DRAFT Strategy for developing a nutrient research plan for the Delta[1]

The Sacramento and San Joaquin Rivers has been known for decades to have elevated concentrations of nitrogen and phosphorus. With one exception, the high nutrient loads were not thought to cause water quality problems in the Delta. The exception is that elevated nutrient concentrations from the San Joaquin Basin contribute to low dissolved oxygen levels in the Stockton Deepwater Ship Channel in fall coincident with high water temperature and large loads of algae from the upper basin[2]. The paradigm that the Delta is resilient to high nutrient concentrations is now being challenged. Elevated nutrient levels are hypothesized to cause, or at least contribute to, four water quality problems besides low oxygen levels in the Stockton Ship Channel (Table 1). These include increased macrophyte and blue-green algal production, shifts in algal species composition and decreased dissolved oxygen concentrations. Each is recognized as a significant water quality problem and to merit follow up. Research evaluating the role of nutrients in these impairments is at a beginning phase. The purpose of this write up is to lay out a strategy for developing a nutrient study plan to determine the relative significance of nutrients in these impairments.

Recommendation #6 of the Delta Stewardship Council's Delta Plan[3] is that the Regional Water Boards develop a research program to determine the role of nutrients in the Delta and to establish safe concentrations. The recommendation specifically states:

The State Water Resources Control Board and the San Francisco Bay and Central Valley Regional Water Quality Control Boards are currently engaged in regulatory processes, research, and monitoring essential to improving water quality in the Delta. In order to achieve the coequal goals, it is essential that these ongoing efforts be completed and, if possible accelerated, and that the legislature and Governor devote sufficient funding to make this possible. The Delta Stewardship Council specifically recommends that:

- *The State Water Resources Control Board and the San Francisco Bay and Central Valley Regional Water Quality Control Boards should adopt a study plan for the development of objectives for nutrients in the Delta and Suisun Marsh by January 1, 2014. Studies needed for development of Delta and Suisun Marsh nutrient objectives should be completed by January 1, 2016. The Water Boards should adopt and begin implementation of nutrient objectives, either narrative or numeric, where appropriate, for the Delta and Suisun Marsh by January 1, 2018.*

Briefly, I outline below some initial steps for carrying out the Council's recommendations. The emphasis is on the development of the research plan (Table 2).

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[2] http://www.swrcb.ca.gov/centralvalley/water_issues/tmdl/central_valley_projects/san_joaquin_oxygen/low_do_report_6-2003/do_tmdl_rpt.pdf

[3] http://deltacouncil.ca.gov/delta-plan/current-draft-of-delta-plan

Conceptually, I plan on having the research plan reviewed by the Central Valley Water Board in December 2013 and transmitted to the Delta Stewardship Council by the beginning of 2014. I envision three key elements for developing the plan. These are (1) coordinating with the San Francisco Bay Water Regional Water Board (R2), (2) assembling a nutrient Technical Advisory Team (TAC) to guide development of the Central Valley Water Board (R5) nutrient plan, and (3) developing the tasks and schedule for the study plan. Each step is described in more detail below.

Coordinate with R2. The Delta Stewardship Council explicitly calls for the two Regional Boards to cooperate in developing the research plan (Table 2). This is farsighted as both Boards have a nexus in Suisun Bay. R5 provides some of the nutrients while R2 has regulatory authority. Topics of mutual interest to both regions include developing quantitative estimates of nutrient and blue-green algal toxin loads from the Central Valley to Suisun Bay, determining the biological importance of nitrogen to phosphorus ratios, having discussions on appropriate dissolved oxygen objectives for back sloughs in the delta and San Francisco Bay and developing a nutrient/phytoplankton model for the delta and Suisun Bay.

