Delta RMP Nutrient Subcommitee FY19/20 Workplan Proposal

Sacramento River Nutrient Change Study Phase 1: Effluent Valve Replacement Hold

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Estimated Start and End Date of Phase 1: 07/02/2019 – 12/30/2020

Project Description

This study will track the effects of changes in nutrient loading resulting from to short-term wastewater holds at the Sacramento River Wastewater Treatment Plant (SRWTP). In the summer of 2019, scheduled wastewater effluent diversions will occur during the Effluent Valve Replacement (EVR) project, part of the EchoWater Project upgrade at the SRWTP. During an EVR diversion no treated effluent will enter the Sacramento River for a period of up to 48 hours. Based on prior research (Kraus et al. 2017) this should create a parcel of effluent-free river water over six miles long in the Sacramento River, which we will compare with the regular SRWTP operations occurring just prior to the EVR hold. The impacts of short-term changes in nutrient loading to the river will be tracked in parcels of water as they move downstream in the Sacramento River and side channels.

The project consists of a week-long river sampling campaign, field measurements and laboratory analyses. The project will use a range of methods, including high frequency fixed stations for water quality, mobile high frequency boat sampling of water quality, "grab" sampling of water quality, phytoplankton biomass, zooplankton biomass, and clam biomass, and phytoplankton carbon uptake (to determine growth rates). Data will be collected to study the response of phytoplankton to a range of nutrient loads and forms, as well as environmental factors including light, turbidity, water residence time, and grazing by zooplankton and clams.

Delta RMP is asked to fund a portion of the project. Regional San will provide staff hours and equipment for project oversight, development of the QAPP, collection of water samples, and coordination of a final report. Funders for additional components of the project are being sought and secured. See also the Budget table.

This project, termed "Sacramento River Nutrient Change Study Phase 1" will generate useful stand-alone information. However, the Phase 1 project is part of a larger proposal to study impacts of events that change nutrient loads. These events include steps in SRWTP upgrade process and operation of Delta cross-channel gates. The project design makes use of these already-planned operations to conduct adaptive management experiments to inform future nutrient management in the Delta.[1]

Study Area

The study will occur in the lower Sacramento River and downstream connecting channels, including Georgiana Slough and the Mokelumne River (Figure 1). The channels in the study area are close enough to the SRWTP that water parcels with or without treated effluent can still be detected and tracked in the river water (i.e.,

[1] Operational changes envisioned for investigation in future phases of the Sacramento River Nutrient Change Study:

(1) In the summer of 2020, there will be a moderate reduction in Sacramento River nutrient concentrations when roughly half of the EchoWater Project Biological Nutrient Removal (BNR) process is initiated.

(2) In the summer of 2021, the EchoWater Project BNR process will be fully operational, which will further reduce average nutrient concentrations in the Sacramento River.

(3) In early spring 2020, near the end of the seasonal winter closure of the Delta Cross Channel, there may be a long slow drawdown of nutrient concentrations by phytoplankton and denitrification in the Mokelumne River.

prior to tidal mixing). In the shallower lower Mokelumne River and Georgiana Slough, light penetrates a greater proportion of the water column than in the deeper lower Sacramento River. Elevated light levels increase the potential for rapid phytoplankton growth when other regulating factors are favorable, namely low turbidity, shallow water depth or stratification, sufficient nutrient concentrations, and low grazing pressure.

Figure 1. Map of the Sacramento-San Joaquin River Delta showing project sampling sites in the lower Sacramento River, Georgiana Slough, and North and South Forks Mokelumne River. (Credit: Regional San)

Study Design

Phase 1 consists of field and laboratory measurements collected in a week-long river sampling campaign, laboratory analyses, and data analyses to determine phytoplankton responses to two different nutrient loading conditions (with and without SRWTP effluent) and other environmental factors.

Study methods will include high frequency fixed stations for water quality; mobile high frequency boat sampling of water quality; “grab” sampling of water quality; biomass and taxonomy of phytoplankton,

zooplankton, and clams; and carbon uptake assays to determine phytoplankton growth rates). Numeric modeling will be used to interpret changes observed in the study.

