NUTRIENT MONITORING PLANNING WORKSHOP

SUMMARY OF EXISTING NUTRIENT MONITORING PROGRAMS, DATA GAPS, AND POTENTIAL DELTA RMP "NO REGRETS" MONITORING ACTIVITIES

BACKGROUND REPORT, POST-WORKSHOP: October 2016

1. Introduction and Objectives for Workshop

The Delta Regional Monitoring Program (RMP) Steering Committee has approved a list of management questions and assessment questions for nutrients in the Delta (Table 1). The data needed to answer these questions will come from a combination of existing monitoring programs and new data collection efforts to fill data gaps.

The Delta RMP only started to collect samples in the spring of 2015. Current priorities are mercury, nutrients, pathogens, and pesticides. Sample collection has begun for mercury, pathogens, and pesticides.

Deciding how to invest in monitoring resources for nutrients is challenging for a few reasons:

1. The Delta is a complex system in terms of hydrology, ecology, and water quality. There is disagreement as to its trophic status and the value (or harm) of current nutrient loadings.
2. There are numerous potential issues to address relative to nutrients, with limited resources.
3. Delta nutrients are already being monitored by other agencies, only some of which participate in the Delta RMP. There is not a common and agreed-on framework for coordination. While some of these efforts are long-term and consistent, other activities are shorter-term, or special studies, or have no secured future funding.

This report reflects feedback received at a Delta RMP nutrient monitoring planning workshop held on September 30, 2016. The goals of this workshop were to:

- **Identify** how much of the nutrient monitoring needed to answer the Delta RMP assessment questions is already happening through **existing programs,**
- Identify critical nutrient data **gaps** for the Delta RMP and develop "no regrets" monitoring activities to fill them (beginning in Calendar year 2017), and
- Develop **budget estimates for "no regrets"** monitoring activities to facilitate multi-year budget planning for the Delta RMP multi-year plan

The purpose of this report is to compile information from the major nutrient monitoring programs and to outline options for "no regrets" actions for workshop participants to review. The report synthesizes the information and recommendations gathered in a) interviews with representatives of Delta monitoring and resource management programs, b) updating earlier information gathered on current monitoring efforts in the Delta (Central Valley Monitoring Directory, Jabusch and Gilbreath 2010), and c) conclusions and recommendations from recently completed data syntheses by ASC (Novick et al. 2015, Jabusch et al. 2016) and USGS (Bergamaschi et al., in press).

Table 1. Delta RMP assessment questions for nutrients. ***Italicized bold-faced questions*** are the highest priority for the initial program.

Type	Core Management Questions	Nutrient Assessment Questions
Status & Trends	***Is there a problem or are there signs of a problem?*** a. Is water quality currently, or trending towards, adversely affecting beneficial uses of the Delta? b. Which constituents may be impairing beneficial uses in subregions of the Delta? c. Are trends similar or different across different subregions of the Delta?	***ST1. How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?*** ***A. Are trends similar or different across subregions of the Delta?*** ***B. How are ambient levels and trends affected by variability in climate, hydrology, and ecology?*** ***C. Are there important data gaps associated with particular water bodies within the Delta subregions?*** ST2. What is the current status of the Delta ecosystem as influenced by nutrients? A. What is the current ecosystem status of habitat types in different types of Delta waterways, and how are the conditions related to nutrients?
Sources, Pathways, Loadings & Processes	Which sources and processes are most important to understand and quantify? a. Which sources, pathways, loadings, and processes (e.g., transformations, bioaccumulation) contribute most to identified problems? b. What is the magnitude of each source and/or pathway (e.g., municipal wastewater, atmospheric deposition)? c. What are the magnitudes of internal sources and/or pathways (e.g. benthic flux) and sinks in the Delta?	***SPLP1. Which sources, pathways, and processes contribute most to observed levels of nutrients?*** ***A. How have nutrient or nutrient-related source controls and water management actions changed ambient levels of nutrients and nutrient-associated parameters?*** ***B. What are the loads from tributaries to the Delta?*** ***C. What are the sources and loads of nutrients within the Delta?*** ***D. What role do internal sources play in influencing observed nutrient levels?*** ***E. Which factors in the Delta influence the effects of nutrients?*** ***F. What are the types and sources of nutrient sinks within the Delta?*** ***G. What are the types and magnitudes of nutrient exports from the Delta to Suisun Bay and water intakes for the State and Federal Water Projects?***
Forecasting Scenarios	a. How do ambient water quality conditions respond to different management scenarios b. What constituent loads can the Delta assimilate without impairment of beneficial uses? c. What is the likelihood that the Delta will be water quality-impaired in the future?	FS1. How will ambient water quality conditions respond to potential or planned future source control actions, restoration projects, and water resource management changes?

2. Executive Summary

What Are the Existing Monitoring Activities Relevant to Delta RMP Assessment Questions?

Long-term routine monitoring, short-term studies, and continuous monitoring networks care collecting nutrient and nutrient-associated data at more than 100 stations in and around the Delta (Figure 1).

Long-term routine monitoring programs include the California Department of Water Resources Environmental Monitoring Program (DWR-EMP, 17 sites, since 1975), the DWR Municipal Water Quality Investigations (MWQI, 14 sites, since 1982), the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA, 2 sites, since 1991), the USGS San Francisco Bay water quality cruise (5 sites each in the Delta and Suisun Bay, since 1969), and Regional San's and the Stockton regional wastewater treatment facilities' ambient water quality monitoring (2 sites each, since 2010 and 1992, respectively).

Short-term studies. Currently active monitoring studies include the MWQI DSM2 nutrient study (5 sites, since 2013), the MWQI Cache Slough Baseline Monitoring Study (11 sites, since 2013), an IEP-funded Sacramento Deepwater Ship Channel (SDSC) study (12 sites, since 2012), and a Regional San research survey (15 sites, 2016).

Continuous monitoring networks include the USGS high-frequency (HF) sensor network (11 sites, since 2013), MWQI Real-Time Data and Forecasting (RTDF) (4 sites, since 1982), EMP chlorophyll sensors (15 sites, since 1971), and DWR North Central Regional Office (NCRO) chlorophyll sensors (24 sites, since 1991).

To What Extent Are These Monitoring Activities Addressing Delta RMP Assessment Questions?

Status & Trends

Overall, the existing monitoring programs provide partial coverage of the Delta RMP's S&T assessment questions (we estimate ~50% coverage; see Table 4).

Long-term routine monitoring programs cover the water column of main channels fairly well. Several short-term studies also provide temporary coverage of some under-monitored areas, including the North Delta. The USGS sensors provide high-frequency data at 11 stations in the North Delta, Sacramento River, Confluence, and South Delta. DWR programs maintain chlorophyll sensors in the Confluence, Central Delta, South Delta, North Delta, Sacramento River, and Suisun Bay subregions.

Sources, Pathways, Loadings, and Processes (SPLP)

Overall, the existing monitoring programs provide limited (we estimate ~25%) coverage for the Delta RMP's SPLP assessment questions.

The existing monitoring activities of USGS and DWR provide good coverage of the types and magnitudes of nutrient loads from the major tributaries, and exports from the Delta to the State and Federal water projects and to Suisun Bay.

The USGS sensor network provides baseline monitoring to help understand SPLP questions at some key locations in the North Delta, Sacramento River, and

the confluence. Future funding for this network is uncertain.

What are the Most Critical Remaining Data Gaps?

Status and Trends

Spatial Coverage

There is little monitoring coverage of shallow waters and the margins of the Delta and Suisun Bay.

There is no long-term routine monitoring in the Eastside tributaries, large areas of the Central, North, and South Delta, the Sacramento River subregion outside the mainstem Sacramento River, and in Suisun Marsh.

Nutrients and Ecosystem Conditions

Addressing gaps in all biological assessment programs is beyond the scope of this report. However, there are some obvious critical gaps, such as program modules that specifically target harmful algae and algal toxins, and a sampling network optimized for detecting and characterizing “beneficial blooms” that support the food web."

In the future, the Delta RMP should go through a similar exercise to identify links between nutrient monitoring and biological endpoints.

Sources, Pathways, Loadings, and Processes

Nutrient Sources to the Delta

Overall, estimates of nutrient loads from tributaries upstream are highly likely to be biased low, because storm events and smaller tributaries are not adequately captured.

Sources and Sinks within the Delta

Nutrient sinks and sources (and especially agricultural sources) in the Delta represent a critical data gap. The current monitoring does not provide the data needed to fill it.

Pathways

Hydrologic sources and source mixing have not been fully evaluated at a number of key Delta in- and outflows. Hydrologic modeling funded by the Delta RMP is expected to fill some of the gaps.

Loadings

POTW compliance monitoring provides good coverage of point source loadings within the Delta, but non-point source loads (agricultural, atmospheric, and others) are poorly understood.

Processes

Data needs for the development of a mechanistic water quality-hydrodynamic model include

- Nutrient model constituents (ammonia, nitrate, nitrite, organic-N, orthophosphate, organic-P, DO, total phytoplankton biomass, EC, temperature, BOD, CBOD).
- Rates and controls on nutrient uptake and transformation at the water/sediment interface and in wetlands
- Baseline data on the microbial foodweb and its role in nutrient cycling
- Biomass of aquatic vegetation.

Forecasting Scenarios

Current models are not ready for this use, in part because specific data are missing to validate rate constants for uptake and loss of nutrients. Current models also cannot evaluate the effects

of nutrients on ecosystem conditions fully enough to answer Delta RMP questions.

Potential Delta RMP Activities to Fill These Gaps

The main objective of this report is to identify options for a few concrete tasks that could be implemented by the Delta RMP to address some of the critical data gaps without the risk of wasting resources. To that end, the following "no regrets" options have been developed for consideration by the Delta RMP committees (Figure 1).

1. Coordination and Integration

Option 1a. Coordination Workshops – FOUNDATIONAL ACTIVITY

Convene one or several workshops on the topic of monitoring coordination, model input needs, and methods consistency. A number of Delta RMP data needs could be met if monitoring agencies were enabled to coordinate on sampling designs, sampling protocols, interlaboratory measurement consistency, and identifying data needs in conjunction with modelers.

Option 1b. Coordination and Integration Tools – FOUNDATIONAL ACTIVITY

Update and maintain a master list/inventory and develop an online monitoring tool of who monitors what, where, and when. This would allow for a thorough evaluation of data gaps and places where additional sampling, analyses, and increased sampling frequencies could be "piggybacked" on the existing programs. Long-term goals are to identify ways the current resources could be more efficiently and effectively applied; foster communication and collaboration; and identify opportunities for leveraging existing sampling efforts.

A web-based tool should allow comparison of sample collection, instrument calibration, analysis methods, and QA/QC results.

2. Status and Trends

Option 2a. "Piggybacking" – FILLS SPATIAL, TEMPORAL, AND PARAMETER GAPS

"Piggybacking" involves the addition of new stations, parameters, and increased sampling frequency *to existing routine monitoring programs*. Resuming monitoring at discontinued EMP stations and/or adding new stations (1-4 total) in under-monitored areas would increase the density and representativeness of spatial coverage. Adding parameters or increasing the frequency of monitoring at existing stations would address parameter and temporal data gaps.

Based on the current inventory of monitoring programs, several obvious data gaps have been identified. However, a certain amount of planning must be completed before decisions are made about how to augment the existing monitoring network.

Option 2b. HAB Sampling – FILLS CONSTITUENT GAPS

This option would fill a critical monitoring gap. The initial focus of this monitoring would be on addressing one or several of multiple objectives: 1) public health and ecosystem concerns, 2) gaining a better understanding of bloom dynamics , and/or 3) their spatial and temporal extent.

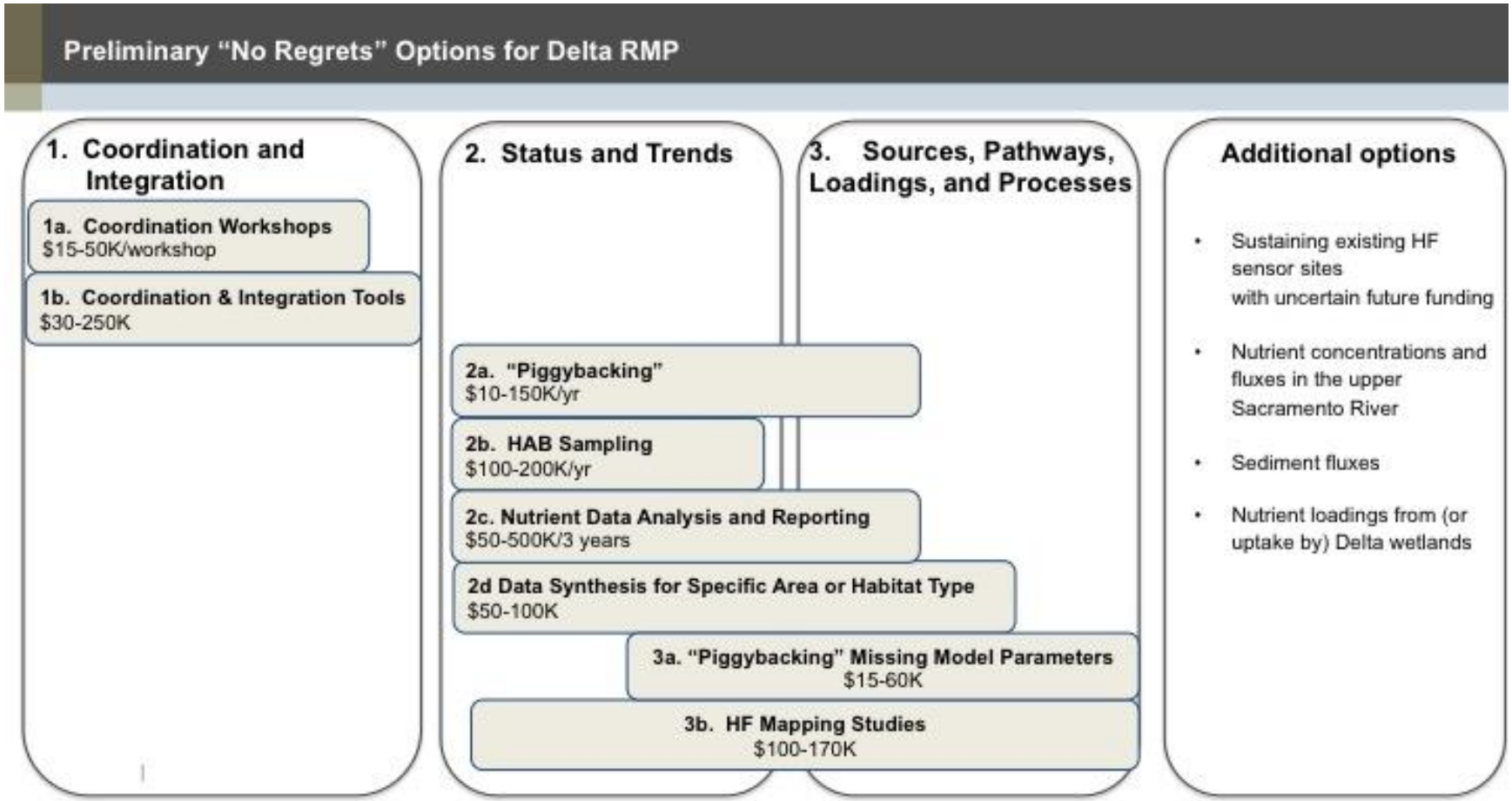

Figure 1.Summary of recommended "no regrets" options for the Delta RMP.

Option 2c. Nutrient Analysis and Reporting – INFORMS FUTURE DESIGN

Continued synthesis and integration of existing data to evaluate the information they provide relative to the Delta RMP assessment questions. Existing nutrient and nutrient-associated data are underutilized. Synthesizing, assessing, and reporting on the wealth of data on generated by monitoring agencies could be a valuable function of the Delta RMP. A biannual report presenting the synthesized information will be produced, which provides the current state of knowledge in answering the Delta RMP assessment questions related to nutrient trends and effects.

Option 2d. Nutrient Data Synthesis for Specific Area or Habitat Type – INFORMS FUTURE DESIGN

Data analysis should also extend to more specific information gaps, such as under-monitored and –analyzed subregions or habitats for which data exist but have not been synthesized and assessed against the Delta RMP assessment questions. At the workshop, participants specifically discussed the idea of a North Delta Synthesis.

For example, a North Delta data analysis would synthesize and assess combined data from the existing data available for this region, including HF sensor monitoring, MWQI data collection efforts, and for the SDSC special study. The North Delta is considered an under-monitored geographic area where important biogeochemical processes occur.

However, analyses of other subregions or habitat types might be considered equally important. For example, there are major problems with HABs, macrophytes, and dissolved oxygen (DO) in the South Delta. Thus, a certain amount of planning must still be completed before decisions are made about scope and goals of the syntheses.

3. Sources, Pathways, Loadings, and Processes

Option 3a. "Piggybacking" Missing Model Parameters – DATA FOR MODELS

Augment suite of measured constituents to existing stations where they are not collected. Option 3b. High Frequency Sensor Mapping Studies – DATA FOR MODELS

Use high frequency sensor data collection cruises to map nutrients and other parameters in subregions to understand nutrient transformations and potential internal loading in under-sampled Delta locations.

The total cost to implement all these options ranges is estimated to be $370,000 to $1,230,000 per year.

