality objectives for ammonium for the Central Valley, including the Delta. In 2013, the USEPA revised its freshwater quality criteria for ammonium (USEPA, 2013). Revised criteria incorporate results of toxicity tests with sensitive freshwater mussel species. Following the USEPA action, the Central Valley Water Board initiated a project to evaluate the criteria to protect aquatic life from ammonium and amend the Basin Plans if needed. Public scoping meetings were held in March 2017. The Central Valley Clean Water Association and other stakeholders are working with staff to develop methods to assess presence of freshwater mussels and other information for consideration of a California-specific water quality objective for ammonia.

6.3 Climate Change Work Plan for the Central Valley Region

In December 2017, the Central Valley Water Board adopted the Central Valley Region Climate Change Work Plan (Resolution R5-2017-0116). The Climate Change Work Plan identifies programmatic priorities and current and proposed initiatives intended to incorporate resiliency in Central Valley Water Board actions. This Work Plan identifies development and implementation of the Delta NRP as a priority task for the near term. Nutrients research and modeling will encompass data collection on environmental parameters that are responding to climate change. The monitoring, studies, data analyses, and modeling performed for the Delta NRP will be useful for understanding and tracking impacts of climate change.

7. Summary and Conclusions

The Delta Nutrient Research Plan has been prepared to fill needed information gaps in order to determine whether development and implementation of nutrient water quality objectives would address existing issues with HABs, macrophytes, low dissolved oxygen and limited abundance of desirable phytoplankton species. Filling the scientific information gaps will require a combination of new monitoring, special studies and computer modeling. In addition, information is needed on protective thresholds and policy options utilized in other arenas and potential management options and their anticipated changes to nutrient loads.

The Delta NRP contains a framework and prioritized actions to develop the necessary information. Collaboration between agencies and entities conducting nutrient-related projects has been identified as vital to the completion of the research identified. Since the recommended research and modeling exceeds existing resources, staff is working with the STAG and other interested parties to develop a Science Action Plan to identify sources of funding and partnerships to systematically fill information gaps over the long-term.

Short-term activities (1-5 years) are focused on completing existing projects, expanding collaboration and coordination with other entities, prioritizing efforts to address HABs and evaluating thresholds, benchmarks and management approaches utilized in other areas. It is anticipated that during the first five years of the effort, potential nutrient reduction benchmarks will be identified that may help address duration and extent of HABs while further evaluation of potential nutrient triggers, targets and/or water quality objectives is conducted.

References

Anderson-Abbs, B.A., M. Howard, K.M. Taberski, and K. R. Worcester. 2016. California Freshwater Harmful Algal Blooms Assessment and Support Strategy. State Water Resources Control Board Surface Water Ambient Monitoring Program. January. https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/SWAMP/HABstrategy_phase%201.pdf

Beck, M.W., Jabusch, T.W., Trowbridge, P.R., and Senn, D.B. 2018. Four decades of water quality change in the upper San Francisco Estuary. *Estuarine, Coastal and Shelf Science*, 212: 11-22. https://doi.org/10.1016/j.ecss.2018.06.021

Berg, M. and M. Sutula. 2015. Factors Affecting the Growth of Cyanobacteria with Special Emphasis on the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project Technical Report 869. Costa Mesa, CA, August. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2015_08_cyano_wp_final.pdf

Bergamaschi, B.A., B.D. Downing, T.E.C Kraus, and B. A Pellerin. 2017. Designing a high-frequency nutrient and biogeochemical monitoring network for the Sacramento-San Joaquin Delta, Northern California. https://pubs.er.usgs.gov/publication/sir20175058

Boyer, K. and M. Sutula. 2015. Factors Controlling Submersed and Floating Macrophytes in the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project. Technical Report No. 870. Costa Mesa, CA, October. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2015_10_macro_whitepaper.pdf

California Natural Resources Agency. 2016. Delta Smelt Resiliency Strategy. http://resources.ca.gov/delta-smelt-resiliency-strategy/

Charter. 2015. Charter Document – Process to Develop a Delta Nutrient Management Strategy. July 27, 2015. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/public_involvement_stag_meetings/2015_0727_charter_final.pdf