Regional San staff will sample at a total of 12 "grab sample" stations, three along the Sacramento River, three along Georgiana Slough, three along the North Fork Mokelumne River and three along the South Fork Mokelumne River. The USGS high frequency sampling boat will sample these river segments daily during the week of study. At each "grab sample" station, vertical profiles of temperature, pH, electrical conductivity, DO and PAR will be taken. Measurements of variable fluorescence will be taken continuously. Discrete samples for turbidity, chlorophyll *a*, picoplankton phytoplankton enumeration, zooplankton enumeration and growth rates, and dissolved inorganic nutrient determinations will be collected. If visual survey of a station indicates that potentially harmful algal species such as *Microcystis sp*. are present, we will collect separate water samples for BSA Environmental Services to measure microcystins. Clams will be collected using benthic trawls.

Phytoplankton enumeration will allow examination of any changes in the proportions of beneficial and potentially harmful phytoplankton. During the 1-week study, changes in phytoplankton growth rates and zooplankton growth rates are expected to be detectable and potentially also changes in phytoplankton biomass. Because changes in zooplankton abundance would be minimal during this short time period and difficult to detect, the study will examine growth of zooplankton.

River discharge, velocity, and other water-quality characteristics will be measured every 15 min at three USGS monitoring stations: Freeport (at RM 46.4), 0.2 km upstream from SRWTP, Walnut Grove (at RM 28.2), 29.2 km downstream of the treatment plant (http://waterdata.usgs.gov/usa/nwis), and Decker Island (approx. RM 7). The monitoring data will be used to plan sampling events and document continuous river conditions. Treated effluent discharge data (hourly averages) will be provided by wastewater treatment plant personnel, along with effluent water quality data, including daily ammonia (NH_4^+) and weekly nitrate (NO_3^-) nutrient concentrations.

Tasks and Scope of Work

This proposal is for the Delta RMP to provide $250,000 for project tasks plus up to $30,000 for ASC to manage subcontracts.

All of the project tasks are described below. Some funds from sources outside of the Delta RMP have been secured. Regional San and other investigators are seeking additional funds to fulfill the budget needs. Although it would not be funding the entire project, Delta RMP will receive updates and final reports for the entire project, as well as data that will be submitted to CEDEN.

Tasks suggested for funding all or in part by the Delta RMP are listed below in order of priority relative to management drivers and assessment questions. See also the budget table. This proposal will be updated and Delta RMP TAC and SC informed if additional funding commitments are made.

1. Plankton and Zooplankton Enumerations: This task will be led by Dr. John Beaver, BSA Environmental Services, Inc. For water samples collected by Regional San staff, BSA staff will identify and count phytoplankton and zooplankton to the lowest taxonomic level possible (e.g., family, genus, or species). Three replicate phytoplankton and zooplankton samples, and one picoplankton sample will be enumerated per station according to standardized BSA methods, including minimum numbers of organisms measured per sample. The purpose of this task is to describe changes to phytoplankton

abundance and species composition in the river resulting from reduced nutrient concentrations, compared to high-nutrient control water.

2. Phytoplankton Growth Evaluations: This task will be performed by Dr. Mine Berg, Applied Marine Sciences, Inc. (AMS). AMS staff will measure photosynthetically active radiation (PAR) [measure of light availability in different parts of the water column], variable fluorescence (Fv/Fm) [a metric of photosynthetic activity and health status of photosynthetic cells], and carbon (C) uptake from the Regional San boat. AMS staff will conduct data analyses, report writing, manuscript writing, and presentations relevant to this task and to project synthesis. The purpose of this task is to directly measure phytoplankton growth during changes in nutrient conditions. This work will help determine when and where growth is occurring and identify if growth changes occurred at particular nutrient concentrations. Products will be quarterly reports, final report, manuscripts, and presentations.