David Senn, San Francisco Estuary Institute (SFEI), is working with Karen Taberski and Naomi Feger from R2 to develop a Nutrient Science Study Plan for Suisun Bay. R2 has a Suisun Bay Workgroup which serves as a TAC. R5 staff will attend the Suisun Bay Workgroup/TAC meetings and provide comments on their study plan. Likewise, when R5 develops a Delta TAC we will invite R2 staff or their technical representatives to attend our meetings. Finally, I will investigate ways that R2 and R5 stakeholders can collaborate on topics of mutual interest. This may include holding periodic joint meetings.

Assemble Nutrient TAC R5 staff will form a Nutrient TAC to guide the development and implementation of the nutrient study plan. Ideally this group should be coordinated through the Delta RMP. If the Steering Committee for the Delta RMP decline, then R5 staff will form another group of interested stakeholders. The Nutrient TAC will need to hold at least three meetings in 2013. The first will be an organization meeting where the need for nutrient studies is explained and stakeholders are invited to participate in development of the study plan by sending technical experts to represent them. This meeting with the Delta RMP is scheduled for 27 February, 2013. The second meeting, or group of meetings, will be with technical nutrient experts to agree on (1) the suite of nutrient related impairments for study in the delta, (2) studies to determine whether nutrients contribute to causing the impairments and, if yes, (3) studies to determine a range of safe concentrations. R5 staff will write a draft study plan to help initiate these discussions. The technical experts will be asked whether they wish to form one or more subgroups to actively help prioritize, design and write each element of the study plan. The second group of meetings will occur between April and September. A final meeting with the larger Delta RMP TAC will be held to review the draft study plan elements, solicit comments and discuss funding. A tentative date for this meeting would be in late October or early November. R5 staff will consider all comments received and is

responsible for writing the final draft study plan. The draft study plan will be complete and available for review at the December Regional Water Board meeting.

Develop Study Plan There are four potential nutrient related impairments in the Delta (Table 1). These include an increased distribution and abundance of submerged and floating aquatic vegetation, increased frequency and geographic distribution of cyanobacterial blooms, changes in pelagic algal community composition, and low dissolved oxygen in back sloughs. The impairments are briefly described below along with some preliminary elements for inclusion in a Delta nutrient study plan.

Macrophyte Colonization A number of non native species of submerged aquatic vegetation (SAV) and floating aquatic vegetation (FAV) have become abundant and widespread in the Delta. Introduced SAV species are *Egeria densa* (brazilian elodea), *Myriophyllum spicatum* (eurasian watermilfoil), *Ludwigia* sp (water primrose) and *Potamogeton crispus* (curly-leaf pondweed). Introduced FAV species are *Eichhornia crassipes (*water hyacinth). Brazilian elodea and water hyacinth are the two most common invasive macrophytes. None of these introduced species have any natural local predators so the only control on their abundance and distribution are physical factors. Many of the SAV and FAV species occur in dense clumps. SAV colonies are often sufficiently prolific to restrict recreational boat traffic, reduce dissolved oxygen at night, harbor ambush fish predators that prey on native juvenile fish, elevate ambient water temperatures by decreasing flow, and cause diurnal pH shifts. Negative impacts of FAV are to block sunlight which suppresses the establishment of native SAV species and other emergent vegetation and to increase the sedimentation of organic matter that contributes to decreases in dissolved oxygen. The Department of Boating and Waterways has attempted to control the spread of non-native macrophytes with regular summer applications of aquatic herbicides.

Lars Anderson, USDA ARS, has produced a DRERIP model outlining the main factors that control macrophyte production in the Delta for the Ecosystem Restoration Program[4]. Factors responsible for SAV abundance include temperature, light and fine grained sediment needed for rooting. Dr. Anderson states that there is little to no nutrient limitation because species can acquire nutrients from both the water and sediment through their roots. Factors promoting the establishment and growth of FAV are light, temperature, and nutrients. Water hyacinths are sensitive to increased salinity. It is important to note that patchy, diverse canopies of SAV and FAV can be beneficial for native fish by providing a refuge from predation and structure that provide habitat for increased invertebrate prey.