Implementation of these options would make good progress toward filling the data gaps for Status and Trends and some progress on the data gaps for Sources, Pathways, Loadings and Processes. Development of water quality models for the Delta is a critical step for understanding sources pathways and processes. Model development is a huge undertaking (estimated annual cost of $1.7M see Trowbridge et al., 2016) that will need to be well planned and have funding from multiple sources.

3. Summary of Existing Nutrient Monitoring in the Delta

Existing monitoring programs are collecting nutrient and nutrient-associated data at more than 100 stations in and around the Delta (Figure 2). At least eight different entities are involved in the data collection. These programs include:

(1) *Long-term routine monitoring* programs that are collecting nutrient and nutrient associated data in and around the Delta on an ongoing basis. These include the California Department of Water Resources Environmental Monitoring Program (DWR-EMP), the DWR Municipal Water Quality Investigations (MWQI), the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA), and Regional San's ambient water quality monitoring. The **EMP** conducts monthly monitoring of general water quality and nutrients (17 sites in the Delta and Suisun Bay), phytoplankton (16 sites), and zooplankton (20 sites) at 14 sites representing main in- and outflows of the Delta. **MWQI** conducts monthly water sampling at main Delta in and outflows and at sites located near water agency intakes. Constituents monitored by MWQI include nutrients and organic carbon (OC). **NAWQA** visits two sites representing the entry points of the Sacramento and San Joaquin rivers to the Delta, Freeport @ Sacramento River (14 times/year) and Vernalis @ San Joaquin River (18 times/year). **Regional San** conducts monthly monitoring at two sites upstream and downstream of the Sacramento Regional Wastewater Treatment Plant. The **Stockton Regional Wastewater Control Facility (RWCF)** conducts monthly monitoring at two sites upstream and downstream of the facility. As part of the HF monitoring network (described below), the **USGS** California Water Science Center (CAWSC) Biogeochemistry Group collects monthly discrete samples at all HF stations (except Vernalis, which DWR monitors). These data are used to calibrate and validate the sensor data, but are also uploaded to NWIS. Analytes include NH4, NO2, NO3, PO4, DOC. TDN, Chl-a, TSS, and optical properties. The USGS San Francisco Bay Water Quality Cruise collects monthly water quality measurements at multiple depths along a transect that extends to Suisun Bay and the Confluence region of the Delta up to Rio Vista on the Sacramento River. Constituents include NO_2^-, NO_3^-, NH_3, PO_4 and dissolved Si.

(2) *Continuous monitoring networks* that are maintained by the USGS and DWR. The USGS CAWSC Biogeochemistry Group currently operates 11 high frequency stations in the Delta: 2 in the Sacramento River subregion, 5 in the North Delta subregion, 3 in the Confluence subregion, and 1 at Vernalis in the South Delta

subregion. **MWQI** maintains one continuous sensor station at Hood, 2 at the South Delta pumps, and 1 inside the State Water Project (SWP) aqueduct. Sites at the pumps and inside the SWP are equipped with a selective ion detector that can measure NO3. All MWQI continuous sites measure chlorophyll and OC. The **EMP** maintains fifteen chlorophyll sensors representing main in- and outflows of the Delta, Suisun Bay, and Suisun Marsh. The DWR North Central Regional Office (**NCRO**) maintains 24 additional chlorophyll sensors in the Central and South Delta.

(3) *Short-term Special Studies* that are currently collecting nutrient and nutrient-associated data at 40 additional locations. The MWQI **DSM2 nutrient study** conducts bimonthly visits to 5 sites representing DSM2 (Delta Simulation Model 2) nodes. The MWQI **Cache Slough Baseline Monitoring Study** conducts bimonthly visits to 11 sites in and around the Cache Slough complex in the North Delta. Both studies have no confirmed sunset date. A IEP-funded monitoring campaign to study the Sacramento Deepwater Ship Channel (**SDSC**) conducts monthly transects at 12 sites from Antioch to the North Delta, to measure nutrients along with other foodweb-related parameters. **Regional San** is about to complete an intensive research survey of phytoplankton growth conditions - including nutrients - at 15 sites along the mainstem Sacramento River.

The major monitoring programs and special studies are listed in Table 2. Station locations for these programs are summarized in Figures 2a (Long-term monitoring programs) and 2b (Short-term special studies). In Appendix A, there is more information about each of the programs. The appendix summarizes

- How and to what extent it addresses Delta RMP assessment questions
- Opportunities
- Constraints
- Program description: Start date, sampling frequency, nutrients monitored, nutrient associated variables monitored
- Sampling locations
- Data availability and reporting.

The scope of this report was limited to evaluating the major nutrient monitoring programs in the Delta. There are other programs that monitor for nutrients (e.g., ILRP, restoration projects, stormwater agencies, DWR O&M). These other programs, and any others that are missing, should be included in any comprehensive inventories of nutrient monitoring.

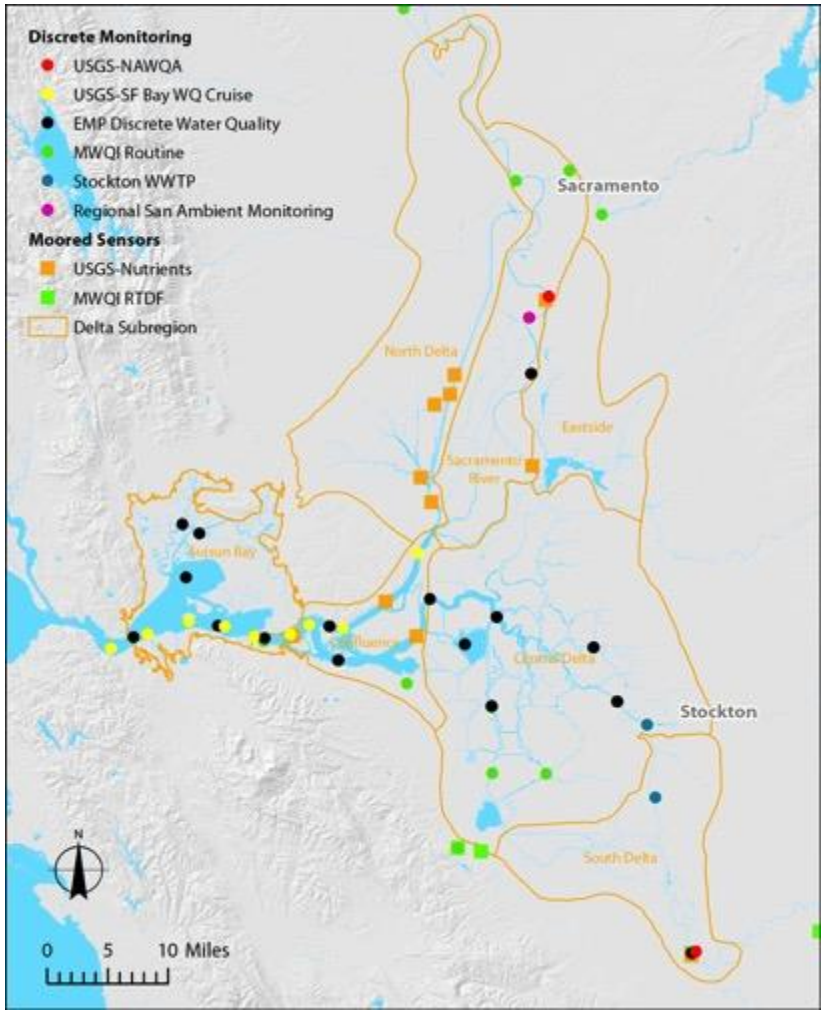

Figure 2a. Current nutrient monitoring locations in the Delta, long-term sites. Proposed subregions: Sacramento River, North Delta, Eastside, Central Delta, South Delta, and Suisun Bay, as described in a recent ASC synthesis report funded by the Delta Science Program (Jabusch et al. 2016).

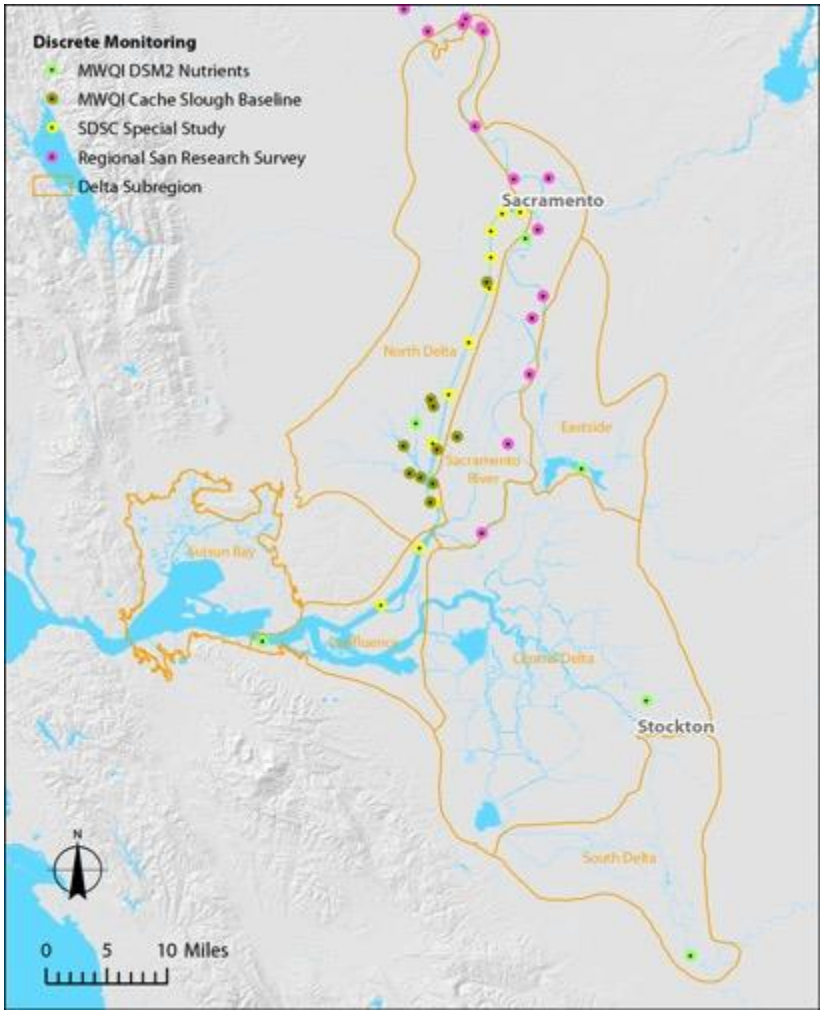

Figure 2b. Current nutrient monitoring locations in the Delta, short-term sites.

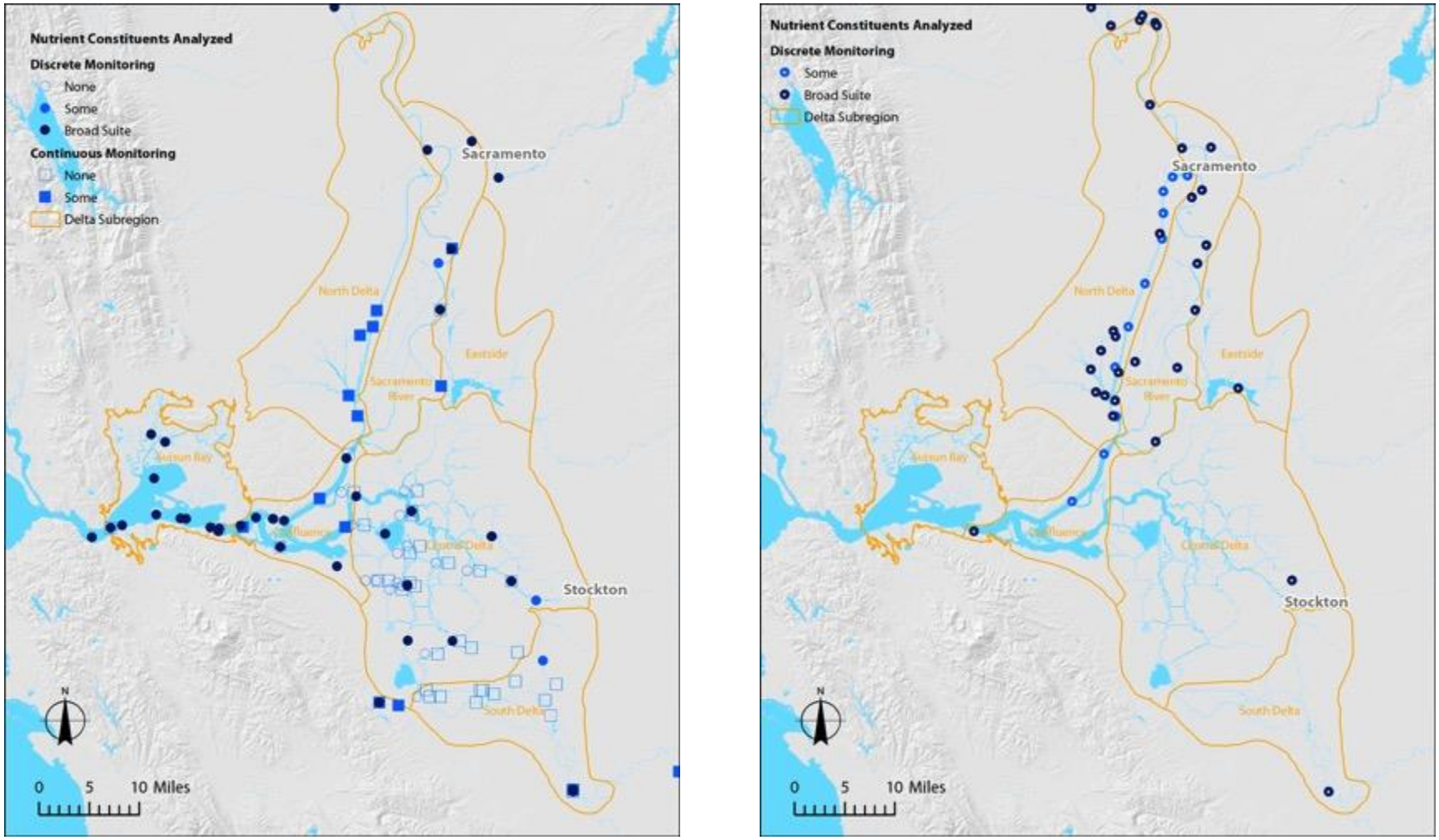

Figure 3. Current long-term (left) and short-term nutrient monitoring locations in the Delta. For each location, the color scale indicates if monitoring captures a broad suite of nutrient and nutrient-associated parameters, only some, or none (for stations that only monitor nutrient-associated variables such as chl or DO).

Table 2. Overview of monitoring programs collecting nutrient and nutrient-associated data.

Program	Since when?	How often?	Where?	What?	Public data access?
Long-term Monitoring					
California Department of Water Resources (DWR) – Environmental Monitoring Program (EMP)					
Discrete Water Quality	1975	Monthly	Northern San Francisco Estuary 12 sites in Delta representing main in- and outflows, 5 in Suisun Bay 3 Delta sites (Hood, Vernalis, Old R @ Rancho del Rio) co-located with flow	**Nutrients:** Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus, silica **Nutrient-associated:** Chlorophyll a, phaeophytin a; general water quality and standard minerals (calcium, EC, TDS, TSS, VSS); DOC, TOC; field measurements (DO, EC, fluorescence, pH, temperature, turbidity, Secchi depth)	http://www.water.ca.gov/bdma/meta/Discrete/data.cfm
Continuous Water Quality	1971	Every 15 minutes	15 sites representing the main inflows and outflows of the Delta, Suisun Bay, and Suisun Marsh (all Delta sites except Confluence sites co-located with flow)	**Nutrient-associated:** Chlorophyll, DO, EC, pH, temperature, turbidity	http://www.water.ca.gov/bdma/meta/continuous/data.cfm
Phytoplankton - Long-term	1975	Monthly	Northern San Francisco Estuary 11 sites in Delta, 5 in Suisun Bay, representing different aquatic habitats 3 Delta	**Nutrient-associated:** Phytoplankton abundance and taxonomic composition	http://www.water.ca.gov/bdma/meta/Phytoplankton/data.cfm

Program	Since when?	How often?	Where?	What?	Public data access?
			sites (Hood, Vernalis, Old R @ Rancho del Rio) co-located with flow		
Zooplankton	1968	Monthly	Northern San Francisco Estuary Currently, 20 fixed stations (10 in Delta, 5 in Suisun Bay) and between 2 and 4 floating entrapment zone stations	**Nutrient-associated:** Zooplankton abundance and taxonomic composition	http://www.water.ca.gov/bdma/meta/zooplankton/data.cfm
DWR – Municipal Water Quality Investigations (MWQI)					
Routine Monitoring	1982	**Discrete:** Monthly	Main inflows and outflows of the Delta 9 sites in the Delta, 4 upstream in Sacramento River watershed, 1 in State Water Project (SWP) downstream. Most Delta sites co-located with flow.	**Nutrients:** Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus Nutrient-associated: UVA, standard minerals, DOC, TOC, turbidity	http://www.water.ca.gov/waterdatalibrary/
Real-time Data and Forecasting (RTDF)	1982	**Continuous:** Every 15 minutes	4 sites at main inflows and outflows of the Delta, one in SWP of the Delta at the Gianelli Pumping/Generating Plant All stations are co-located with flow	**Nutrients:** nitrate (Ion Chromatography Analyzer) **Nutrient-associated:** EC, TOC/DOC	http://cdec.water.ca.gov/queryTools.html
U.S. Geological Survey (USGS)					

Program	Since when?	How often?	Where?	What?	Public data access?
National Water Quality Assessment Program (NAWQA)	1991	**Discrete:** 14 events/year (Freeport)/18 events/year (Vernalis) Grab sampling from bridge (Vernalis)/by boat (Freeport)	Sacramento and San-Joaquin-Tulare basins 2 sites in Delta (both co-located with flow)	**Nutrients:** Ammonia, nitrate, nitrite, total nitrogen, orthophosphate, total phosphorus, organic nitrogen **Nutrient-associated:** Dissolved and particulate carbon, ultraviolet light absorbing constituents	http://waterdata.usgs.gov/nwis
CAWSC Biogeochemistry Group High Frequency (HF) Nutrient Monitoring Network	2013 Future funding uncertain	**Continuous**, Every 15 minutes for in situ HF measurements **Discrete**: Grab sampling by boat each, approximately monthly	11 Stations: 2 in the Sacramento River subregion, 5 in the North Delta subregion, 3 in the Confluence subregion, and 1 at Vernalis in the South Delta subregion. Discrete samples are collected at these stations monthly Stations co-located with flow: Freeport and Walnut Grove (Sacramento River); Liberty Island and Cache Slough (North Delta); Jersey point (Confluence); and Vernalis (South Delta)	**Continuous, Nutrients:** Nitrate, phosphate (sensors deployed on an event basis), ammonium (under development) **Continuous, Nutrient-associated sensors:** Temperature, conductivity, pH, DO, turbidity, chlorophyll-a, phycocyanin (a tracer for blue-green algae such as *Microcystis*), and fluorescent dissolved organic matter (fDOM, a proxy for dissolved organic carbon concentrations). **Discrete, nutrients:** include NH4, NO2, NO3, PO4, TDN.	