3. Numeric Modeling of Proportional Water Volumes and Mixing, Subtasks 1-3: This task will be performed by Resource Management Associates (RMA). The purpose of this task is to better understand water sources, mixing, transport time and age, which will improve interpretation of the data collected. RMA will use their suite of Delta numerical model applications to perform this work. The water modeling will be closely integrated with the other tasks in the project. The modelers and field researchers will be in close contact both before and after the field surveys take place to ensure that: the models focus on confluences in the study area where there is uncertainty regarding water inflows and tidal fluxes, the field data are collected at locations that will assist the modelers in calibrating their models to the water movements occurring during the specific week of the field work, and that the field researchers have a clear understanding of the modeling results. The modeling adds value to the overall project by increasing the ability of the researchers to interpret the field data. For example, having proportions of source waters at each location sampled, along with travel time estimates, allows more accurate determination of whether changes in phytoplankton biomass and species composition along the length of the study area are due to growth, grazing, or dilution by tributary inflows. The modeling task has four components:
    a. RMA will estimate the percentage of source waters supplied to Georgiana Slough, the North Fork Mokelumne River, and the South Fork Mokelumne River during the summer of 2019 during a period of Regional San wastewater hold (part of the EchoWater Project). Model calculations will help identify sources of phytoplankton, zooplankton, nutrients, and other chemical constituents entering the three river channels by identifying the proportion of water in each river sample from a set of upstream and downstream sources. Upstream sources include SRWTP effluent stream, Sacramento River, Mokelumne River and Cosumnes River, and potentially a downstream source from the San Joaquin River depending on inflow levels and tidal mixing. RMA will gather boundary condition data (hydraulic data), QA/QC the data, run and refine the flow and transport models, and provide written reports, calculations, and other documentation, as necessary, to report the study's findings to the project team.
    b. RMA will refine the existing RMA model grid of the study area to improve the spatial resolution by increasing the grid dimension from 1-D to 2-D at major confluences and other areas of interest. The existing RMA model grid is one-dimensional at some confluences, so increasing the grid to two dimensions will improve the spatial resolution of the flow and transport and stage calibration locally and at selected downstream locations.
    c. RMA will test and refine model performance of the 2-D grid at the confluences of the Sacramento River and Georgiana Slough, the Sacramento River and the Delta Cross Channel, and the Delta Cross Channel and Snodgrass Slough. The model will be refined using data

collected by Regional San in this study. Vertical and cross-channel profiles of temperature, dissolved oxygen, and electroconductivity measurements will be used to test the model's replications of water mixing.

Task 3 deliverables will include a final report describing background information for the modeling applications, data acquisition, modeling results, and interpretation of results. Modeling results will include estimates of source water volumes and mixing at sampled locations and times, documentation on grid updates and checks of flow and stage calibration, metadata used in modeling refinements.

4. Zooplankton Growth and Condition: This task will be led by Dr. Wim Kimmerer, RTC-SFSU. Dr. Kimmerer and his staff will conduct zooplankton sampling onboard the Regional San boat. SFSU staff will determine zooplankton abundance, biomass using a FlowCam, and life-stage (copepods) or size (cladocera) distributions, and reproductive rates. Zooplankton growth rates will be determined by sorting field-collected zooplankton into cohorts by size and monitoring their growth in short-term incubations. Analyses will evaluate zooplankton abundance, growth, reproduction, and mortality relative to environmental and nutrient conditions. They will also collect and analyze samples molecularly for identification of foods consumed by the zooplankton. **Note: funding for this task is being sought outside of the Delta RMP. A small portion of funding could be available through the Delta RMP as shown in the proposed Budget.**

Sacramento River Nutrient Change Study Phase 1 Tasks supported by other funds:

5. Numeric Modeling of Proportional Water Volumes and Mixing, Subtask 4: RMA will add a particle tracking evaluation to the model output. RMA will use their particle tracking module (part of the RMA suite of modeling tools) to calculate particle transport through the study area and estimate travel time of parcels of water entering the study area from different sources or time points. The products will be documentation describing the particle tracking model set-up, travel time estimates and two movie-style visualizations of particle transport.
6. Discrete water quality sampling: Regional San staff will conduct the "grab" sampling for water temperature, dissolved oxygen (DO), pH, electrical conductivity, turbidity, chlorophyll *a*, dissolved inorganic nutrients, and phytoplankton and zooplankton abundance using Regional San's vessel, the Guardian. Regional San Environmental Laboratory staff regularly operate this vessel for monthly Sacramento River water quality compliance sampling. Collection of grab samples will be closely coordinated with the high frequency data collection to ensure the correct timing of grab samples in the wastewater-containing and wastewater-free parcels of water.
7. High frequency water quality data collection and analyses with mapping: This task will be led by Dr. Brian Bergamaschi and Dr. Tamara Kraus, USGS. USGS staff will characterize changes occurring during transport of wastewater-free parcels in comparison to associated wastewater-containing parcels down Sacramento River and into distributary channels, including characterization of changes in nutrients, phytoplankton community, and net ecosystem productivity. High speed maps will be made using boat-mounted, flow-through instrumentation system collecting continuous, underway measurements of location, time, temperature, conductivity, pH, dissolved oxygen, turbidity, beam attenuation, dissolved organic matter fluorescence, chlorophyll-a fluorescence and nitrate. The data will be streamed to onboard computers in real time so that the investigators can make prompt decisions regarding interesting findings from identifiable changes along each transect. In situ data will be used to detect the presence and absence of treated wastewater effluent and to quantify wastewater-derived constituent concentrations. A key outcome of the high frequency data collection will be nitrogen transformation (e.g., nitrification) rates across a range of nutrient concentrations and habitat types.

8. Laboratory Analyses of Water Samples: Water will be analyzed by the Regional San Environmental Laboratory for ammonium, nitrate/nitrate, dissolved phosphorus, and dissolved inorganic carbon.
9. Clam collection and analyses: This task will be led by Dr. Tim Mussen, Regional San Environmental Laboratory and Scientific Research Section. Dr. Mussen and a Regional San intern will conduct clam enumerations (counts and biomass) and use these data to calculate clam grazing rates.
10. Reports and manuscripts: This task will be led by Dr. Lisa Thompson, in collaboration with the rest of the Project Team. Products will include quarterly progress reports and a final project report/manuscript. Regional San will also coordinate and ensure preparation of a QAPP for all components of the project. QAPP components for Delta RMP-funded activities can be excerpted and copied into the Delta RMP QAPP. Water quality, phytoplankton, zooplankton, and clam data collected during this project will be subjected to quality assurance/quality control review and then submitted for upload to CEDEN using the Chemistry, Field Collection, and Taxonomy templates.

Relevance to Delta RMP Management and Assessment Questions

This proposal directly addresses the following Delta RMP Management and Assessment Questions. Specific information gaps identified in the Delta Nutrient Research Plan (DNRP, CVRWQCB 2018) are listed on pg. 10.

Status and Trends –Questions 1 and 1.C

1. How do concentrations of nutrients (and nutrient-associated parameters) vary spatially and temporally?
   C. Are there important data gaps associated with particular water bodies within the Delta subregions

Explanation: Previous study of a wastewater hold did not investigate effects in channels other than the Sacramento River.

Sources, Pathways, Loadings and Processes – Questions 1, 1.A, and 2A

1. 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?

2. How are nutrients linked to water quality concerns such as harmful algal blooms, low dissolved oxygen, invasive aquatic macrophytes, low phytoplankton productivity, and drinking water issues?
   A. Which factors in the Delta influence the effects of nutrients on the water quality concerns listed above?

Explanation: The project will track the effects of a significant change in nutrient loading. Comparisons between channels will allow examination of factors of light availability and water residence time.

Forecasting Scenarios

How will nutrient loads, concentrations, and water quality concerns from Sources, Pathways, Loadings & Processes Question 2 respond to potential or planned future source control actions, restoration projects, water resource management changes, and climate change?