The State Board has awarded $50K to the Southern California Coastal Water Research Project (SCCWRP) to provide a literature review to help R5 develop a nutrient study plan. The contract is executed and the money available for use. R5 staff tentatively intend to ask the contractor to use a portion of the funds to prepare a white paper on the primary factors controlling the establishment and growth of macrophytes. Emphasis

[4] Andersen, L. 2008. Draft Aquatic Vegetation Growth Conceptual Model. Sacramento CA: Delta Regional Ecosystem Restoration Implementation Plan.

would be on the efficacy of nutrients to control the abundance and distribution of brazilian elodea and water hyacinth in the delta. The white paper would also describe in general terms additional studies needed to confirm the importance of nutrients and, if necessary, determine safe concentration ranges. The white paper would be used to inform the nutrient study plan for macrophytes and focus development of research solicitation proposals in 2014 and beyond. A detailed white paper workplan will be prepared after discussion with the Contractor. The white paper should be completed by September 2013 for review by the nutrient TAC and for use in developing the macrophyte portion of the nutrient research strategy.

Harmful cyanobacterial algal blooms *Microcystis aeruginosa* and to a lesser extent *Aphanizomenon* spp. blooms have occurred periodically in the Delta since 1999[5]. The blooms appear to originate in the lower San Joaquin River (Central Delta) between June and September and to be tidally distributed across the system including to the confluence of the Sacramento and San Joaquin Rivers in the Western Delta. Water quality in the Central Delta is under the jurisdiction of R5 while the Western Delta is in R2 suggesting that any potential control action will need to be coordinated between the two Water Boards. Factors influencing the growth of *Microcystis* were reviewed by Mioni *et al*. (2012)[6]. These include water temperatures above 19^0C, longer water residence times because the species grow slowly, and high nutrient levels, particularly reduced forms of nitrogen which are preferentially taken up. Unpublished results for the summer of 2007 and 2008 support these observations (personal communication, Peggy Lehman). *Microcystis* blooms occurred in the Central Delta when it consisted mostly of Sacramento River water because of reverse flow from increased water use in the Southern Delta by agriculture and by the State and Federal pumps at Tracy. Sacramento River water contains a higher concentration of ammonia than does the San Joaquin River. Reverse flows also tend to increase water residence time in the warmer Central Delta. Finally, *Microcystis* biomass was found to increase as the proportion of ammonium to total dissolved nitrogen increased.

A decline in cyanobacterial biomass and the frequency of blooms has been documented in other aquatic systems after reductions in nutrient inputs[7]. However, the declines did not occur in a clear dose-response fashion to decreases in the form, concentration or ratio of nutrients. This suggests that nutrient control of cyanobacteria in the Delta should only be attempted after careful evaluation of all the factors likely to control its abundance and distribution, including nutrients.

[5] Lehman *et al*., 2005. Distribution and toxicity of a new colonial Microcystis aeruginosa bloom in the San Francisco Bay Estuary, Califonria. Hydrobiologia 541:87-90

[6] Mioni, *et al.* 2012. Harmful cyanobacterial blooms and their toxins in Clear Lake and the Delta (California). Report prepared for the Central Valley Regional Water Quality Control Board.

Lehman *et al.* 2008. The influence of environmental conditions on the seasonal variation in *Microcystis* abundance and microcystins concentrations in San Francisco Estuary. Hydrobiologia 600:187-204

[7] Heisler, J *et al*. 2008. Eutrophication and harmful algal blooms: A scientific consensus. 8:3-13.

Microcystis blooms are of concern because they release liver toxins that can cause cancer in people and wildlife[8]. In addition, ambient microcystin concentrations during bloom conditions may impact the growth and survival of zooplankton and fish in the estuary[9] and could contribute to the pelagic organism decline by reducing the amount of high quality food at the base of the food chain[10].