Program	Since when?	How often?	Where?	What?	Public data access?
				Discrete, nutrient-associated: Chl-a, DOC, TSS, and optical properties.	
DWR – North Central Region Office (NRCO) Water Quality Evaluations					
Central Delta Monitoring – Continuous	2007	**Continuous:** Every 15 minutes	10 sites representing critical areas of the Central Delta to characterize water quality on the path that Sacramento River water takes to Clifton Court Forebay. All sites are co-located with flow. .	**Nutrient-associated:** Chlorophyll, temperature, SC	http://www.water.ca.gov/waterdatalibrary/
Central Delta Monitoring – Discrete		**Discrete:** Grab sampling by boat or shoreside upon each continuous monitoring site visit (can vary from weekly to every 3 weeks)		**Nutrient-associated:** Chlorophyll, phaeophytin, TSS	http://www.water.ca.gov/waterdatalibrary/
Rock Slough Monitoring – Continuous	2001	**Continuous:** Every 15 minutes	5 monitoring stations between Old River and Contra Costa Canal. One site co-located with flow: Old R @ Bacon Island.	**Nutrient-associated:** SC, temperature	http://www.water.ca.gov/waterdatalibrary/
Rock Slough Monitoring – Discrete		**Discrete:** Grab sampling by boat or shoreside upon each continuous monitoring site visit (can vary from weekly to every 3 weeks)		**Nutrient-associated:** SC, temperature	http://www.water.ca.gov/waterdatalibrary/
South Delta Monitoring – Continuous	1991	**Continuous:** Every 15 minutes	14 monitoring stations in the South Delta and southern Central Delta. Six sites are co-located with flow: Grant Line Canal: above barrier & nr Clifton Court Forebay; Middle	**Nutrient-associated:** Chlorophyll, DO, pH, temperature, turbidity, SC	http://www.water.ca.gov/waterdatalibrary/
South Delta Monitoring – Discrete		**Discrete:** Grab sampling by boat or shoreside upon each continuous		**Nutrient-associated:** Chlorophyll, phaeophytin, TSS	http://www.water.ca.gov/waterdatalibrary/

Program	Since when?	How often?	Where?	What?	Public data access?
		monitoring site visit (can vary from weekly to every 3 weeks)	R @ Union Pt.; Old R: @ DMC - below dam & @ Tracy Wildlife Association; Victoria Canal nr Byron		
National Pollution Discharge Elimination System (NPDES)					
POTW effluent monitoring	Varies by facility	Varies by facility, depending on discharge volume and parameter (daily - annual)	15 NPDES facilities located in the Delta and 40 upstream (below major dams) in the Central Valley.	Typical effluent monitoring include ammonia and nitrate+nitrite, some facilities also measure total Kjeldahl Nitrogen and total phosphorus Nutrient-associated: pH	https://ciwqs.waterboards.ca.gov/ciwqs/readOnly/CiwqsReportServlet?inCommand=reset&reportName=esmrAnalytical
Regional San					
Ambient water quality (Receiving Water)	2010 End date TBD	Monthly grab sampling by boat	2 sites, Freeport and Cliff's Marina (Freeport site co-located with flow)	**Nutrients:** Ammonium, total nitrogen	
Stockton RWCF					
Ambient water quality (Receiving Water)	2016 End date TBD	Monthly grab sampling by boat	2 sites, up- and downstream of facility	**Nutrients:** Ammonium **Nutrient-associated:** salinity, temperature, pH, turbidity, DO	
Short-term Studies					
DWR – MWQI					
DSM2 Nutrient Study	2013 End date TBD	**Discrete:** Twice a month Grab sampling by boat	DSM2 nodes 5 sites in the Delta. One station (SJR @ Vernalis) is co-located with flow.	**Nutrients:** Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-	http://www.water.ca.gov/waterdatalibrary/

Program	Since when?	How often?	Where?	What?	Public data access?
				phosphate, phosphorus **Nutrient-associated:** Physical parameters, biological oxygen demand (BOD), carbonaceous biological oxygen demand (CBOD), chlorophyll, and phaeophytin	
Cache Slough baseline monitoring and analysis	2013 End date TBD	**Discrete:** Twice a month Grab sampling by boat	11 sites in Cache Slough Complex, Prospect Slough stairstep, and Liberty Cut, Sacramento Deepwater Ship Channel (SDSC) 4 sites are co-located with flow: Cache Slough, Liberty Island, Miner Slough, and Lisbon Weir.	**Nutrients:** Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus **Nutrient-associated:** Standard minerals, TOC, DOC, UVA, suspended solids, chlorophyll, phaeophytin	http://www.water.ca.gov/waterdatalibrary/
DWR – EMP-associated Special Studies					
DWR Special Studies Research Program	No current data collection	N/A	N/A	N/A	
US Bureau of Reclamation					
Sacramento Deepwater Ship Channel (SDSC) baseline monitoring	2012 End date TBD	**Discrete:** Monthly in the spring, summer, and fall	12 stations located in the SDSC, the Prospect Slough stairstep, and Liberty Cut. 2 stations co-located with flow: NL 34 (Rio Vista) and NL 70 in	**Nutrients:** Ammonium, nitrate, soluble reactive phosphorus (SRP) **Nutrient-associated:** Temperature, specific conductance, turbidity, suspended solids,	

Program	Since when?	How often?	Where?	What?	Public data access?
			SDSC	phytoplankton and zooplankton abundance and taxonomic composition.	
Regional San					
Research Survey	2016 only	**Discrete:** Intensive one-time surveys in spring and fall, monthly grab sampling at RM44, all by boat. Two stops (Hood, Freeport) are co-located with flow.	15 sites along mainstem Sacramento River and major tributaries.	**Nutrients:** Ammonium, nitrate + nitrite, Kjeldahl N, phosphate, silicate, uptake experiments (NH4+C, NO3+C) **Nutrient-associated:** Temperature, turbidity, pH, EC, DO, chlorophyll, photosynthetically active radiation (PAR), picoplankton, phytoplankton, isotopes, microzooplankton, macrozooplankton, clams.	

4. How Much Are Delta RMP Nutrient Data Needs Already Covered by Existing Programs?

Status & Trends (ST)

ST-1 – How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally? — **ANSWER: PARTIAL OVERALL COVERAGE**

Due to the existence of the 40-year data record generated by the EMP, regional long-term trends are reasonably well understood. Data from additional programs (MWQI, Regional San and IEP special studies) extend the spatial coverage to under-monitored areas in the North Delta and the Sacramento River upstream of the legal Delta. USGS high frequency in situ sensors add temporal resolution for a suite of parameters (NO3, temperature, specific conductivity, DO, pH, turbidity, chlorophyll-a, phycocyanin, fDOM) at stations in the North Delta and Sacramento River subregions. The DWR NCRO monitoring network contributes to the spatial and temporal density of chlorophyll data in the Confluence, Central Delta, South Delta, North Delta, and Sacramento River subregions (see Appendix A, page 47).

The monthly monitoring frequency used by most programs is sufficient for detecting changes in most nutrient-related parameters on the order of 50% change over 10 years. High frequency sensors, where they exist, significantly improve the power to detect trends (see power analysis in Jabusch et al., 2016).

ST-1A – Are trends similar or different across subregions of the Delta?
— **PARTIAL COVERAGE**

The Delta can be roughly divided into seven subregions for the purpose of status and trends monitoring for nutrient-related parameters (Jabusch et al., 2016). EMP and other programs provide good spatial coverage of these regions but lack stations in the North Delta or Eastside subregions and Suisun Marsh. Recent efforts by MWQI and USGS started filling some of these gaps but their continuation is uncertain.

The question cannot be fully answered until we have a more complete assessment of spatial variability within subregions and how representative the existing stations are. However, as proof of concept, the EMP dataset was recently used to assess whether trends in nutrients parameters between 1975 and 1995 were similar or different in different regions of the Delta (ASC, 2016). For most of the nutrient variables, most of the sites had no detectable trends (i.e., no statistically significant trend); however, when long-term trends were detectable, the direction of trend was mostly consistent across the entire region. The exception was ammonia, for which the direction of trend was positive at sites in the Sacramento River, Confluence, and Suisun Bay subregion; negative at South Delta sites; and mixed at Central Delta subregion sites.

ST-1B – How are ambient levels and trends affected by variability in climate, hydrology, and ecology?
— **PARTIAL COVERAGE**

Robust long-term data sets (water quality, biology, hydrology) generated

by IEP, USGS, and DWR provide a good starting point for these types of analyses. Ongoing data synthesis efforts using advanced statistical models (WRTDS, GAMs, etc.) will reveal any specific data needs for answering questions about key drivers. These data needs will likely be for confounding[1] variables that need to be controlled in the statistical models.

ST-1C – Are there important data gaps associated with particular water bodies within the Delta subregions?

— GOOD COVERAGE

Current data coverage and gaps of existing waterbodies have been reasonably well documented through recent synthesis reports (Novick et al., 2015, Jabusch et al, 2016).

***ST-2 – What is the current status of the Delta ecosystem as influenced by nutrients?* — UNKNOWN**

ST-2A – What is the current ecosystem status of habitat types in different types of Delta waterways, and how are the conditions related to nutrients?

— UNKNOWN

There are a number of biological monitoring programs and special studies in the Delta that could be relevant to this assessment question. Recognized critical data gaps include the lack of monitoring data on the spatial and temporal distribution of both beneficial algal blooms (e.g. diatoms) and harmful algal blooms (e.g., *Microcystis)*. However, the main focus of this report is on the nutrient and nutrient-related monitoring parameters. Addressing gaps in biological assessment programs is beyond the scope of this effort. In the future, the Delta RMP should go through a similar exercise to identify links between nutrient monitoring and biological endpoints.

***SPLP-1 – Which sources, pathways, and processes contribute most to observed levels of nutrients?* — LIMITED OVERALL COVERAGE**

The existing monitoring by USGS and DWR provides insight into the types and magnitudes of nutrient loads from the Sacramento River and San Joaquin River to the Delta, and exports from the Delta to the water intakes of the State and Federal water projects and to Suisun Bay.

SPLP-1A – How have nutrient or nutrient-related source controls and water management actions changed ambient levels of nutrients and nutrient-associated parameters?

— PARTIAL COVERAGE

The existing long-term historical data on ambient concentrations and effluent loads allow the evaluation of major trends in relation to known large-scale changes in source-controls (e.g. elimination of point sources for phosphorus; effects of Regional San's planned upgrade) but not necessarily at the finer temporal and spatial scale needed to evaluate impacts of more specific water management actions or non-point source impacts.

SPLP-1B – What are the loads from tributaries to the Delta?

— GOOD COVERAGE

The existing monitoring by USGS captures loads in nutrients from the Sacramento and San Joaquin rivers

[1] In statistics, a confounding variable "explains away" some or all of the correlation between an independent and a dependent variables.

reasonably well under most conditions (with the exception of short-term high intensity events). Loads from the other tributaries – Calaveras, Cosumnes, and Mokelumne Rivers and the Yolo Bypass – are not routinely monitored.

SPLP-1G– What are the types and magnitudes of nutrient exports from the Delta to Suisun Bay and water intakes for the State and Federal Water Projects? — **GOOD COVERAGE**

Sampling frequency and parameters measured at current stations in the Confluence and at the water intakes are sufficient to answer the question.

SPLP-1C – What are the sources and loads of nutrients within the Delta?
SPLP-1D – What role do internal sources play in influencing observed nutrient levels?
SPLP-1E – Which factors in the Delta influence the effects of nutrients?

SPLP-1F– What are the types and sources of nutrient sinks within the Delta?

FM-1– How will ambient water quality conditions respond to potential or planned future source control actions, restoration projects, and water resource management changes?

— **VERY LIMITED COVERAGE**

A mechanistic biogeochemical-hydrodynamic model is needed to address these questions. Current monitoring is not sufficient, and for the most part not been designed, to provide the necessary data.

5. Critical Data Gaps

Coordination and Integration

There is a need for an up-to-date and maintained inventory of all nutrient monitoring in the Delta. The summary in this report is a good start but limited to the major programs. The Central Valley Monitoring Inventory (www.centralvalleymonitoring.org) was a complete list but has fallen out of date. Not having a complete and searchable inventory is a foundational gap in the program.

The workshop illustrated the utility of a forum for monitoring agencies to coordinate on sampling designs, sampling protocols, interlaboratory measurement consistency and data management, as well as to discuss data needs with modelers. There is no regular forum like this for nutrients in the Delta, which is an organizational gap in the program. Holding an annual workshop with nutrient monitoring agencies, modelers, managers, and researchers would implement one of the recommendations from the Modeling White Paper (Trowbridge et al., 2016).

Status and Trends

Spatial Coverage

There is still much uncertainty around spatial variation of nutrients within and across subregions and what geographic differences in conditions tell us about nutrients and the ecosystem.

Subregions

Sampling by DWR-EMP or any other single monitoring effort does not have the spatial coverage needed to characterize nutrient status and trends in all Delta subregions. The focus in determining additional locations should be on adding missing sentinel sites for specific areas that are currently missing them. The most critical gaps in spatial coverage include

- North Delta, including Cache/Liberty complex, Yolo Bypass, and Barker Slough
- Eastside tributaries
- Large areas of the Central and South Delta
- Georgiana Slough
- Suisun Marsh
- Mainstem Sacramento River and tributaries upstream of the confluence with the Cache/Liberty complex

North Delta: The North Delta is believed to be a dynamic system with strong gradients of nutrients and other biogeochemical constituents, but relatively few historic monitoring data of this system exist. The EMP does currently not have sampling stations in the North Delta. The U.S. Geological Survey (USGS) has installed 5 moored sensors in the North Delta between February 2013 and August 2014.and also conducts monthly sampling of nutrients and chl-a at these stations. Other programs are monitoring nutrients at stations located in the North Delta (e.g. Cache Slough Complex Baseline Study), but data collection is currently not coordinated among different programs, and continuation of these efforts is uncertain. Data that exists to date should be synthesized to a) evaluate what information they provide about spatial variability in this region, b) document the findings of the analyses in the context of the Delta RMP

assessment questions, and c) contribute information to inform future long-term monitoring designs.

Eastside Tributaries: The North-East corridor has been identified as ecologically important but little information exists regarding nutrient concentrations, loadings, and associated phytoplankton and aquatic plant productivity. The EMP does currently not have sampling stations in this subregion. Other programs such as the MWQI are currently conducting short-term monitoring studies in this subregion that may fill some data gaps.

Other under-monitored areas: there is still much uncertainty around spatial variation of nutrients within and across large areas of the Central and South Delta, Georgiana Slough, and Suisun Marsh.

Under-monitored habitats. There are significant data gaps in the coverage of aquatic (vegetated) habitats in margin areas of the Delta, such as sloughs and wetlands around the periphery of the Delta (e.g. North Delta, Eastside Corridor, and Suisun Marsh). The current monitoring is focused on the main water channels.

Ecosystem conditions

Harmful Algal Blooms

There is general agreement that there is an urgent need for monitoring of harmful algal blooms (HABs) and the presence of algal toxins. HABs present a serious threat to ecosystem conditions and human health. HABs would not occur and could not be sustained without abundant nutrients. Even as the role of nutrients as a driver in the system remains unclear, it is recommended that HABs be treated pragmatically as a "nutrient-associated" issue, so that this extremely critical data gap can be filled.

Additional Gaps

Overall, workshop participants felt that focusing status and trends monitoring on nutrients only is too restrictive and that monitoring should also be related to effects.

Alternative monitoring approaches should be evaluated for filling gaps. Some of the routine sampling designs in the Delta are not effective for detecting certain algae blooms. For example, currently used methods for phytoplankton sampling have a high degree of uncertainty for detecting algae that occur in patchy colonies, such as *Microcystis*.

Large-scale synoptic surveys of aquatic habitats (e.g. high-speed mapping) could be useful to identify important aquatic habitats that should be sampled.