Explanation: The project is an opportunity to examine effects of a major change in nutrient loads. On an yearly average basis, current nitrogen loads from Regional San and the Sacramento River upstream of Regional San are 14,000 and 18,500 kg N/day, respectively. In fall, when the project monitoring will occur, the difference will be more marked as Sacramento River upstream nitrogen loads are lower than the yearly average.

Effectiveness Tracking

How did nutrient loads, concentrations, and water quality concerns from Sources, Pathways, Loadings & Processes Question 2 respond to source control actions, restoration projects, and water resource management changes?

Explanation: The project is a "preview" of changes expected due to the Regional San EchoWater upgrade. The project uses an adaptive management approach to monitoring by utilizing pre-planned operational changes to field-test hypotheses of effects of the upgrade.

BUDGET

Task	Description	**Proposal to Delta RMP** [1]	Other funding and in-kind **secured**	Still seeking funding [1]	task total
1	Phytoplankton and zooplankton enumeration (BSA Environmental Services)	$30,000	$0	$0	$30,000
2	Phytoplankton growth evaluations (Applied Marine Sciences, Inc).	$103,000	$0	$0	$103,000
3	Numeric modeling of proportional water volumes and mixing (Resource Management Associates)	$102,000	$0	$23,688	$125,688
4	Zooplankton growth and condition (San Francisco State University)	$15,000	$0	$154,000	$169,000
5	Discrete water quality sampling (Regional San [2])	$0	$211,635	$0	$211,635
6	High frequency data collection and mapping (USGS [3])	$0	$210,000	$0	$210,000
7	Laboratory analyses of water samples (Regional San)	$0	*(within Task 5)*	$0	$0
8	Clam collection and analyses (Regional San)	$0	*(within Task 5)*	$0	$0
9	Reporting and manuscripts (Regional San and project team)	$0	*(within Task 5)*	$0	$0
	Subcontract Management [4](ASC)	$30,000	$0	$0	$30,000
	Project totals	$280,000	$421,635	$177,688	$879,323

1. Proposal calls for Delta RMP support up to $250,000 plus contract administration. Efforts will be made to minimize the total number of subcontracts. If external funding is found for the entire Task 4, for example, Delta RMP would not contribute to Task 4.
2. Applied Marine Sciences and SFSU will have staff on Regional San boat to collect data and samples for tasks 2 and 4, respectively.
3. Task supported by USGS ($60,000 for in-kind boat and equipment resources) and US Bureau of Reclamation ($150,000).
4. Includes executing and managing contracts, reviewing and paying invoices, reporting to SC and finance subcommittee regarding status of agreements and payments. Does not include reporting about project findings and technical information, which will be done by Regional San and project team.

Supporting Information

Background - Best Available Science and Conceptual Models

Water and nutrients from the Sacramento River enter Georgiana Slough, and, via the Delta Cross Channel, the North Fork Mokelumne River and South Fork Mokelumne River, providing an opportunity to test the effects of changes in water transit time, depth, light, and nutrient loading on phytoplankton and zooplankton productivity and biomass. High frequency boat mapping, performed by the USGS in support of the Delta Regional Monitoring Program, is able to detect patterns in numerous aquatic variables in these side channels, including nutrient concentrations, turbidity, and chlorophyll a. Biogeochemical model predictions (Zhang et al. 2018) suggest that EchoWater Project upgrades to the SRWTP will result in substantial changes in nutrient concentrations in these side channels. During the EVR diversions the load of ammonia and nitrate from SRWTP will be zero, providing an opportunity to investigate the potential impacts of nutrient load reductions that are lower than those mandated in SRWTP's current NPDES permit.