Climate Action Team (CAT). 2010. Climate Action Team Report to Governor Schwarzenegger and the California Legislature. California Environmental Protection Agency. April 2010. Available at: http://www.climatechange.ca.gov/climate_action_team/reports/index.html

Cloern, J., N. Knowles, L. Brown, D. Cayan, M. Dettinger , T. Morgan , D. Schoellhamer, M. Stacey, M. van der Wegen , R. Wagner and A. Jassby. 2011. Projected Evolution of California's San Francisco Bay- Delta-River System in a Century of Climate Change. PLoS One 6(9): e24465. doi:10.1371/journal.pone.0024465

Cloern, J.E., A. Malkassian, R. Kudela, E. Novick, M. Peacock, T. Schraga, D. Senn. 2015. The Suisun Bay Problem: Food Quality or Food Quantity? Suisun Synthesis II Report Section 6. Prepared for the San Francisco Bay Nutrient Management Strategy. (Note: previously published in the Interagency Ecological Program for the San Francisco Estuary (IEP) Newsletter, 27(1)15-33). http://www.water.ca.gov/iep/docs/IEP_Vol27_1.pdf

Cloern, J.E., A. Robinson, A. Richey, L. Grenier, R. Grossinger, K.E. Boyer, J. Burau, E.A. Canuel, J.F. DeGeorge, J.Z. Drexler, C. Enright, E.R. Howe, R. Kneib, A. Mueller-Solger, R.J. Naiman, J.L.Pinckney, S.M. Safran, D. Schoelhamer, and C. Simenstad. 2016. Primary Production in the Delta: Then and Now. San Francisco Estuary and Watershed Science 14(3). https://escholarship.org/uc/item/8fq0n5gx

CVRWQCB. 2014. 2014 Delta Strategic Work Plan. Central Valley Water Quality Control Board, Rancho Cordova, California.

https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/strategic_workplan_baydelta/2014_delta_strategic_workplan.pdf

CVRWQCB. 2017 Climate Change Work Plan. Central Valley Water Quality Control Board, Rancho Cordova, California. https://www.waterboards.ca.gov/centralvalley/water_issues/climate_change/

Dahm, C., A. Parker, A. Adelson, M. Christman, and B. Bergamaschi. 2016. Nutrient dynamics of the Delta: Effects on primary producers. San Francisco Estuary and Watershed Science. In Press. Will be available: https://escholarship.org/uc/jmie_sfews/14/4

Delta Cyanobacteria Science Work Group. 2015. Cyanobacteria Knowledge Gap Document. Prepared for Delta Nutrient Science and Research Program, Stakeholder and Technical Advisory Group and the Central Valley Regional Water Quality Control Board, November https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2015_1125_cyanohab_knowgaps_final.pdf

Delta Drinking Water Work Group, 2017. Delta Nutrients Drinking Water Issues White Paper. Prepared for the Delta Nutrients Stakeholder and Technical Advisory Group and the Central Valley Regional Water Quality Control Board, June. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2017_0515_dw_whitepaper_final.pdf

Delta Macrophyte Work Group, 2016. Macrophytes Knowledge Gap Document. Prepared for Delta Nutrient Science and Research Program, Stakeholder and Technical Advisory Group and the Central Valley Regional Water Quality Control Board, June. https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2016_0627_macro_info_gaps.pdf

Delta Stewardship Council. 2014. Workshop on Delta Outflows and Related Stressors Panel Summary Report. May 2014. (Panel: Denis Reed, James (Tim) Hollibaugh, Josh Korman, Ernst Peebles, Kenneth Rose, Pet Smith, Paul Montagna). http://deltacouncil.ca.gov/sites/default/files/documents/files/Delta-Outflows-Report-Final-2014-05-05.pdf

Delta Stewardship Council. 2017. Operation Baseline (Studying the Effects of the Regional San Treatment Plant Upgrade). Retrieved from http://deltacouncil.ca.gov/operation-baseline

Delta Stewardship Council, Delta Science Program. 2016. Delta Science Plan. 9 May.