Sources, Pathways, Loadings, and Processes

Ultimately, the best tool to answer these assessment questions is a mechanistic water quality-hydrodynamic model. Current models are not ready for this use but are being upgraded to interface with nutrient modules. Gaps in data to calibrate and validate the models will need to be addressed by augmenting existing monitoring programs with additional parameters, stations, and sampling events (increased sampling frequency). Short-term intensive monitoring and special studies will be needed to understand processes, derive rate constants.

Upstream Sources and Loadings

USGS monitoring at Freeport and Vernalis provides data on loads to the Delta from the major tributaries, with the exception of short-term high

intensity events. Less is known about loads from other tributaries such as the Yolo Bypass or Eastside tributaries, which may be significant during some periods, in certain conditions such as above average wet years and high-intensity events.

Upstream Loadings

The existing HF sensor at Freeport may be in jeopardy because of uncertain future funding. It is a potential future data gap. Vernalis lacks a HF nitrate sensor, which is also a big data gap.

Overall, nutrient load estimates for upstream sources are probably biased low, because storm events are not adequately captured. This gap could be filled and prevented from widening through storm sampling to characterize the hydrograph, or by adding/ maintaining nutrient sensors at Freeport, Vernalis, and potentially additional entry points to the Delta such as the Yolo Bypass or Mokelumne River.

Within the Delta

Sources

Nutrient sinks and sources in the Delta, esp. Delta Island drains, are not well understood. Filling this information gap will require a combination of strategic monitoring at strategically selected sentinel sites, intensive studies, research, and modeling. Real-time monitoring – consisting of simultaneous collection of nutrient concentration and flow data – will provide baseline data needed to calculate fluxes and differences in concentrations up- and downstream of potential sources (e.g. major island drains) and sinks (e.g. waterbodies with long residence times functioning as potential transformation hot spots). Additional intensive studies such as strategic high-frequency mapping or grab sample campaigns would be needed to increase spatial coverage during important time periods and to fill in parameters for which there are no routine sensors, such as ammonium and phosphate. Special research studies are needed to establish important transformation processes and calculate transformation rates. More refined estimates of water imports and exports are needed to calculate loads. Finally, combined hydrological and biogeochemical modeling is needed to estimate potentially important sources and sinks at times and locations where there is no monitoring.

Pathways

Developing a better understanding of how waters from different sources flow and mix in the Delta continues to be one the biggest challenges. At many key locations representing Delta in- and outflows, hydrologic sources and source mixing have not been fully evaluated under a wide range of flow conditions. Hydrodynamic models are available that can be applied to fill this gap.

The lack of sediment sampling hinders the evaluation of the accumulation and fate of nutrients within the Delta. In some areas of the Delta, the sediment is believed to be a source of nutrients.

Loadings

Good information exists on point source loadings within the Delta, but non-point source loads are poorly understood. Land use export models combined with targeted monitoring of fluxes at key locations are needed to characterize these important sources of nutrients.

Processes

Critical information gaps that limit our understanding of important large-scale

processes and fluxes, and thus limit model development, include:

- Lack of data for nutrient model constituents at some model inflow boundaries, such as Lisbon/Yolo, Cosumnes, Mokelumne, and Calaveras.
- Rates and controls on nutrient uptake and transformation (including mineralization) in the aquatic environment, and especially at the water/sediment interface and in wetlands.
- Role of organic material in Delta in moving nutrients through the system
- Baseline data on the microbial foodweb and its role in nutrient cycling
- Conceptual model gaps preventing the closure of nitrogen budgets, including the role of denitrification and nitrous oxide production
- Biomass of submerged and floating aquatic vegetation (SAV/FAV). This information is a prerequisite to understanding the role of SAV/FAV in nutrient cycling
- Lack of measurements at depth, which are required for model calibrations and improved load estimates
- Lack of isotope data for nitrogen and other parameters to illuminate these processes and others.
- Stoichiometry of primary producers. Stoichiometric data would provide insights in nutrient requirements of primary producers.

DSM2 is the primary model in use now for simulating water quality conditions in the Delta. DWR is conducting a special study to collect additional data to calibrate and validate a nutrient module for DSM2. Even with this study, there are still more data gaps for nutrient modeling with DSM2-QUAL, which include

- Temporal availability of measurement data limits Delta-wide model runs to a monthly time steps, and therefore, outputs. Processes occurring at shorter time scales cannot be calibrated. Weekly or daily time steps may be necessary to adequately address some nutrient-related questions
- Spatial availability of data limits quality of model calibration regionally
- Lack of individual constituent measurements limits use of model for some constituents

There are plans for adding nutrient modules to other existing hydrodynamic models of the Delta (SCHISM, CASCaDE). These models are more complex than DSM2. Therefore, more data and special studies will be needed to set model boundary conditions and to calibrate these models.

Forecasting Scenarios

A linked physical-biogeochemical model is needed to generate predictions under scenarios of possible changes and management actions in the Delta. Current models are not ready for this use, in part because specific data are missing to validate rate constants for uptake and loss of nutrients. Current models also cannot evaluate the effects of nutrients on phytoplankton production.

6. Approaches for Addressing Critical Monitoring and Analysis Needs

Feedback received in interviews with representatives of Delta monitoring and resource management programs suggests that the current monitoring network could be integrated and optimized to better address Status and Trends questions for nutrients and to provide baseline data that help answer questions concerning Sources, Pathways, Loadings, and Processes.

Possible approaches toward achieving this goal will be outlined generally in this section. The approaches can be implemented through a mixture of short-term and long-term actions. Some of the options are obvious "no regrets" actions. Others require significant resources and institutional support.

Approaches for Better Coordination and Integration of Existing Monitoring Efforts

Policy-Level Coordination

There are opportunities to fill data gaps through better integration of existing data collection and evaluation efforts (by DWR, USGS, Delta RMP, and others). Alignment of program objectives and permit requirements would facilitate alignment of monitoring designs (e.g., coordinate monitoring requirements for renewed State Board Water Right Decisions, Delta Science Program directed action goals, Delta Nutrient Research Plan study questions, and Delta RMP assessment questions).

Technical Coordination

Even if program objectives cannot be perfectly aligned, actions could be taken to make the data collected by the different programs more accessible and more easily shared such as:

- Foster sensor network interoperability between USGS and DWR programs.
- Integrate and synchronize grab sample collection by different programs (EMP, MWQI, NRCO, USGS, Delta RMP)
- Interlab comparisons and coordination of QA programs. Sensors are the highest priority – because of the near-complete absence of such efforts to-date and associated missed opportunities for data integration. The second tier consists of comparisons of analytical methods for discrete samples (e.g., NH4 at low levels, organic-N, organic-P) and of associated sampling and handling procedures.

Recommended approaches for achieving better coordination also include the use of shared tools to facilitate such efforts. Existing tools include

- Central Valley Monitoring Directory as an online resource for information on who is monitoring what and where
- Data visualization tools, such as the Estuary Portal, for coordinating data sharing and assessment

This approach would require additional investment to update the inventory and upgrading and adapting data visualization and mapping tools so that

they specifically meet the identified needs.

Finally, an annual workshop and smaller workgroups would be good approaches for improving coordination between agencies and for tackling issues such as laboratory intercalibration.

Data Analysis and Synthesis

The Delta RMP has completed three synthesis reports to date: one on high-frequency sensor monitoring and two on grab sample monitoring (the latter reports were completed with in-kind funding from DWR[2] and DSP[3]). The reports have used a limited portion of the data available to answer specific questions about monitoring design optimization, which fed directly into this report. Some of the recommendations from the first reports have already been implemented by DWR, which is a significant benefit to the Delta RMP. Additional analysis of data is likely to yield more insights.

Monitoring data should be synthesized and translated into useful information on an ongoing basis. Moreover, additional data collection should only proceed if there is also enough funding for data analysis, synthesis, and interpretation. For example, a number of short-term studies are currently collecting nutrient data in the North Delta, filling information gaps. These data should be synthesized and assessed against Delta RMP assessment questions to evaluate new information gained and remaining monitoring gaps.

The scope of additional synthesis tasks should be carefully planned by the Nutrient Subcommittee to ensure that it builds off of previous work and clearly addresses Delta RMP assessment questions. In addition, coordination with other agencies who prepare data reports could yield benefits if their reports could be modified to meet Delta RMP needs.

Approaches for Addressing Data Gaps Relative to Understanding Status and Trends

Increasing Spatial Coverage

Existing long-term monitoring programs do not cover all regions of the Delta. Additional long-term monitoring stations are needed in the following regions:

- North Delta, including Cache/Liberty complex, Liberty island, Yolo Bypass, and Barker Slough
- Eastside tributaries
- Large areas of the Central and South Delta
- Georgiana Slough
- Suisun Marsh

Improving and Increasing Temporal Coverage

Timing of Sampling

There is a need to improve attention to flow conditions during sample collection (where in the *tide* as well as relative to storm events, reservoir releases, water exports, barriers, etc.).

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[2] Novick E, Holleman H, Jabusch T, Sun J, Trowbridge P, and Senn D, Guerin M, Kendall C, Young M, Peek S. 2015. Characterizing and quantifying nutrient sources, sinks and transformations in the Delta: synthesis, modeling, and recommendations for monitoring. San Francisco Estuary Institute, Richmond, CA. http://sfbaynutrients.sfei.org/sites/default/files/Main manuscript.pdf

[3] Jabusch T, Bresnahan P, Trowbridge P, Wong A, Salomon M, and Senn D. 2015. Summary and Evaluation of Delta Subregions for Nutrient Monitoring and Assessment. San Francisco Estuary Institute, Richmond, CA. http://www.sfei.org/sites/default/files/biblio_files/MainReport-DSP_2016-06-30.pdf

High-Frequency Sensor Technology Development

Ammonium: At present, there are no commercially available sensors for in situ measurement of ammonium, although the USGS currently has two prototype ammonium sensors operating periodically in the Delta and is exploring options for a sensor that could be incorporated into boat-based mapping campaigns.

Completing the full development of existing prototype ammonium sensors would enable routine high frequency monitoring of ammonium, allowing baseline monitoring needed to understand ammonium dynamics in the Delta.

HABs: A long-term continuous monitoring network of adequate spatial density, equipped with optimized phycocyanin sensors, has the potential to serve as an observation and warning system for cyanoHABs. Current instruments generally report low or no presence of blue-green algae, because they miss large algae cells and *Microcystis* aggregates, which are responsible for most occurring blooms.

Monitoring Ecosystem Conditions

Collecting Data on Microcystis/HABs

Add collection of net phytoplankton sampling, analysis of toxins in the water column and/or in clams, and/or molecular detection of toxigenic strains to existing routine monitoring.

Exploring Alternative Monitoring Designs for Evaluating Status and Trends

Alternatives to traditional sampling and analysis methods to fill-in the gaps should continue to be explored. For example, the feasibility of a randomized probabilistic design for assessing nutrient conditions across the Delta or specific habitats in the Delta should be evaluated to determine cost-effectiveness.

Approaches for Addressing Data Gaps Relative to Understanding Sources, Pathways, Loadings, and Processes

Collecting Data Needed for Modeling

Add Missing Nutrient Parameters to Existing Monitoring Locations

In addition to adding new stations to improve Status and Trends assessment, missing nutrient parameters are needed at some of the existing monitoring locations representing model boundary conditions (currently monitored by MWQI DMS2 Nutrient Study, USGS, NCRO).

Ideally, monitoring should occur at all model boundaries (these locations are fairly standard across Delta models). Discrete sampling should be co-located with HF sensors, to collect additional parameters for which there is no sensor. Additional high frequency sampling should be timed for when the rates of nutrient dynamics are high or boundary conditions (inflows AND exports) are changing rapidly.

Baseline Data Collection With High-Frequency Sensor Network

An extended high-frequency nutrient sensor network of strategically placed continuous monitoring stations would provide additional critical baseline monitoring data needed for models. These data will also help improve trend detection and loading estimates. Sensors should include in situ high frequency nitrate analyzers and may also include PO4 and NH4 analyzers.

Bergamaschi et al. (in review) have produced a nutrients sensor synthesis report for the Delta RMP. This report includes examples for nutrient sensor network designs to help address Delta RMP assessment questions.

Example 1: Minimal network focused on Fluxes and Loads. Core network of three stations that include:

1. Sacramento River @ Walnut Grove (existing)
2. Cache Slough @ Ryer Island (existing)
3. San Joaquin River downstream of the Stockton wastewater treatment plant

This core network would capture temporal variability in fluxes and loads from the Sacramento River watershed including the Sacramento urban area and Regional wastewater treatment plant; from the San Joaquin River including the Stockton wastewater treatment plant, and from the North Delta.

Network 2: Internal sources, processes and rates. Network of six new stations that may include:

1. Sacramento River @ Rio Vista
2. San Joaquin River @ Jersey Point
3. Old River @ Frank's Tract
4. Old River nr Byron
5. Middle River nr Holt
6. Middle River @ Middle River

The goal of this network would be to document internal nutrient loads in the Central Delta including loading from island drains and wetlands, and evaluate the extent to which nutrients are attenuated through interaction with wetlands and submerged islands. Includes monitoring of nutrient concentrations of water bound for export. Presumes external loadings to the Delta are adequately constrained by other stations and/or programs.

Special studies for calibrating models

Special studies to understand processes, establish rate constants, and calibrate models are also needed. The focus of the studies will depend on the processes and parameters in the model, and may include

- Tidal exchange of nutrients by marshes
- Nutrient dynamics at the sediment/water interface (role of denitrification)

High-Frequency Mapping

Boat-based high-frequency mapping provides the quickest and easiest approach for collecting data that assist in model calibration and validation. HF mapping is a cost-effective approach that allows to

- Characterize areas that are currently not represented in the fixed station design (e.g., back sloughs)
- Help resolve gradients in nutrient concentrations and other parameters, and
- Identify nutrient sources and hot spots of nutrient consumption or transformation.

Process and Fate Studies

Stable Isotopes: Stable isotope analysis is a promising analytical tool for evaluating sources, transport, uptake, and transformation of nutrients in various ecosystem components. Stable isotope analyses are a potential tool to study changes in nutrient processing

before, during, and after the implementation of the EchoWater Project.

7. Options for "No Regrets" Nutrient Monitoring for the Delta RMP

The operational definition of **"no regrets" activities** for this report are actions that:

- Fill a clear gap in the networks of fixed monitoring stations,
- Provide necessary data for models,
- Meet any other obvious baseline monitoring and analysis needs
- Follow a flexible and adaptable design that can inform future nutrient questions.

The purpose of this document is to outline "no regrets" nutrient monitoring options for the Delta RMP. The previous section outlined some broad approaches to filling data and information gaps relative to the Delta RMP's assessment questions. This section highlights options for a few concrete tasks that could be implemented by the RMP to start to address these gaps without risk of wasting resources. The table on page 35 shows the data gap that each option would address relative to answering Delta RMP assessment questions.

The estimated costs for each option are for planning purposes only. These estimates are rough and will need to be confirmed if the Delta RMP decides to implement any of these options.

Not all of these options meet the operational definition for "no regrets" *per se.* Some recommendations can be considered foundational activities that should occur so that "no regrets" activities can be implemented.

1. Coordination and Integration (Foundational Activities)

Option 1a. Coordination Workshops – FOUNDATIONAL ACTIVITY

- Hold regular workshops and meetings among modelers and monitoring agencies to coordinate data collection, understand data needs for models, evaluate monitoring program efficacy in relation to program objectives, and optimize monitoring designs. These workshops would each result in a brief report with a list of recommendations for new nutrient monitoring locations and timing, and plans for increased coordination among the monitoring agencies.
- Hold workshops on laboratory quality assurance/intercalibration and field/lab SOPs. The goal is to promote consistency between the various programs that conduct discrete grab sample and continuous monitoring. Workshop participants considered the continuous sensor network interoperability as the most critical gap. A workshop would address QAQC, data management, and data access and synthesis, and could set the stage for inter-group comparisons.

Estimated cost: $15-50k per workshop

***Option 1b. Coordination and Integration Tools* — FOUNDATIONAL ACTIVITY**

- Update the inventory of nutrient monitoring programs with a more detailed summary of what data are collected: where, what (e.g., NO3, NO2, NH4, DON, TDN, TN, TP etc.), when (start date-end date, approx. frequency). This would allow for a thorough identification of data gaps and places where additional sampling or simply additional analyses could be "piggybacked". This activity could also help identify ways the current resources could be more efficiently and effectively applied.
- *Extended activity I:* Update and maintain an online geodatabase of who monitors what, where, and when, including cruise tracks. The inventory should be able to keep track of the history of changes in each program. Programs that were not included in this report should be added (e.g., ILRP, stormwater, pre- and post-restoration monitoring).
- *Extended activity II:* Develop or customize available data visualization and integration tools to readily compile all nutrient data in the Delta.
- *Extended activity III:* Reporting on nutrient trends in the Delta.

Estimated cost: $30-250k

2. Status and Trends

***Option 2a. "Piggybacking"*— FILLS SPATIAL, TEMPORAL, AND PARAMETER GAPS**

"Piggybacking" involves the leveraging of existing programs to ensure critical data are collected. It involves the addition of new stations, parameters, and increased sampling frequency *to existing routine monitoring programs*. It would make sense to "piggyback" onto the EMP to the extent that it is feasible and practical, because the EMP has been collecting monthly data for more than 40 years with consistent timing relative to tides, and has been measuring a broad suite of nutrient and nutrient-associated variables.