Under our conceptual model, the factors of transit time, light, and nutrient loading will result in different outcomes for phytoplankton productivity and biomass occurring in the side channels compared to those living in the mainstem Sacramento River. In the mainstem Sacramento River, where water depth is sufficient to make light limiting to phytoplankton growth (AMS 2017), we predict that decreased nutrient loading will have little effect on phytoplankton biomass or the higher levels of the aquatic food web (Figure 2). However, in the side channels, where a combination of decreased depth, increased transit time, and decreased turbidity may increase light availability (i.e., euphotic zone depth), we predict that phytoplankton productivity and biomass will be regulated by nutrient availability. Under scenarios with lower nutrient loading, we would expect to see less phytoplankton growth and biomass than under the current loading scenario. The diagrams in Figure 2 assume that nutrient loading from other sources upstream of Freeport are constant across situations, and that during the summer SRWTP effluent is a high proportion of the total nutrient load to the Sacramento River. The diagrams assume a time frame of days, during which increases in phytoplankton and zooplankton growth rates would be detectable, and potentially also changes in phytoplankton biomass. However, changes in zooplankton abundance and clam biomass would be minimal during this short time period and difficult to detect. These diagrams do not make an assumption about whether increased phytoplankton biomass would be in the form of beneficial or harmful algal species, but we would be able to observe any changes through the high frequency boat mapping surveys, and through phytoplankton enumerations (species counts and biomass). Changes in nutrient loading from SRWTP will be apparent in the mainstem Sacramento River, but are unlikely to manifest in changes in phytoplankton response until the water reaches the river side channels, where other key factors, namely depth, transit time, and euphotic zone depth are more favorable for phytoplankton growth.

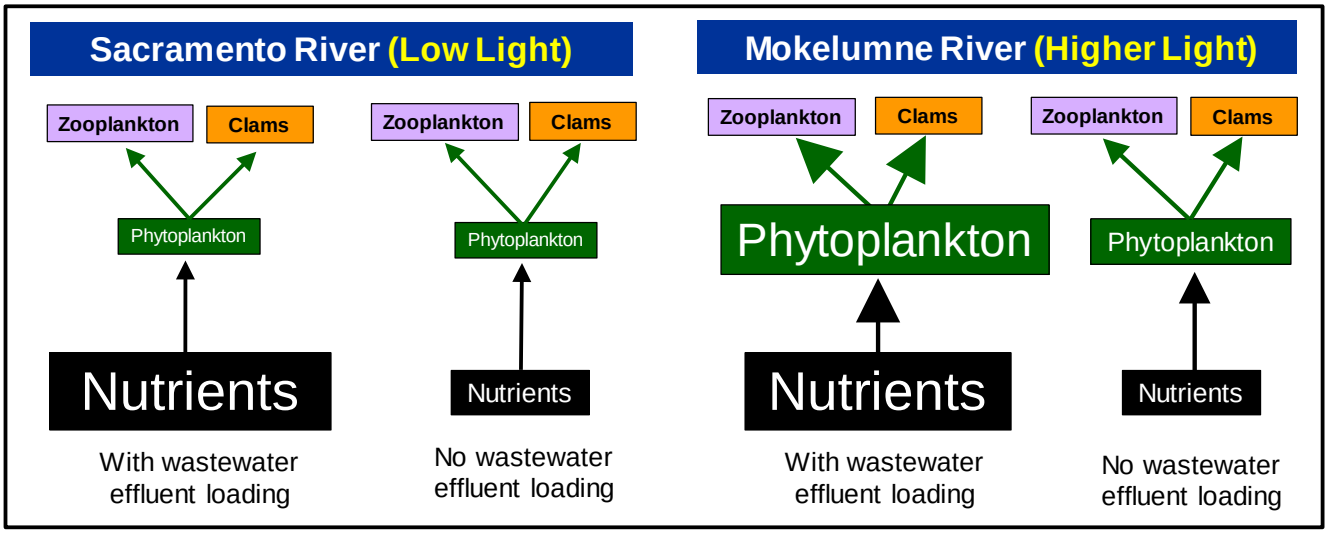

Figure 2. Food web diagrams showing potential nutrient load (focusing on dissolved inorganic nitrogen, DIN) and biomass transfer under four situations: (1) Current effluent nutrient loading, (2) No effluent loading, as will occur during Effluent Valve Replacement diversions, (3) Current loading plus increased light availability, and (4) No effluent loading plus increased light availability. The thickness of each arrow indicates the amount of nutrients or biomass transferred through the food web, relative to the other situations. The font size of the text shows biomass at each trophic level relative to the other situations. Outcomes for nutrient loading scenarios BNR Part 1 and BNR Part 2 are anticipated to be intermediate to the more extreme contrast between current effluent nutrient loading and the EVR no effluent loading scenario.