Delta Stewardship Council, Delta Science Program. 2017. 2017-2021 Science Action Agenda.

Delta Stewardship Council. 2018. Climate Change and the Delta: A Synthesis. Public review draft, March 23. http://deltacouncil.ca.gov/docs/delta-plan/climate-change-and-delta-synthesis-public-draft-march-23-2018

Downing, B.D., B.A. Bergamaschi, and T.E.C. Kraus. 2017. Synthesis of Data from High-Frequency Nutrient and Associated Biogeochemical Monitoring for the Sacramento-San Joaquin Delta, Northern California. https://pubs.er.usgs.gov/publication/sir20175066

Downing, B. D., B.A. Bergamaschi, C. Kendall, T.E.C. Kraus, K.J Dennis, A.J. Carter, and T.S. Von Dessonneck. 2016. Using Continuous Underway Isotope Measurements To Map Water Residence Time in Hydrodynamically Complex Tidal Environments. Environmental Science & Technology, 50(24), 13387-13396. doi: http://dx.doi.org/10.1021/acs.est.6b05745

DRMP. 2016. Summary of Existing Nutrient Monitoring Programs, Data Gaps, and Potential Delta RMP "No Regrets" Monitoring Activities. Nutrient Monitoring Planning Workshop. Oct 2016. https://www.waterboards.ca.gov/rwqcb5/water_issues/delta_water_quality/delta_regional_monitoring/studies_reports/drmp_workshop_rpt_20161017.pdf

Flippin, J., S. Roy, J. Diamond, J. Rath, J. Harcum and T. Grieb. 2017. DO Criteria Recommendations for Suisun Marsh. Technical Report. Tetra Tech, Inc. 3746 Mt. Diablo Blvd. Suite 300. Lafayette, CA. 10711 Red Run Blvd, Suite 150. Owings Mills, MD. https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/suisunmarsh/Suisun%20Marsh%20DO%20Criterion%20Final%20Report,%20June%2023,%202017.pdf

Forlani, G., M. Pavan, M. Gramek, P. Kafarski, and J. Lipok. 2008. Biochemical bases for a widespread tolerance of cyanobacteria to the phosphonate herbicide glyphosate. *Plant Cell Physiol.* 49(3)443-456.

Harris, T.D. and V.H Smith. 2016. Do persistent organic pollutants stimulate cyanobacterial blooms? *Inland Waters* 6:124-130.

IEP. 2016. Interagency Ecological Program Science Strategy – Needs for Near-Term Science in Five Areas of Emphasis. March. http://www.water.ca.gov/iep/docs/2016_IEP_Science_Strategy_FINAL_02-21-2017.pdf

Jabusch, T., P. Trowbridge, and M. Heberger. 2018. Modeling to Assist Identification of Temporal and Spatial Data Gaps for Nutrient Monitoring. Prepared for the Delta Regional Monitoring Program. Final report in preparation.

Jabusch, T., P. Trowbridge, A. Wong and M. Heberger. 2018. Assessment of Nutrient Status and Trends in the Delta in 2001-2016: Effects of Drought on Ambient Concentrations and Trends. Prepared for the Delta Regional Monitoring Program. Final report in preparation.

Kimmerer, W. and M. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-Dan Joaquin Delta using a particle-tracking model. San Francisco Estuary and Watershed Science 6(1) Article 4. https://escholarship.org/uc/item/547917gn

Knowles, N. and L. Lucas. 2015. CASCaDE II: Computational Assessment of Scenarios of Change for the Delta Ecosystem, Project Final Report. Prepared for the Delta Stewardship Council. https://cascade.wr.usgs.gov/reports/C2_final_report/CASCaDE_2_Final_Report.pdf

Kraus, T. E. C., K. D. Carpenter, B. A. Bergamaschi, A. E. Parker, E. B. Stumpner, B. D. Downing, N. M. Travis, F. P. Wilkerson, C. Kendall, and T. D. Mussen (2017), A river-scale Lagrangian experiment examining controls on phytoplankton dynamics in the presence and absence of treated wastewater effluent high in ammonium, Limnology and Oceanography, 62(3), 1234-1253, doi: 10.1002/lno.10497 http://onlinelibrary.wiley.com/doi/10.1002/lno.10497/full