Based on the current inventory of monitoring programs, the spatial, temporal, and parameter data gaps that could be filled by "piggybacking" activities include

- Resume monitoring at discontinued EMP stations and/or add new stations (1-4 total) to existing routine monitoring in under-monitored areas, to increase the density and representativeness of spatial coverage. Potential locations:
  - Central Delta: Little Potato Slough, Middle River at Union Point, San Joaquin River at Prisoner's Point (existing DWR-EMP chlorophyll sensor), and Staten Island
  - Eastside: potential locations include Mokelumne River at New Hope Road and Delta Cross-Channel
  - North Delta: opportunities for co-locating discrete sampling sites with the existing USGS sensor stations include Cache Slough (CCH), Deep Water Shipping Channel (DWS), Liberty Cut (LCT), Liberty Island (LIB), and Toe Drain North of Stair Steps (TOE).

- Sacramento River: potential locations include Freeport (USGS sensor and sampling station) and Walnut Grove (USGS sensor WGA)
- South Delta: potential locations include San Joaquin River at Mossdale (existing DWR-EMP chlorophyll sensor) and Old River near Tracy.

Piggybacking may also extend to high-intensity sampling during high-flow events. Additional discrete sampling that targets large storms, to improve calculation of loads from the Sacramento and San Joaquin Rivers, and potentially additional tributaries, such as the Yolo Bypass and eastside tributaries, during high discharge events. The potential activity is to conduct sampling along the hydrograph to fully characterize various nutrient types. Field crews that are already collecting water samples during storm events for other constituents would collect the samples.

Planning to complete before deciding how to augment the existing monitoring network includes:

- Complete the inventory. The inventory of existing nutrient monitoring should be updated (see Option 1b above) to provide a comprehensive view of existing nutrient monitoring in the Delta.
- Agree on a list of critical parameters. The broad suite of nutrient and nutrient-associated parameters that are needed at key locations should be identified. Needed measurements include additional drivers of biological activity, such as temperature and turbidity.
- Determine the optimal frequency of monitoring for each parameter. Increase sampling frequency at ecologically important locations and times. For example, more frequent sampling during critical times will provide more useful data for monitoring algal blooms. More monitoring is recommended in the spring and fall. For high frequency measurements, moored sensors could be deployed at fixed stations but could also be considered for stations that get moved around (e.g. shipside HF sensor for salinity-based stations).
- Develop relationships between chlorophyll *a* and algal biomass.

Assessment questions: ***ST1, ST1A****.*
Estimated cost: $10-150k/yr

Option 2b. HAB Sampling – Fills Parameter Gaps

Fill a critical ecosystem condition indicator gap by adding HAB monitoring. The initial focus of this monitoring would be on addressing public health and ecosystem concerns, and gaining a better understanding of bloom dynamics and their spatial and temporal extent. HAB sampling would follow a targeted design that would track the development and occurrence of blooms and would be triggered when certain conditions (e.g. visual inspection) suggest a bloom is forming. Measurements may include sampling and filtration of water samples for toxin analysis, net phytoplankton collection for microscopic analysis, or molecular techniques for detecting the presence of toxic algal strains. HAB sampling will need to encompass a broad range of additional parameters, including nutrient measurements and other indicators of biological activity, such as flow, temperature, and EC.

Recommended foundational activities include

- *Prior to implementation:* establish a protocol for a tiered monitoring response to HABs. SWAMP is currently developing a sampling and laboratory analysis guide that will include Standard Operating Procedures for field collection and laboratory methods, tiered approach to sampling and analysis, and performance based quality assurance. This document is expected to provide guidance for decisions about sampling sites and the timing of sample collection.

Assessment questions: ST1, ST1A, ***ST2, ST2A****. Estimated cost: $100-200k/yr*

Option 2c. Nutrient Data Analysis and Reporting – INFORMS FUTURE DESIGN

This option consists of continued synthesis and integration of existing data. The synthesis reports completed so far have focused on two datasets (EMP and USGS high-frequency sensor networks) and on questions about optimizing monitoring designs (Novick et al. 2015, Bergamaschi et al., in press, Jabusch et al. 2016, see Appendix C Bibliography for full references and links). Additional datasets and assessment questions could be evaluated, such as questions about the effects of nutrients on the ecosystem. The first step of additional synthesis work would be for the Nutrient Subcommittee to provide clear direction on the Delta RMP assessment questions to be answered, how the scope of work differs from the previous reports, and whether other agencies (e.g. DWR, USGS) could modify their reports to answer the questions (e.g. include a specific analysis, table, or figure). *Assessment questions:* ***ST1, ST1B, ST1C****, ST2, ST2A, SPLP1, SPLP1C. Estimated cost: $500k/3 years (2 high-level FTEs, multi-year effort).*

Data analysis should also extend to more specific information gaps, such as focused analyses of under-monitored subregion for which data exist but have not been synthesized and assessed against the Delta RMP assessment questions. The focus could be on under-monitored subregions, such as the North Delta, and/or habitat types, such as low-flow channels. At the workshop, participants specifically discussed the idea of a North Delta Synthesis.

Option 2d. Nutrient Data Synthesis for Specific Area or Habitat Type – INFORMS FUTURE DESIGN

With oversight by the Nutrient Subcommittee, synthesize and assess all existing data for this region, including data from HF sensor monitoring, MWQI data collection efforts, and for the SDSC special study. The North Delta is considered an under-monitored geographic area where important biogeochemical processes occur. Current monitoring conducted by USGS, MWQI, and SDSC may help address this need. These data should be synthesized and assessed against the Delta RMP assessment questions. Such an analyses would also inform a regional monitoring design and reveal remaining uncertainties and needs. Some of these data will be summarized in technical reports (MWQI und USGS studies), others may be published in scientific journals (SDSC study and USGS research). The final product would be a synthesis of findings from these sources – to the extent that they are available - and additional statistical analyses of the data. The analysis would also include data from the Sacramento River, to evaluate differences in biogeochemical

processes. Presentation could be in a standalone technical report or as a section in a larger report describing the overall nutrient trends in the Delta. *Assessment questions:* ***ST1, ST1B, ST1C, ST2, ST2A, SPLP1, SPLP1C.*** *Estimated cost: $50-100k (Data compilation/statistical analyses/technical report).*

3. Sources, Pathways, Loadings, and Processes

Option 3a. "Piggybacking" Missing Model Parameters – DATA FOR MODELS

Augment suite of parameters analyzed on discrete samples (to inform modeling) to existing stations where they are not collected. *Assessment questions: ST1, ST1A,* ***SPLP1, SPLP1B, SPLP1C, SPLP1F, SPLP1G.*** *Estimated cost: $15-60k/yr*

Option 3b. High Frequency (HF) Mapping – DATA FOR MODELS

Use HF data collection cruises to map nutrients and other parameters in subregions to understand nutrient transformations and potential internal loading in under-sampled Delta locations. The recommended monitoring campaign would be designed to characterize seasonal changes in flow and water quality. It would consist of 2-4 high-speed boat HF data collection cruises (~4 days each) to characterize spatial variability and characterize biogeochemical gradients in under-monitored subareas (e.g. South and North Delta) and/or waterbody types (e.g. back sloughs) under different flow scenarios. (E.g. 2 winter sampling events and 2 summer sampling event in the North/Northeast, Central Delta/ Sacramento River subregions and/or the South Delta. Measurements include: NO3, NH4, PO4, DO, chl-a, and BGA pigments. *Assessment questions: ST1, ST1A, ST1B, ST2, ST2A,* ***SPLP1, SPLP1C, SPLP1D, SPLPF.*** *Estimated cost: $100K-$170K (Depending on # of water cruises and locations; scalable)*

Additional Options

The following additional options meet the "no regrets" definition to a large degree, but not entirely. They were identified as "next best" options for potentially useful projects. All of them have some downside risk. These options have been included in the report to provide the Delta RMP committees with a broader perspective of options to consider.

- **Sustaining Existing HF Sensor Sites With Uncertain Future Funding.** In some circumstances, it may be an appropriate task for the Delta RMP to fund the continuation of HF monitoring and/or other stations that provide critically needed information and would otherwise be lost due to a lack of funding. For example, there is a possibility that the HF nutrient sensor network might become unfunded in the future. However, more in line with the Delta RMP's stated mission would be to leverage the existing network through improved coordination, integration and synthesis of data that are being collected, and additional monitoring that fills critical gaps that have yet to be filled. That is, adding capacity and bringing in additional resources rather than replacing the funding sources for existing ones. This option should only be considered if all other options have been exhausted and no other funding source can be identified.
- **Nutrient concentrations and fluxes in the upper Sacramento River (upstream of the legal Delta).** Sample nutrient concentrations at upper Sacramento River locations, such as Knight's Landing, Verona, and Discovery Park, to better characterize nutrient concentrations and fluxes in the upper Sacramento River (upstream of the legal Delta). This activity would further reduce uncertainty around variability in constituent concentrations and estimates of sources and loadings entering from the Sacramento River watershed. However, it is outside of the geographic area the Delta RMP is focusing on and there are a number of seemingly critical data gaps (from the RMP's perspective) inside the Delta that remain unfilled.
- **Sediment flux.** Nutrient fluxes in sediment remain a critical data gap, and there is a dearth of sediment nutrient data. The potential activity would be design and implement a pilot study for a seasonal sampling program that would create a baseline for characterizing nutrient fluxes at the sediment/water interface. However, this monitoring would provide its full value only if combined with controlled research experiments and modeling. Rates of exchange and transformation in various types of Delta sediments are needed to simulate a range of environmental conditions and management scenarios.
- **Nutrient loadings from (or uptake by) Delta wetlands** are a significant data gap. One potential approach for filling this gap would be a pilot study by strategically collecting nutrient data at the mouth of a selected

tidal marsh sloughs or diked wetlands outfall. Such monitoring would be most useful if performed before and after a wetland restoration project. As for sediments, a monitoring study would provide its full information value only in combination with experimental research and modeling, which would be required to establish biogeochemical processes and rates of exchange and transformation.

Table 3. Summary of options for "No Regrets" Nutrient Monitoring for the Delta RMP

Project	Gap	Scope	Assessment Questions	Cost/year
1. Coordination and Integration				
1a. Coordination workshops	Informs future design	Coordinate, prepare, and facilitate workshop; write workshop summary or report		$15-50K
1b. Coordination and Integration Tools	Informs future design	Update and maintain a master list of who monitors what, where, and when. Include a cruise track. Inventory should be able to keep track of the history of changes in each program. Lower end: basic Wiki or Google site (similar to TAC site) with compilation of tables. High end: fully upgraded mapping and data entry tools for monitoring directory; staff time to customize and populate Estuary Portal with desired metadata, data, functions, and web services (data visualization and integration tools) that may be missing. Report on nutrient trends in the Delta.		$30-$250K
			Total – Coordination and Integration	*$45-$300K*
2. Status and Trends				
2a. "Piggybacking"	Fills spatial, temporal, or parameter gaps	Lower end: analysis of broad suite of nutrient- and nutrient-associated parameters by DWR Bryte Laboratory (12-48 samples): e.g. monthly sample collection at new stations (1-4 total) added to existing routine monitoring in under-monitored areas. High end: four new superstations (4 HF sensors combined with monthly grab sampling)	**ST1, ST1A**	$10-150K
2b. HAB Sampling	Fills parameter gaps	Targeted sampling of HABs. Options include sampling and filtration of water samples toxin analysis, net phytoplankton collection for microscopic analysis, or molecular techniques for detecting the presence of toxic algal strains. Broad range of additional measurements (nutrients and measurements for other drivers of biological activity). (10-20 sampling events/10-20 stations).	ST1, ST1A	$100-$200K
2c. North Delta Data Analysis	Informs future design	Data compilation, statistical analyses/trend analyses, evaluation of data against assessment questions/data interpretation, preparation of technical report	**ST1, ST1B, ST1C**, ST2, ST2A, SPLP1, SPLP1C	$50-300K

Project	Gap	Scope	Assessment Questions	Cost/year
2c. Nutrient Data Analysis and Reporting	Informs future design	Data compilation, statistical analyses/trend analyses, evaluation of data against assessment questions/data interpretation, preparation of technical report.	**ST1, ST1B, ST1C**, ST2, ST2A, SPLP1, SPLP1C	$50-200K
2d. Data Analysis for Specific Area or Habitat Type	Informs future design	Data compilation, statistical analyses/trend analyses, evaluation of data against assessment questions/data interpretation, preparation of technical report	**ST1, ST1B, ST1C**, ST2, ST2A, SPLP1, SPLP1C	$50-300K
			Total – Status and Trends	*$210-$700K*
3. Sources, Pathways, Loadings, and Processes				
3a. “Piggybacking” Missing Model Parameters	Data for models	Broad suite of nutrient- and nutrient related parameters (~12-44 samples: 1-4 stations x 12 events)	ST1, ST1A, **SPLP1, SPLP1B, SPLP1C, SPLP1F, SPLP1G**	$15-60K
3b. HF Mapping Studies	Data for models	Installation of nitrate sensor	ST1, ST1B, **SPLP1, SPLP1B**	$100-170K
			Total – Sources, Pathways, Loadings, and Processes	*$115-$230K*
			Total – All Projects	***$370-1,230K***

Table 4. Estimated coverage of Delta RMP monitoring questions by existing monitoring and significance of proposed activities for addressing them. This table does not include Coordination and Integration activities.

	Assessment Questions	Existing monitoring	2a. Piggyback	2b. HAB sampling	2c. Nutrient data analysis and reporting	2d. Data synthesis for specific area or habitat type	3a. Piggyback model parameters	3b. HF mapping studies
ST1	**How do concentrations of nutrients (and nutrient-associated variables) vary spatially and temporally?**	◔						
ST1A	Are trends similar or different across subregions of the Delta?	◑	★	★	★		★	★
ST1B	How are ambient levels and trends affected by variability in climate, hydrology, and ecology?	◑	★	★	★	★		★
ST1C	Are there important data gaps associated with particular water bodies within the Delta subregions?	◔			★	★		

Legend

◔ Signifies coverage of questions by existing data. Pie size indicates the extent to which current programs provide data coverage for addressing the question.

★ ☆ Signifies that the “no regrets” activity would generate substantial relevant data. The size of the star indicates the degree to which the proposed activity would improve data coverage for addressing the assessment question. Open stars relate to assessment questions that are not considered an initial priority in the Delta RMP Monitoring Design.

ST2	**What is the current status of the Delta ecosystem as influenced by nutrients?**	?						
ST2A	What is the current ecosystem status of habitat types in different types of Delta waterways, and how are the conditions related to nutrients?	?	☆	☆	☆	☆		☆
SPLP1	**Which sources, pathways, and processes contribute most to observed levels of nutrients?**	◔						
SPLP1A	How have nutrient or nutrient-related source controls and water management actions changed ambient levels of nutrients and nutrient-associated parameters?	◑	★		★			★
SPLP1B	What are the loads from tributaries to the Delta?	◕	★		★			
SPLP1C	What are the sources and loads of nutrients within the Delta?	◔	★		★	★	★	★

SPLP1D	What role do internal sources play in influencing observed nutrient levels?							
SPLP1E	Which factors in the Delta influence the effects of nutrients?							
SPLP1F	What are the types and sources of nutrient sinks within the Delta?							
SPLP1G	What are the types and magnitudes of nutrient exports from the Delta to Suisun Bay and water intakes for the State and Federal Water Projects?							
FM1	How will ambient water quality conditions respond to potential or planned future source control actions, restoration projects, and water resource management changes?							

Appendix A: Descriptions of Existing Nutrient Monitoring Activities in the Delta

List of Programs

1. California Department of Water Resources (DWR) – Environmental Monitoring Program (EMP)
2. DWR – Municipal Water Quality Investigations (MWQI)
3. DWR – North Central Region Office (NRCO) Water Quality Evaluations
4. DWR – Special Studies Research Program
5. U.S. Bureau of Reclamation – Sacramento Deepwater Ship Channel
6. U.S. Geological Survey (USGS) – National Water Quality Assessment (NAWQA) Program
7. USGS – High-Frequency (HF) Nutrient Monitoring Network
8. Regional San - Monitoring of Sacramento River Receiving Waters and Upstream Waters
9. Stockton RWCF – Monitoring of Receiving Waters

1. California Department of Water Resources - Environmental Monitoring Program (EMP)
Summary:

How and to what extent does it address Delta RMP assessment questions?

The EMP has been collecting nutrient data as part of larger monitoring program since 1975. Due to the existence of the 40-year data record generated by the EMP, regional long-term trends are reasonably well understood. The EMP can be considered as the core data collection effort for addressing the Delta RMP Status & Trends (S&T) nutrient assessment questions. Data from EMP stations are also critical for Delta RMP Sources, Pathways, and Loadings questions such as calculating nutrient exports from the Delta from water withdrawals and Delta outflow.

Opportunities

The EMP operates under the auspices of the Interagency Ecological Program (IEP), which has a strong interest in the Delta RMP S&T nutrient assessment questions and in collaborating with the Delta RMP on nutrient monitoring. Therefore, the EMP invites feedback for how the program can be optimized to address the Delta RMP nutrient assessment question ST-1 ("How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?").

The IEP community is particularly interested in the effects of changes in nutrients on phytoplankton, zooplankton, and other components of the estuarine foodweb. Therefore, there is particular interest, as a next step, in collaborating to address question S&T2 ("What is the current status of the Delta ecosystem as influenced by nutrients?") and looking at ways for optimizing nutrient monitoring in concert with improving monitoring of biology and other ecosystem aspects.