Questions and Hypotheses to be addressed in Phase 1 and future phases

Question 1: Will a substantial reduction in DIN concentrations have a positive, neutral, or negative effect on desirable phytoplankton growth in the Delta?

> Hypothesis 1: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta.

Question 2: How will low and high irradiance combined with a substantial reduction in DIN concentrations impact phytoplankton growth in the Delta?

> Hypothesis 2A: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta under low irradiance.
>
> Hypothesis 2B: A substantial reduction in DIN concentration will have a negative impact on phytoplankton growth in the Delta under high irradiance.

Question 3: How will increased residence time combined with a substantial reduction in DIN concentrations impact phytoplankton growth and biomass accumulation in the Delta?

> Hypothesis 3A: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta under low residence time.
>
> Hypothesis 3B: A substantial reduction in DIN concentration will have a negative impact on phytoplankton growth in the Delta under high residence time.

Question 4: How will grazing pressure change and impact phytoplankton biomass accumulation with increased irradiance and water residence times under high and low nutrient scenarios?

Hypothesis 4A: Under low residence time and low irradiance, grazing pressure will not impact phytoplankton biomass accumulation with either low or high DIN concentrations.

Hypothesis 4B: Under high irradiance and low residence time, grazing pressure will not impact phytoplankton biomass accumulation with either low or high DIN concentrations.

Hypothesis 4C: Under high residence time and high irradiance, grazing pressure will negatively impact phytoplankton biomass accumulation with high DIN concentrations but not with low DIN concentrations.

Relevance to Delta RMP Management Driver – Delta Nutrient Research Plan

This proposal addresses key scientific uncertainties and fills important information gaps identified in the Delta Nutrient Research Plan (DNRP, CVRWQCB 2018. Specifically, this project will address, in part, six management sub-questions posed in the DNRP.

1. What are the main factors affecting potential nutrient-related effects and how does the relative importance of these factors vary with space and time? (Delta Nutrient Research Plan, Table 1, p. 23)
2. What are the important processes that transform nutrients in the Delta and what are the rates at which these processes occur? (Delta Nutrient Research Plan, Table 1, p. 23)
3. Can nutrient management in the northern Delta (e.g., Yolo Bypass, Sacramento River, and Sacramento Deep Water Ship Channel) increase abundance or nutritional quality of pelagic phytoplankton? (Delta Nutrient Research Plan, Table 1, p. 23)
4. What is the level and type of change in nutrients needed to affect change in HABS, macrophytes, or phytoplankton abundance? (Delta Nutrient Research Plan, Table 1, p. 23)
5. What are the most likely alterations in nutrient conditions due to climate change, Delta habitat restoration, and changes in nitrogen forms and loads? (Delta Nutrient Research Plan, Table 1, p. 24)
6. What nutrient levels are needed to support adequate primary productions and a healthy food web, particularly for endangered fish species? (Delta Nutrient Research Plan, Table 1, p. 24)

RMA model outputs will provide an additional benefit to the Delta RMP. The model outputs be useful in interpreting the USGS high frequency data maps, since the model outputs will provide information on the proportional upstream sources of the water that was sampled for the maps.

References

Applied Marine Sciences, Inc. (AMS). 2017. Final Report: Spatial and seasonal patterns in irradiance phytoplankton, and grazers along the Sacramento River, California. Submitted to Sacramento Regional County Sanitation District, Sacramento, California. August 14, 2017. 65 p.

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Kraus TEC, Carpenter KD, Bergamaschi, BA, Parker AE, Stumpner EB, Downing BD, Travis NM, Wilkerson FP, Kendall C, Mussen TD. 2017. A river-scale Lagrangian experiment examining controls on phytoplankton dynamics in the presence and absence of treated wastewater effluent high in ammonium Limnology and Oceanography 62 (3): 1234-1253.

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