Kraus, T.E.C., K. O'Donnell, B.D. Downing, J.R. Burau, and B.A. Bergamaschi. 2017. Using paired *in situ* high frequency nitrate measurements to better understand controls on nitrate concentrations and estimate nitrification rates in a wastewater-impacted river. Water Resources Research, 53. https://doi.org/10.1002/2017WR020670

Kraus, T.E.C., B.A. Bergamaschi, and B.D. Downing. 2017. An Introduction to High-Frequency Nutrient and Biogeochemical Monitoring for the Sacramento-San Joaquin Delta, Northern California. US Geological Survey Scientific Investigations Report 2017-5071. https://pubs.er.usgs.gov/publication/sir20175071

Krich-Brinton, A. and T. Grovhoug. 2017. Projected Nutrient Load Reductions to the Sacramento-San Joaquin Delta Associated with Changes to Four POTWs. Memorandum prepared by Larry Walker Associates for Regional San and the Delta Nutrient Research Plan Stakeholder and Technical Advisory Group, January.

https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/public_involvement_stag_meetings/2017_0417_massbal_memo.pdf

Lee, J., A.E. Parker, F.P. Wilkerson, R.C. Dugdale, 2015. Uptake and inhibition kinetics of nitrogen in *Microcystis aeruginosa*: regults from cultures and field assemblages collected in the San Francisco Bay Delta, CA. Harmful Algae 47:126-140.

Lehman, P.W., G. Boyer, M. Satchwell and S. Waller. 2008. The influence of environmental conditions on the seasonal variation of Microcystis cell density and microcystins concentration in San Francisco Estuary. Hydrobiologia 600:187-204.

Lehman, P.W., K. Marr, G.L. Boyer, S. Acuna and S.J. Teh. 2013. Long-term trends and causal factors associated with Microcystis abundance and toxicity in San Francisco Estuary and implications for climate change impacts. Hydrobiologia 718:141-158.

Lehman, P.W., C. Kendall, M.A. Guerin, M.B. Young, S.R. Silva, G.L. Boyer, and S.J. Teh. 2015. Characterization of the *Microcystis* bloom and its nitrogen supply in San Francisco Estuary using stable isotopes. Estuaries and Coasts 38:165-178.

Meyer, J.S., P.J. Mulholland, H.W. Paerl, A.K. Ward. 2009. A Framework for Research Addressing the Role of Ammonium/Ammonium in the Sacramento-San Joaquin Delta and the San Francisco Bay Estuary Ecosystem. A final report to the CALFED Science Program, Sacramento, CA. April.
http://www.science.calwater.ca.gov/pdf/workshops/workshop_ammonium_research_framework_final_041609.pdf

National Research Council. 2012. Sustainable Water and Environmental Management in the California Bay-Delta. Committee on Sustainable Water and Environmental Management in the California Bay-Delta, March.
http://dels.nas.edu/Report/Sustainable-Water-Environment/13394

North Coast Regional Water Quality Control Board, 2010. Klamath River Total Maximum Daily Loads (TMDLs) addressing Temperature, Dissolved oxygen, Nutrient, and Microcystin Impairments in California. Final Staff Report. Santa Rosa, March.
https://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river/100927/staff_report/00_CoverPage_TableofContents.pdf

Novick, E., R. Holleman, T. Jabusch, J. Sun, P. Trowbridge, D. Senn, M. Guerin, C. Kendall, M. Young, and S. Peek. 2015. Characterizing and quantifying nutrient sources, sinks, and transformation in the Delta: synthesis, modeling, and recommendations for monitoring. Report prepared for the California Dept. Water Resources.
http://sfbaynutrients.sfei.org/books/dwr-contract-deliverable

NRP Prioritization Work Group, 2017. Revised Prioritization Process Proposal. Presented to the NRP Stakeholder and Technical Advisory Group, 10 April.
https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/public_involvement_stag_meetings/2017_0417_stagmtg_prior_rev.pdf

Paerl, H., W. Gardner, K. Havens, A. Joyner, M. McCarthy, S. Newell, B. Qin, and J. Scott. 2016. Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae 54:213-222.