Coordination between the Delta RMP and the IEP Science Management Team provides an opportunity for aligning program activities to achieve mutual objectives for ecosystem monitoring and assessment.

Constraints

The EMP needs to operate within its mandate of determining compliance with D-1641 water quality standards.

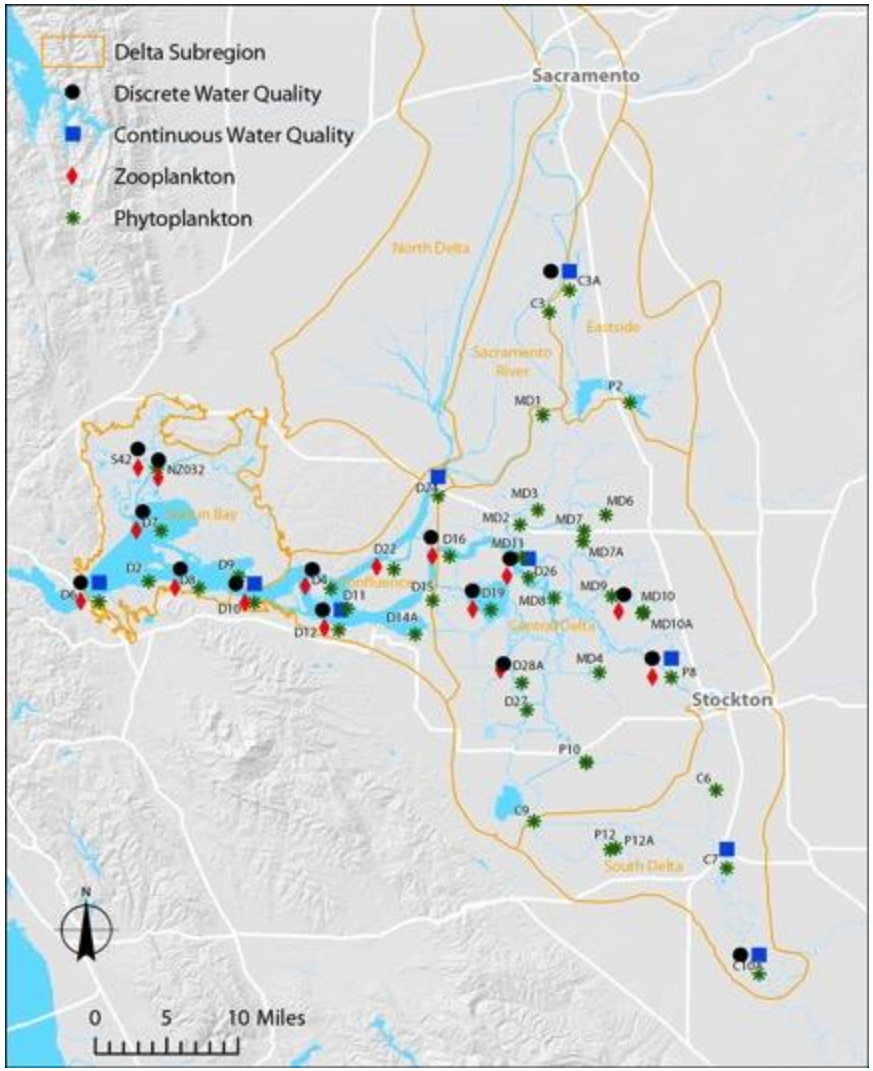
Program Description: DWR-EMP

Related Goals and Activities: Has been collecting nutrient data at sites in the Sacramento-San Joaquin Delta and Suisun Bay since 1975.

EMP's Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Discrete Water Quality	1975	Monthly Grab sampling by boat	Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus, silica	Chlorophyll a, phaeophytin a; general water quality and standard minerals (calcium, EC, TDS, TSS, VSS); DOC, TOC; field measurements (DO, EC, fluorescence, pH, temperature, turbidity, Secchi depth)
Continuous Water Quality	1971	Every 15 minutes	None	Chlorophyll, DO, EC, pH, temperature, turbidity
Phytoplankton	1975	Monthly Sample collection with submersible pump by boat	None	Phytoplankton abundance and taxonomic composition
Zooplankton	1968	Monthly Sample collection with a mysid net, a Clarke-Bumpus net (targets adult and juvenile copepods, and cladocerans), and a pump (targets adult and juvenile cyclopoid copepods of the genera *Limnoithona* and *Oithona*, copepod nauplii, and rotifers) by boat	None	Zooplankton abundance and taxonomic composition

Sampling Locations:



List of Monitoring Stations

Station Code	Location	Subregion	Program Element	Co-located with Flow
C3A	Sacramento River @ Hood	Sacramento River	Discrete Water Quality, Real-time Data, Phytoplankton	X
C7A	San Joaquin River @ Mossdale	Central Delta	Real-time Data	X
D16	San Joaquin River @ Twitchell Island	Central Delta	Discrete Water Quality	
D16A	San Joaquin River near Twitchell Island	Central Delta	Real-time Data	
D19/D19A	Frank's Tract	Central Delta	Discrete Water Quality, Real-time Data, Phytoplankton	
D28A	Old River @ Rancho Del Rio	Central Delta	Discrete Water Quality, Phytoplankton	X
D29	San Joaquin River at Prisoners Point	Central Delta	Real-time Data	X
MD10A	Disappointment Slough @ Bishop Cut	Central Delta	Discrete Water Quality, Phytoplankton	
P8	San Joaquin River @ Buckley Cove	Central Delta	Discrete Water Quality, Phytoplankton	
P8A	San Joaquin River @ Rough and Ready Island	Central Delta	Continuous Water Quality	X
D4	Sacramento River above Point Sacramento	Confluence	Discrete Water Quality, Phytoplankton	
D10	Sacramento River @ Chipps Island	Confluence	Discrete Water Quality	
D10A	Sacramento River @ Mallard Island	Confluence	Continuous Water Quality	X
D11A	Sacramento River Near Sherman Lake	Confluence	Continuous Water Quality	
D12/D12A	San Joaquin River @ Antioch Ship Channel	Confluence	Discrete Water Quality, Continuous Water Quality	
D22	Sacramento River @ Emmaton	Confluence	Discrete Water Quality	
D24A	Sacramento River @ Rio Vista	Confluence	Continuous Water Quality	X
D6/D6A	Martinez	Suisun Bay	Discrete Water Quality, Phytoplankton, Continuous Water Quality	
D7/D7A	Grizzly Bay	Suisun Bay	Discrete Water Quality, Phytoplankton, Continuous Water Quality	
D8	Suisun Bay off Middle Point nr. Nichols	Suisun Bay	Discrete Water Quality, Phytoplankton	

Station Code	Location	Subregion	Program Element	Co-located with Flow
D8A	Suisun Cutoff near Ryer Island	Suisun Bay	Continuous Water Quality	
D9A	Honker Bay	Suisun Bay	Continuous Water Quality	
NZ032	Montezuma Slough, 2nd bend from mouth	Suisun Bay	Discrete Water Quality*	
NZS42	Suisun Slough @ Volanti Slough	Suisun Bay	Discrete Water Quality*	
C10A	San Joaquin River near Vernalis @ SJR Club	South Delta	Discrete Water Quality, Phytoplankton, Real-time Data	X

* Only when the surface specific conductivity is below 20,000 μS/cm.

Data availability and reporting: data are available online as excel files; annual water quality report.

2. California Department of Water Resources – Municipal Water Quality Investigations (MWQI)
Summary:

How and to what extent does it address Delta RMP assessment questions?

Data from the MWQI extends the spatial coverage of EMP for examining regional long-term trends. This includes stations upstream of the Sacramento urban area at the Sacramento River and American River and stations in the South Delta at the Old River and Middle River. The MWQI Delta Simulation Model 2 (DSM2) nutrient monitoring study and Cache Slough Baseline Monitoring extend the spatial coverage to the North Delta and Eastside, which are subregions of the Delta that are currently not monitored by EMP.

Opportunities

The MWQI Program tries to support the needs of other programs by providing resources for sample collection. There is a mutual interest in developing a pre-restoration baseline, particularly in the North Delta/Cache Slough Complex, and assessing the effects of planned habitat restoration activities on water quality. This include nutrients and nutrient-associated ecosystem responses, as they pertain to potential changes to in-stream drinking water quality.

Constraints

The MWQI sample collection is limited by resources and funding. The Cache-Slough Baseline Monitoring and the DSM2 nutrient study were planned and designed as short-term monitoring projects, even though they are to be continued indefinitely per current workplan.

Program Description: MWQI

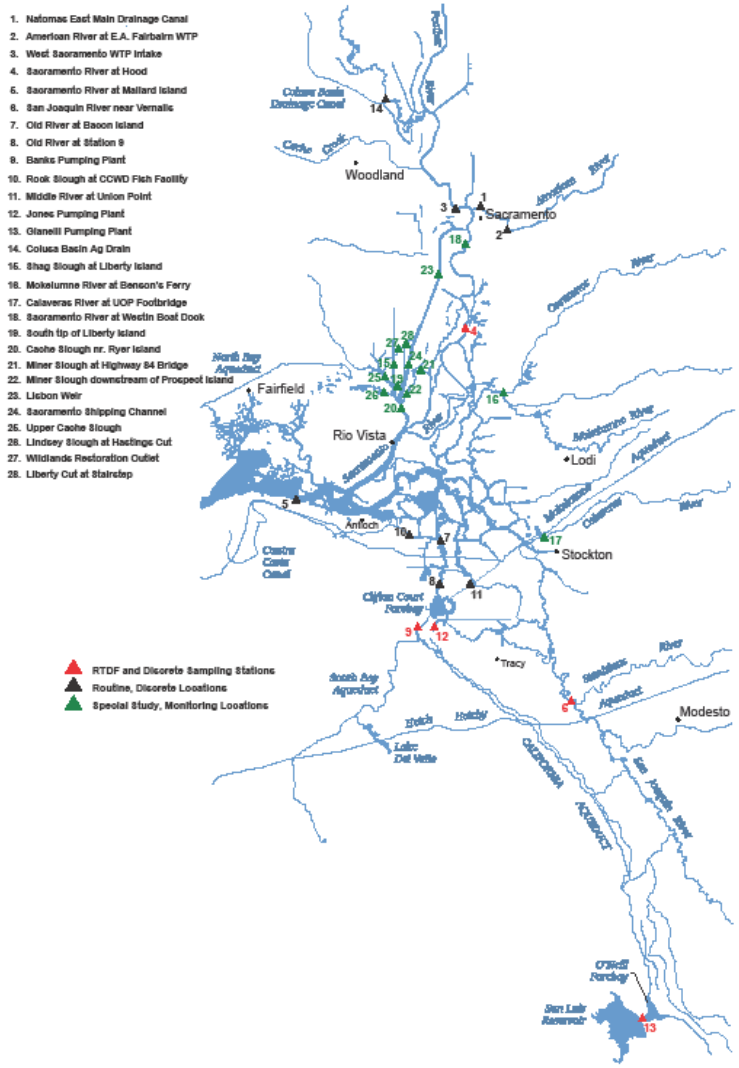
Related Goals and Activities: MWQI Program data are used in drinking water supply studies, to identify long-term trends in drinking water quality, and to help DWR and other agencies research and mitigate drinking water issues in Delta waters and the State Water Project (SWP). Additionally, in collaboration with the Bay-Delta Office and Operations & Maintenance Division, monitoring data are used to develop an "early warning" system that provides advance notice to Delta water users of possible drinking water quality problems. Aside from MWQI's routine monitoring, other samples are collected for short-term monitoring projects, including The Delta Simulation Model 2 (DSM2) nutrient monitoring study and Cache Slough Baseline Monitoring.

MWQI's Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Routine Monitoring	1982	Monthly Grab sampling by boat	Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus	UVA, standard minerals, DOC, TOC, turbidity
Real-time Data and Forecasting (RTDF)	1982	Every 15 minutes	Nitrate	EC, TOC/DOC
DSM2 Nutrient Study	2013	Twice a month Grab sampling by boat	Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus	Physical parameters, biological oxygen demand (BOD), carbonaceous biological oxygen demand (CBOD), chlorophyll, and phaeophytin
Cache Slough baseline and monitoring analysis	2013	Twice a month Grab sampling by boat	Ammonia, Kjeldahl nitrogen, nitrite + nitrate, organic nitrogen, ortho-phosphate, phosphorus	Standard minerals, TOC, DOC, UVA, suspended solids, chlorophyll, phaeophytin

Sampling Locations:

Figure 2. MWQI Discrete and RTDF Monitoring Locations



Data availability and reporting: online: DWR Water Data Library (all data), CDEC (real-time data); annual reports; daily, weekly, and/or monthly emails to subscribers of distribution list.

3. California Department of Water Resources, North Central Region Office (NCRO) Water Quality Evaluations
Summary:

How and to what extent does it address Delta RMP assessment questions?

The NCRO does not monitor nutrients. This collection effort contributes to the spatial density of continuous and discrete chlorophyll data in the Confluence, Central Delta, South Delta, North Delta, and Sacramento River subregions. Including these data in assessments would increase statistical power for long-term trend detection in these subregions and contribute to a better understanding of the spatial variability of chlorophyll in these subregions.

Opportunities

Explore the feasibility of collaborating and piggybacking nutrient parameters to some of the 39 existing stations. Options for adding NO3 sensors to the existing sensors and additional analyses of discrete water samples could be explored.

Constraints

Monitoring stations for this program are limited to the Central and South Delta.

Program Description: NRCO Water Quality Evaluations

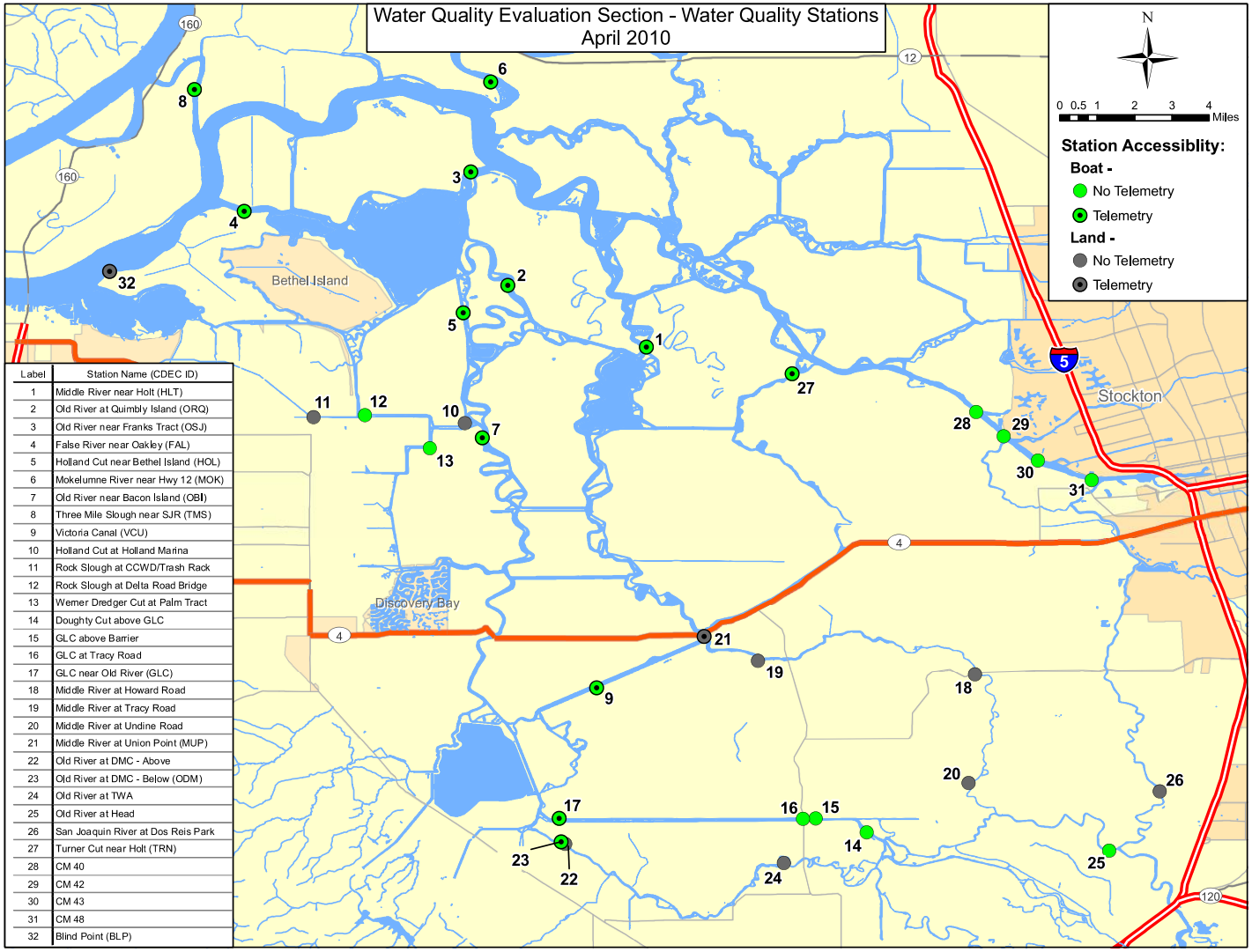
Related Goals and Activities: The Water Quality Evaluation Section out of DWR's North Central Region Office maintains a total of 32 time-series water quality stations encompassing three current Delta projects: Rock Slough Monitoring Program, South Delta Monitoring Program, and Central Delta Monitoring Program.

Each of these projects has specific objectives and monitors a specific suite of water quality constituents. Continuous water quality parameters that are collected include: water temperature, specific conductance, pH, turbidity, dissolved oxygen, and chlorophyll *a*. In addition, discrete water grab samples are obtained for analysis at DWR's Bryte Laboratory. The discrete constituents measured at many of the stations include chlorophyll *a*, phaeophytin *a,* and total suspended solids.

NCRO's Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Central Delta	Continuous (every 15-minutes) / Discrete (can vary from weekly to every 3 weeks	None	Chlorophyll, temperature, SC / Chlorophyll, phaeophytin, TSS
Rock Slough Monitoring	Continuous (every 15-minutes) / Discrete (can vary from weekly to every 3 weeks	None	SC, temperature
South Delta Monitoring	Continuous (every 15-minutes) / Discrete (can vary from weekly to every 3 weeks	None	Chlorophyll, DO, pH, temperature, turbidity SC / Chlorophyll, phaeophytin, TSS

Sampling Locations: Stations for the Central Delta, Rock Slough, and South Delta Monitoring are shown on the following map.



Label	Station Name (CDEC ID)
1	Middle River near Holt (HLT)
2	Old River at Quimbly Island (ORQ)
3	Old River near Franks Tract (OSJ)
4	False River near Oakley (FAL)
5	Holland Cut near Bethel Island (HOL)
6	Mokelumne River near Hwy 12 (MOK)
7	Old River near Bacon Island (OBI)
8	Three Mile Slough near SJR (TMS)
9	Victoria Canal (VCU)
10	Holland Cut at Holland Marina
11	Rock Slough at CCWD/Trash Rack
12	Rock Slough at Delta Road Bridge
13	Werner Dredger Cut at Palm Tract
14	Doughty Cut above GLC
15	GLC above Barrier
16	GLC at Tracy Road
17	GLC near Old River (GLC)
18	Middle River at Howard Road
19	Middle River at Tracy Road
20	Middle River at Undine Road
21	Middle River at Union Point (MUP)
22	Old River at DMC - Above
23	Old River at DMC - Below (ODM)
24	Old River at TWA
25	Old River at Head
26	San Joaquin River at Dos Reis Park
27	Turner Cut near Holt (TRN)
28	CM 40
29	CM 42
30	CM 43
31	CM 48
32	Blind Point (BLP)

Data availability and reporting: online: DWR Water Data Library (all data), CEDEC (real-time data); technical reports.

4. DWR Special Studies Research Program
Summary:

How and to what extent does it address Delta RMP assessment questions?

This research effort makes significant contributions to our understanding of the development and occurrence of harmful algal blooms (HABs) in the Delta and the role of nutrient cycling and sources and other environmental factors in these conditions. However, it is not a routine long-term monitoring effort, which would be needed to address prioritized Delta RMP assessment questions as framed. The studies provide spatially and temporally limited information on ecosystem status (ST-2) relative to HABs and contribute to the scientific knowledge base for determining how these conditions are related to nutrients (ST-2A).

Opportunities

The DWR Special Studies Research Program would be a potential partner in the design, development, and maintenance of a long-term monitoring program for *Microcystis*. This DWR section has conducted special studies of *Microcystis* bloom biomass, cyanobacteria species composition, toxin production, and environmental conditions (including nutrients) in the Delta since 2003. Such studies have included the use of isotopes to study the relative importance of ammonium and nitrate as nitrogen sources to *Microcystis* blooms observed in 2007, 2008, 2014, 2015, and how sources of ammonium used by *Microcystis* vary spatially and temporally in the Delta (2015)

Constraints

Not a routine monitoring effort. There is no continued, long-term funding for *Microcystis* monitoring. Recent efforts have been funded as part of a larger Drought Response Program funded by IEP.

Program Description: DWR Special Studies Research Program

Related Goals and Activities: The DWR Special Studies Research Program designs and implements scientific studies to answer current ecosystem questions in the San Francisco Estuary Watershed. This includes the use of FlowCAM technology to characterize Delta plankton use of traditional and molecular methods to characterize harmful algal blooms and algal toxin production, und the use stable isotopes to characterize the role of nutrient cycling and sources in harmful algal bloom development. Ongoing Microcystis studies are currently focusing on the lower San Joaquin River. However, there is no ongoing regular data collection effort

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Characterization of microcystin blooms and the role of nutrients and other environmental conditions in harmful algal bloom development	N/A	Ammonium, nitrate, phosphate; stable isotopes (NH4, NO3, PO4)	Microcystin, phytoplankton biomass and taxonomic composition.

Data availability and reporting:

Oral presentations and posters at professional meetings and science conferences, scientific publications, technical reports.

5. Sacramento Deepwater Ship Channel (U.S. Bureau of Reclamation, UC Davis, Central Valley Regional Water Board, USGS)

Summary:

How and to what extent does it address Delta RMP assessment questions?

This effort provides baseline data for nutrients and ecological conditions in under-monitored areas of the North Delta, including the Sacramento Deepwater Ship Channel (SDSC). These data help evaluate spatial and seasonal variability of nutrients and nutrient-associated variables in the North Delta.

Opportunities

Data from this project could help fill an existing data gap regarding spatial and temporal variability in nutrients, nutrient-associated parameters, and ecological conditions in the North Delta (Delta RMP assessment questions S&T1 and S&T2).

Constraints

This project is not a routine monitoring effort with long-term funding. It is a research project and the data are not readily accessible in a public database.

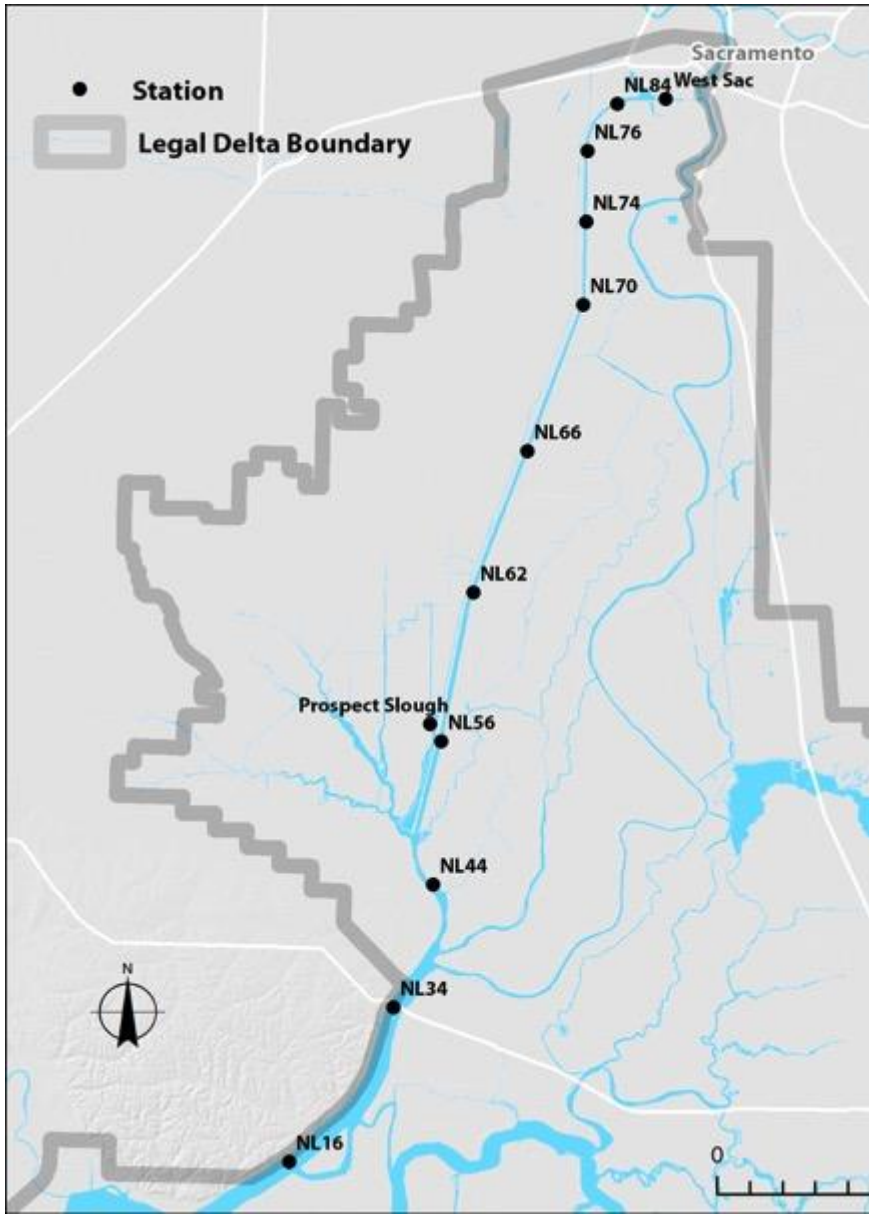
Project Description: Sacramento Deepwater Ship Channel

Related Goals and Activities: developing a baseline for experiments focused on increasing the food supply of the North Delta. Data are collected monthly in the spring, summer, and fall during 48hr boat runs scheduled to occur at low ebb tides. Monitoring occurs at 12 stations located in the Sacramento Deepwater Ship Channel (SDSC), the Prospect Slough stairstep, and Liberty Cut. Monitoring includes continuous YSI measurements and vertical nutrient profiles.

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
SDSC baseline monitoring	2012	Monthly in the spring, summer, and fall	Ammonium, nitrate, soluble reactive phosphorus (SRP)	Temperature, specific conductance, turbidity, suspended solids, phytoplankton and zooplankton abundance and taxonomic composition.

Sampling Locations:



Data availability and reporting:

Data from this project have not yet been released and published, expect for oral presentations at professional meetings and science conferences.

6. USGS National Water Quality Assessment (NAWQA) Program
Summary:

How and to what extent does it address Delta RMP assessment questions?

The discrete monitoring conducted by the NAWQA program at the Freeport and Vernalis sites partially addresses Question ST-1 "How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?" and touches on "How are ambient levels and trends affected by variability in climate, hydrology, and ecology?" by monitoring additional parameters such as flow, temperature, and DOC. The Vernalis and Freeport sites capture inflows from the Sacramento and San Joaquin, which account for the majority of all freshwater inputs to the Delta, thereby this monitoring program is very important for answering Question SPLP-1 "What are the loads from tributaries to the Delta?"

Opportunities

Additional discrete sampling targeting storms (2 to 3 high flow events) would provide better information to calculate load models for high discharge events. Sampling along the hydrograph to fully characterize short-term changes in various nutrient types would improve load estimates from the Sacramento and San Joaquin watersheds (SPLP-1 "What are the loads from tributaries to the Delta?")

Constraints

The NAWQA program captures some of the wet event variability by sampling 2x/month during some months in the wet season, but this sampling does not sufficiently capture the short-term variability in nutrient concentrations in relation to the hydrograph.

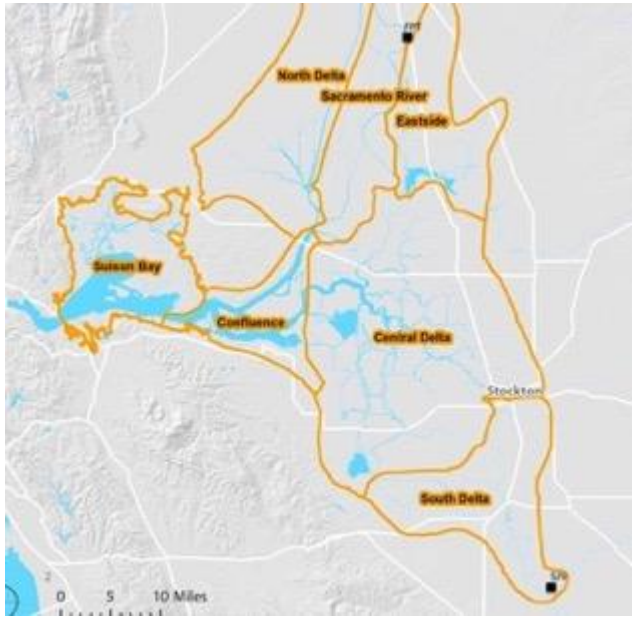
Program Description: NAWQA

Related Goals and Activities: The NAWQA program currently maintains monitoring stations at Freeport and Vernalis that represent terminus stations of the San Joaquin and Sacramento River Basin watersheds. The two stations are part of a of water quality monitoring stations representative of "study units" throughout the Nation to provide a framework for national and regional water-quality assessment.

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
NAWQA	1991	14 events/year (Freeport)/18 events/year (Vernalis) Grab sampling from bridge (Vernalis)/by boat (Freeport)	Ammonia, nitrate, nitrite, total nitrogen, orthophosphate, total phosphorus, organic nitrogen.	Dissolved and particulate carbon, ultraviolet light absorbing constituents.

Sampling Locations:



Data availability and reporting:

Data are available on the USGS National Water Information System (NWIS: http://waterdata.usgs.gov/nwis); technical reports (nationwide assessments).

7. USGS High-Frequency (HF) Nutrient Monitoring Network

Summary:

How and to what extent does it address Delta RMP assessment questions?

The current HF nutrient sensor network operated by the USGS CAWSC Biogeochemistry Group provides continuous monitoring of nitrate, temperature, specific conductance, pH, DO, turbidity, chlorophyll-a, phycocyanin (pigment found in cyanobacteria), DOM fluorescence at key locations in the North Delta (Toe Drain, Deep Water Shipping Channel, Liberty Cut, Liberty Island, Cache Slough), Sacramento River (Freeport and Walnut Grove), Confluence (Decker, Jersey Point, Confluence) and South Delta (Vernalis). While some of these stations have been operated since 2013, others were only recently installed (Jersey Point and Confluence, see below table). The data these stations provide help evaluate the temporal variability for the measured parameters at these stations at multiple scales (diurnal, seasonal, annual, short-term ephemeral events). With respect to ranges in concentrations, data help assess spatial variability in the North Delta, Sacramento River conditions above and below the outflow of the Sacramento Regional Wastewater Treatment Plant, contributions for the San Joaquin River watershed to the Delta, and fluctuations in the Confluence region. Data help address most of the assessment questions:

- ST-1 – How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?
- ST-1A – Are trends similar or different across subregions of the Delta? *(**For Sacramento River, North Delta, Confluence, and South Delta subregions**)*
- ST-1B – How are ambient levels and trends affected by variability in climate, hydrology, and ecology?
- ST2-A – St-2A could also be added: What is the current ecosystem status of habitat types in different types of Delta waterways, and how are the conditions related to nutrients?
- SPLP – 1A How have nutrient or nutrient-related source controls and water management actions changed ambient levels of nutrients and nutrient-associated parameters?
- SPLP-1B – What are the loads from tributaries to the Delta?
- SPLP-1C – What are the sources and loads of nutrients within the Delta?
- SPLP-1D What role do internal sources play in influencing
- observed nutrient levels?
- SPLP-1E – Which factors in the Delta influence the effects of nutrients?
- SPLP-1F – What are the types and sources of nutrient sinks within the Delta?
- SPLP-1G – What are the types and magnitudes of nutrient exports from the Delta to Suisun Bay and water intakes for the State and Federal Water Projects?

Opportunities

Augmented and sustained HF monitoring will help to (1) improve the assessment of long- and short-term changes, (2) understand the effects changing nutrient concentrations may have in different parts of the Delta, (3) quantify loads to and from the Delta, and (4), help

identify important sources, sinks, and nutrient-transforming processes in the Delta. Continued and improved HF monitoring at points were nutrients are entering and exiting the Delta will provide more complete answers to the assessment questions listed above.

Constraints

Due to technological limitations, it is not yet possible to continuously monitor all desired parameters in situ. In addition, the cost of implementing a high-frequency nutrient monitoring network can be quite large. Future funding for the existing nutrient stations has not yet been secured. For example, there is no funding available to implement a nitrate sensor at Vernalis.

Program Description: USGS HF Nutrient Monitoring Network

Related Goals and Activities: The overarching purpose of the ongoing USGS HF monitoring efforts in the Delta is to continuously measure the tidally dependent variation in nutrients and water quality to investigate their role and impact on habitat conditions and phytoplankton productivity. The goal of the project is to provide continuous real-time habitat status and trends information to managers and researchers and thereby to assist operational management and environmental assessment.