SFB NMS. 2016. San Francisco Bay Nutrient Management Strategy Science Plan Report. September.
http://sfbaynutrients.sfei.org/sites/default/files/2016_NMSSciencePlan_Report_Sep2016.pdf

Systech Water Resources, Inc.2011. Task 4 technical Memorandum – Sensitivity Analysis of Water Quality Entering the Delta. Prepared for the California Urban Water Agencies and Central Valley Drinking Water Policy Work Group, April.
https://www.waterboards.ca.gov/centralvalley/water_issues/drinking_water_policy/sensitivity_analysis.pdf

Ta, J., L.W.J. Anderson, M.A Christman, S. Khanna, D. Kratville, J.D. Maden, P.J. Moran, and J.H. Viers. 2017. Invasive Aquatic Vegetation Management in the Sacramento-San Joaquin River Delta: Status and Recommendations. San Francisco Estuary and Watershed Science 15(4) https://doi.org/10.15447/sfews.2017v15iss4art5

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. Prepared for the Central Valley Regional Water Quality Control Board, March.
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

Van Nieuwenhuyse, E., R. Dahlgren, B. Bridges, and H Horner. 2011. Nutrient Enrichment Experiments in the Delta-Mendota Canal. US. Bureau of Reclamation and UC Davis. April.

Ward, A.K. and H.W. Paerl. 2017. Delta Nutrients Public Workshop: "Role of Nutrients in Shifts in Phytoplankton Abundance and Species Composition in the Sacramento-San Joaquin Delta", November 29-30, 2016. Report of the Workshop Panel prepared for the Central Valley Regional Water Quality Control Board, May.
https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2017_0530_phyto_wp.pdf

West Yost Associates. 2011. Wastewater control Measures Study. Prepared for the Central Valley Regional Water Quality Control Board Drinking Water Policy Workgroup, March.
https://www.waterboards.ca.gov/rwqcb5/water_issues/drinking_water_policy/dwp_wastewtr_cntrl_meas_stdy.pdf

Wilkerson, F., D. Dugdale, P. Glibert, and A. Parker. 2017. Response to Delta Nutrients Public Workshop: "Role of Nutrients in Shifts in Phytoplankton Abundance and Species Composition in the Sacramento-San Joaquin Delta", November 29-30, 2016. 1 May.
https://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/public_involvement_stag_meetings/2017_0515_com_wdgp.pdf

Appendix 1. Delta Nutrient Research Plan Science Work Group and STAG Participants

Appendix 1a. Science Work Group Participants

Individual	**Agency/Institution**	**Science Work Group**
Mine Berg	Applied Marine Sciences	Cyanobacteria
Raphael Kudela	U.C. Santa Cruz	Cyanobacteria
Peggy Lehman	Department of Water Resources	Cyanobacteria
Tim Mussen	Sacramento Regional County Sanitation District	Cyanobacteria
Daniel Orr	California Department of Fish and Wildlife	Cyanobacteria
Alex Parker	California Maritime Academy	Cyanobacteria
Karen Taberski	San Francisco Regional Water Quality Control Board	Cyanobacteria
Kim Ward	State Water Resources Control Board	Cyanobacteria
Stephanie Fong	State and Federal Contractors Water Agency	Cyanobacteria/Phytoplankton Workshop
David Senn	San Francisco Estuary Institute	Cyanobacteria/Modeling/Phytoplankton Workshop
Martha Sutula	Southern California Coastal Water Research Project	Cyanobacteria/Macrophyte
Lisa Thompson	Sacramento Regional County Sanitation District	Cyanobacteria/Modeling/Phytoplankton Workshop
Tom Grovhoug	Larry Walker Associates	Drinking Water
Brian Laurenson	Larry Walker Associates	Drinking Water
Terrie Mitchell	Regional San	Drinking Water
Tony Pirondini	City of Vacaville	Drinking Water
Rachel Pisor	Department of Water Resources	Drinking Water
Lynda Smith	Metropolitan Water District	Drinking Water
Mike Trouchon	Larry Walker Associates	Drinking Water
Mike Wackman	San Joaquin County & Delta Water Quality Coalition	Drinking Water
Elaine Archibald	Archibald Consulting	Drinking Water
Jennifer Clary	Clean Water Action	Drinking Water
Debbie Webster	Central Valley Clean Water Association	Drinking Water/Phytoplankton Workshop
Louise Conrad	Department of Water Resources	Macrophyte
Shruti Khanna	LAWR, U C Davis	Macrophyte
Patrick Moran	USDA, Agricultural Research Service	Macrophyte
John Madsen	U C Davis/USDA, Agricultural Research Service	Macrophyte
Kathy Boyer	San Francisco State University	Macrophyte
Diana Engle	Larry Walker Associates	Macrophyte
Jeff Cornwell	Horn Point Laboratory, U Maryland	Macrophyte
Angela Llaban	CA Dept. Parks & Rec, Div. Boating & Waterways	Macrophyte
Eli Ateljevich	Department of Water Resources	Modeling

Individual	Agency/Institution	Science Work Group
Eric Danner	NOAA Fisheries	Modeling
Michael Deas	Watercourse Engineering, Inc.	Modeling
Joe Domagalski	US Geological Survey	Modeling
Chris Enright	Delta Stewardship Council	Modeling
Edward Gross	Resource Management Associates	Modeling
Marianne Guerin	Resource Management Associates	Modeling
Paul Hutton	Metropolitan Water District	Modeling
Phil Trowbridge	San Francisco Estuary Institute	Modeling
John Durand	U C Davis	Macrophyte/Phytoplankton Workshop
Bill Fleenor	UC Davis	Modeling/Phytoplankton Workshop
Linda Dorn	Regional San	Phytoplankton Workshop
Ian Wren	Baykeeper	Phytoplankton Workshop
James Ervin	San Jose Regional Wastewater Facility	Phytoplankton Workshop
Mary Lou Esparza	Central San	Phytoplankton Workshop
Robert Schlipf	San Francisco Regional Water Quality Control Board	Phytoplankton Workshop
Stephen Louie	California Department of Fish and Wildlife	Phytoplankton Workshop
Chris Foe	Central Valley Regional Water Quality Control Board	Cyanobacteria/Macrophyte/Modeling/ Drinking Water
Christine Joab	Central Valley Regional Water Quality Control Board	Cyanobacteria/Macrophyte/Modeling/ Phytoplankton Workshop/Drinking Water
Janis Cooke	Central Valley Regional Water Quality Control Board	Phytoplankton Workshop/Drinking Water

Appendix 1b. Stakeholder and Technical Advisory Group Members

Individual	Organization	Representing
Terrie Mitchell	Sacramento Regional Sanitation	Large POTWs
Debbie Webster	Central Valley Clean Water Assoc.	Small POTWs
Dalia Fadl	City of Sacramento	MS4
Kyle Ericson	City of Sacramento	MS4
Renee Pinel	Western Plant Health Assoc.	Irrigated Agriculture
Amrith Gunasekara	CA Dept. Food and Agriculture	Agricultural Agencies
Mark Cady	CA Dept. Food and Agriculture	Agricultural Agencies
Kirk Wilbur	California Cattlemen's Association	CAFOs
Lynda Smith	Metropolitan Water District	Water Supply
Elaine Archibald	California Urban Water Agencies (CUWA)	Drinking Water
Rachel Pisor	CA DWR	Drinking Water
Paul Bedore	Port of Stockton	Waterways
Leandro Ramos	CA State Parks - Boating & Waterways	Waterways
Stephen Louie	CA Dept. Fish and Wildlife	Resource Management
Brooke Jacobs	CA Dept. Fish and Wildlife	Resource Management
Eddie Lucchesi	Mosquito and Vector Control Assoc.	Mosquito Abatement
David Smith	Mosquito and Vector Control Assoc.	Mosquito Abatement
Jon Rosenfield	The Bay Institute	Environmental Groups