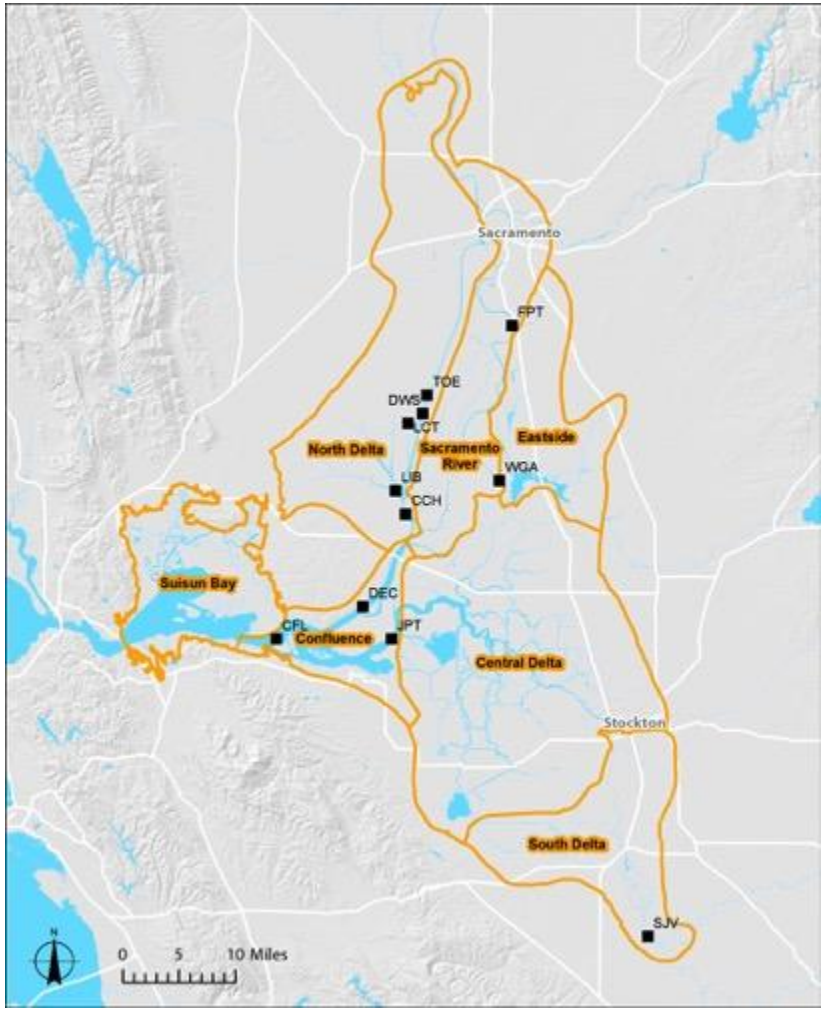
Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
HF monitoring network	2013 (see table on next page for details)	Continuous (15 minute sampling frequency)	Nitrate, phosphate (sensors deployed on an event basis), ammonium (under development)	Temperature, conductivity, pH, DO, chlorophyll-a, phycocyanin (a tracer for blue-green algae such as *Microcystis*), and fluorescent dissolved organic matter (fDOM, a proxy for dissolved organic carbon concentrations).

List of the USGS CAWSC Biogeochemistry Group's High Frequency water quality monitoring stations. All of these stations are currently equipped with a SUNA nitrate analyzer and YSI EXO2, with the exception of the station at Vernalis* (SJV) which does not have an EXO2 deployed. All of the EXO2 sondes are equipped to measure temperature, conductivity, pH, dissolved oxygen, turbidity, chlorophyll-a, phycocyanin (a tracer for blue-green algae such as *Microcystis),* and fluorescent dissolved organic matter (fDOM, a proxy for dissolved organic carbon concentrations). Station data are available on the USGS National Water Information System (NWIS: http://waterdata.usgs.gov/nwis). Deployment of in situ phosphate analyzers at these stations occurs on a project or event basis, and in situ ammonium analyzers are under development.

Site Name	**Site Abbreviation**	**NWIS Station Number**	**Date Established**	**Latitude**	**Longitude**
Freeport	FPT	11447650	8/30/2013	38.456111	121.500278
Walnut Grove	WGA	11447890	8/21/2013	38.257778	121.517222
Toe Drain North of Stair Steps	TOE	11455139	8/19/2014	38.365180	121.637730
Liberty Cut	LCT	11455146	1/31/2014	38.328850	121.667531
Deep Water Shipping Channel	DWS	11455335	4/11/2014	38.341667	121.643889
Liberty Island	LIB	11455315	7/15/2013	38.242222	121.686111
Cache Slough	CCH	11455350	2/1/2013	38.212778	121.669167
Decker Island	DEC	11455478	1/24/2013	38.093333	121.736111
Confluence	CFL	11455508	9/12/2016	38.04953	121.8755
Jersey Point	JPT	11337190	9/12/2016	38.05253	121.68834
San Joaquin River at Vernalis*	SJV	11303500	1/21/2015	37.676111	121.265278

Sampling Locations:



Data availability and reporting:

Station data are available on the USGS National Water Information System (NWIS: http://waterdata.usgs.gov/nwis)

8. USGS San Francisco Bay Water Quality Cruise

How and to what extent does it address Delta RMP assessment questions?

This program contributes to our understanding of long-term trends and spatial variability along a transect in Suisun Bay and the lower Sacramento River, including Rio Vista (ST1, ST1A).

Opportunities

Future collaboration with this program could potentially help address common questions about nutrients and ecosystem conditions that require data collection on a larger geographic scale across the Bay and Delta.

Constraints

The sampling design and monthly cruise schedule are designed to meet long-term water quality data needs for San Francisco Bay. Sampling is limited to a relatively small portion of the Delta and the timing of sampling relative to the tide is different from the EMP, which samples within a one-hour window of the expected occurrence of high tide slack at a sampling location.

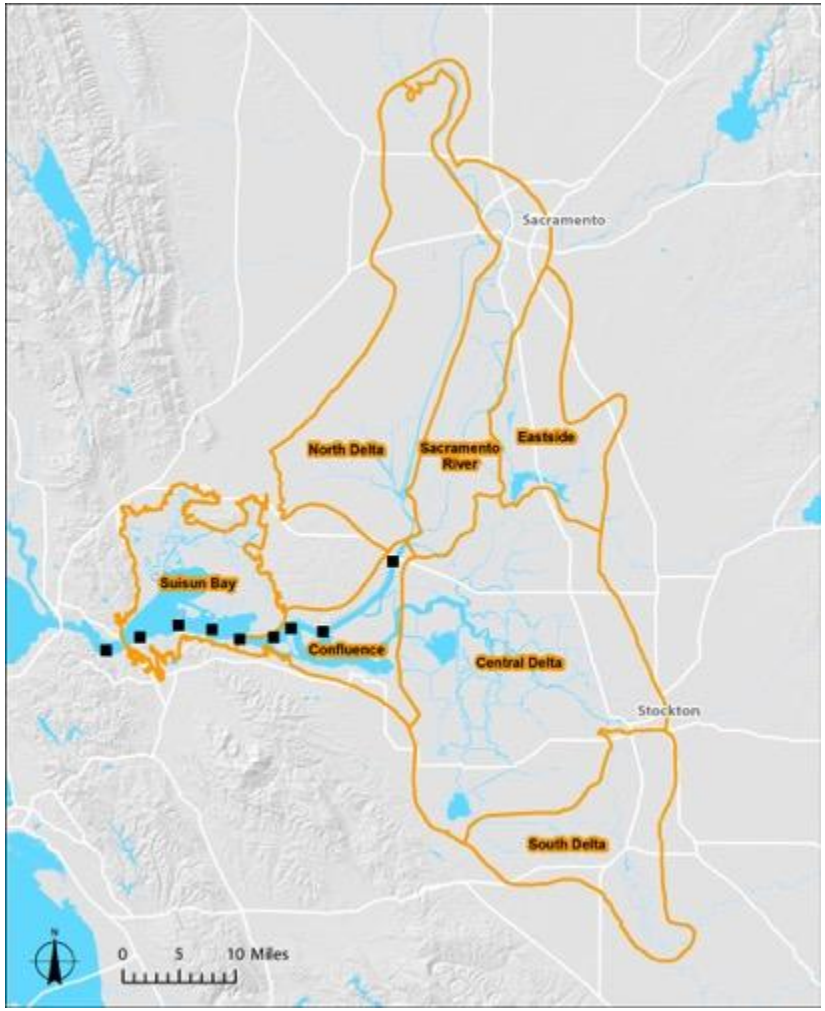
Program Description: USGS HF Nutrient Monitoring Network

Related Goals and Activities: The program includes regular measurements of water quality along a 145 kilometer transect spanning the length of the entire estuarine system, at 37 fixed sampling locations spaced 3-6 kilometers apart. These sampling stations are located along the central deep channel, from the southern limit of South Bay, through Central Bay, San Pablo Bay, Carquinez Strait, Suisun Bay, and ending at Rio Vista on the Sacramento River.

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
North Bay/Full Bay cruises	1969	Monthly	NO_2, NO_{3+2}, NH_3, PO_4, and dissolved Si	Salinity, temperature, suspended particulate matter, dissolved oxygen, light penetration, and chlorophyll concentration

Sampling Locations:



Data availability and reporting: data can be queried and visualized on "Access USGS--San Francisco Bay & Delta" (http://sfbay.wr.usgs.gov/). The website also provide access to numerous research publications and technical reports based on this dataset.

9. Regional San - Monitoring of Sacramento River Receiving Waters and Upstream Waters
Summary:

How and to what extent does it address Delta RMP assessment questions?

Regional San's monitoring tracks seasonal changes in nutrients upstream and downstream of the Sacramento Regional Wastewater Treatment Plant. A 2016 research survey takes snapshots of nutrient concentrations and other actors that potentially affect phytoplankton growth within the Sacramento River (from RM 95 to RM 19). These activities partially address question ST-1 for the Sacramento River mainstem within the Sacramento River subregion and upstream of the Delta ("How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?"). The research survey also contributes to the data and knowledge base for addressing questions ST-2 ("What is the current status of the Delta ecosystem as influenced by nutrients?") and ST-2A ("What is the current ecosystem status of habitat types in different types of Delta waterways, and how are the conditions related to nutrients?"). Regional San (and other POTWs) also conduct effluent monitoring, which is important for answering SPLP questions.

Opportunities

Regional San's research program contributes to studies evaluating the potential ecosystem effects of different nutrient concentrations and forms (ST-2).

Constraints

Regional San is a small organization relative to others conducting nutrient and ecological studies in the region and depends on successful collaborations to address questions of interest on a larger ecosystem scale.

Program Description: Regional San - Monitoring of Sacramento River Receiving Waters and Upstream Waters

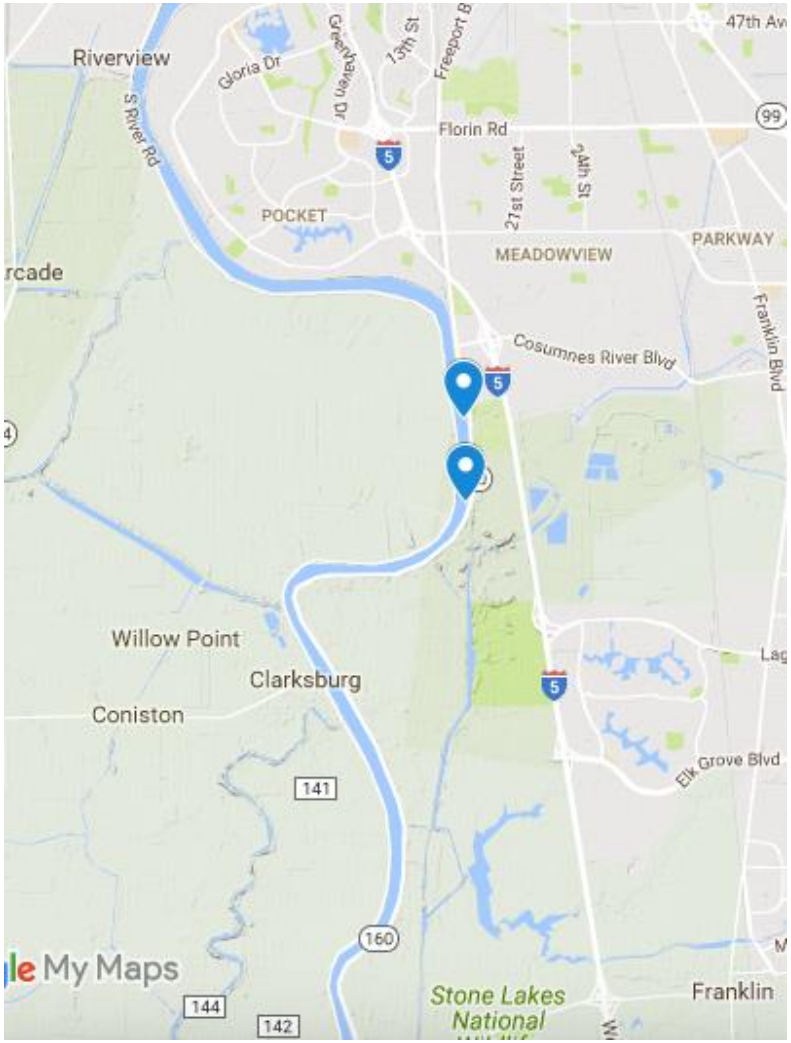
Related Goals and Activities: Regional San collects ambient nutrient data as part of research studies in the Sacramento River and Delta and conducts monthly monitoring of ambient conditions upstream and downstream of the effluent diffuser in the Sacramento River. The research studies are investigating the factors regulating phytoplankton growth. Furthermore, Regional San funds the USGS nutrient sensor at Freeport (However, there is no long-term funding commitment. See USGS High-Frequency (HF) Nutrient Monitoring Network).

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Research Survey	2016 (1-year duration)	Intensive one-time surveys in spring and fall of 2016 (RM19 to RM95), combined with monthly sampling at RM44	Ammonium, nitrate + nitrite, Kjeldahl N, phosphate, silicate, uptake experiments (NH4+C, NO3+C)	Temperature, turbidity, pH, EC, DO, chlorophyll, photosynthetically active radiation (PAR), picoplankton, phytoplankton, isotopes, microzooplankton, macrozooplankton, clams
Ambient water quality (Receiving Water)	2010	Monthly at 2 stations (Freeport Bridge and Cliff's Marina)	Ammonium, total N	

Sampling Locations for Regional San 2016 research survey:

Regional San Receiving Water Monitoring Stations



Data availability and reporting:

Presentation at scientific conferences, project reports, manuscripts, response to Requests for Information.

10. Stockton RWCF - Monitoring of Receiving Waters
Summary:

How and to what extent does it address Delta RMP assessment questions?

Receiving water monitoring tracks seasonal changes in ammonium and ambient water quality parameters upstream and downstream of the Stockton Regional Wastewater Control Facility. This monitoring contributes data to assess question ST-1 for the San Joaquin River up- and downstream of the facility and (combined with effluent data) helps to evaluate loadings from this source (SPLP-2C "What are the sources and loads of nutrients within the Delta?" and SPLP2D "What role do internal sources play in influencing observed nutrient levels?"

Opportunities

Potential piggybacking of monitoring parameters.

Constraints

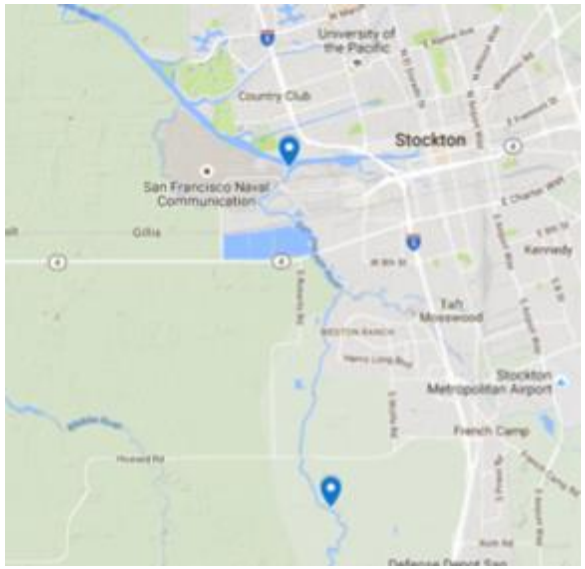
The City of Stockton has a small monitoring program relative to others described here with a very local scope.

Program Description: Stockton RWCF - Monitoring of Receiving Waters
Related Goals and Activities: The Stockton RWCF monthly conducts monitoring of ambient conditions upstream and downstream of the effluent diffuser.

Monitoring of Nutrients and Nutrient-associated Variables

Program Element	Start	Sampling frequency	Nutrients monitored	Nutrient-associated variables monitored
Ambient water quality (Receiving Water)	1992	Monthly at 2 stations	Ammonium	EC, pH, temperature, turbidity, DO

City of Stockton Receiving Water Monitoring Stations



Data availability and reporting:

Presentation at scientific conferences, project reports, manuscripts, response to Requests for Information.

Appendix B: List of Acronyms

ASC	Aquatic Science Center
BOD	biological oxygen demand
C	carbon
CASCaDE	Computational Assessments of Scenarios of Change for the Delta Ecosystem
CBOD	carbonaceous biological oxygen demand
chl-a	chlorophyll a
DO	dissolved oxygen
DOC	dissolved organic carbon
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
EC	electric conductivity
EMP	Environmental Monitoring Program
FAV	floating aquatic vegetation
fDOM	fluorescent dissolved organic matter
FS	Forecasting Scenarios
GAMs	general additive models
HF	High-frequency
IEP	Interagency Ecological Program
MWQI	Municipal Water Quality Investigations
N	nitrogen
NAWQA	National Water Quality Assessment
NCRO	North Central Regional Office
NDO	net Delta outflow
NH4	ammonium
NO3	nitrate
nr	near
N/A	not applicable
OC	organic carbon
P	phosphorus
PO4	phosphate
RM44	River Mile 44
RMP	Regional Monitoring Program
RTDF	Real-Time Data and Forecasting
SAV	submerged aquatic vegetation
SC	specific conductance
SDSC	Sacramento Deepwater Ship Channel
SCHISM	Semi-Implicit Cross-scale Hydroscience Integrated System Model
SPLP	Sources, Pathways, Loadings, and Processes
SRP	soluble reactive phosphorus
ST, S&T	Status & Trends
SWP	State Water Project
TBD	to be determined
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
USGS	U.S. Geological Survey
UV	ultraviolet
UV	ultraviolet A
VSS	volatile suspended solids
WRTDS	weighted regressions on time, discharge, and season

Appendix C: References

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