As mentioned previously, the State Board has awarded $50k to SCCWRP to help R5 develop a nutrient study plan. R5 staff tentatively intends to ask the contractor to use a portion of the funds to develop a white paper on cyanobacterial blooms. The paper should summarize the peer reviewed literature on the primary factors that contribute to the blooms with an emphasis on potentially controllable nutrient related factors. The white paper would also recommend additional studies needed to confirm the importance of nutrients and to determine safe levels. A detailed workplan will be prepared after discussion with the Contractor. The white paper should be complete by September 2013 for review by the Nutrient TAC and to inform development of the overall nutrient research program.

Shifts in Algal Species Composition The algal community in the Delta has changed over the last several decades from diatoms to a flagellate/blue-green algal dominated community[11]. Diatoms are assumed to be more nutritious to primary consumers like zooplankton than flagellates and bluegreen algae. There have also been decreases in the overall biomass of pelagic algae. Changes in algal food quality and quantity or "bottom up" effects are one of the four factors hypothesized to contribute to the pelagic organism decline[9].

The cause of the algal community shift is not known but hypothesized contributing factors are elevated ammonia concentrations, changes in the ratio of nitrogen to phosphorus, decreases in the amount of incoming San Joaquin River water and climate change. Ammonia concentrations greater than about 0.056 mg N/L have been shown to

[8] Chorus *et al* (1999). Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management. World Heath Organization. E &FN son, London.

[9] Ger *et al*., 2009. *Microcystin*-LR toxicity on dominant copepods *Eurytemora affinis* and *Pseudodiaptomus forbesi* of the upper San Francisco Estuary. Science of the total Enviroment 407:4852-4857.

Lehman *et al* 2010. Initial impacts of *Microcystis* on the aquatic food web in the San Francisco Estuary. Hydrobiologia 637:229-248.

[10] Sommer *et al* 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32:270-277.

[11] Lehman, P. 1998. Phytoplankton species composition, size structure, and biomass and their possible effect on copepod food availability in the low salinity zone of the San Francisco Bay/Delta and Suisun Bay. IEP technical report No 62. August 1998.

Lehman, P. 2000 The influence of climate on phytoplankton community biomass in San Francisco Bay estuary. Limn and Ocean 45(3):580-590

Lehman, P. 2000. Phtyoplankton biomass, cell diameter, and species composition in the low salinity zone of northern San Francisco Bay Estuary. Estuaries 23 (2):216-230.

Brown, T. 2010. Phytoplankton community comnposition: the rise of the flagellates. IEP Newsletter.

inhibit nitrate uptake by diatoms in Suisun Bay[12]. Ammonia induced suppression of nitrate uptake prevented spring algal blooms from developing in Suisun Bay[13]. Changes in nitrogen utilization and nitrogen to phosphorus ratios have been observed to change phytoplankton species composition elsewhere and may also do so in the Delta[14].

Nutrient concentrations and ratios will change in the Delta within the next ten years. In 2010 the Central Valley Regional Board adopted a revised permit for the Sacramento Regional Wastewater Treatment Plant (SRWTP). The plant is the largest discharger in the Central Valley and is responsible for over 90-percent of the ammonia entering the delta[15]. The new permit included average monthly ammonia limits of 1.5 mg N/L in winter and 2.4 mg N/L in summer. Average monthly ammonia effluent concentrations in the discharge are about 25 mg N/L. So, the new permit will decrease ammonia loads entering the delta by about 10-fold. The permit also includes nitrate limits of 10 mg N/L. This will require the SRWTP to denitrify about half of its nitrate to gaseous N_2. The result will be that total dissolved nitrogen concentrations entering the Delta from the Sacramento River will decrease by about 50% when the new plant is completed in 2020. SRWTP staff does not believe that phosphorus loads will change as most of the phosphorus in their effluent is now in a dissolved form (personal communication, Kurt Ohlinger). As a result, nitrogen to phosphorus ratios should decline because of the decrease in nitrogen.

Longer term changes in the hydrology and water quality of the Delta may occur over the next century that could alter pelagic primary production rates and species composition. In the immediate future these include water rights decisions mandated by the Delta Stewardship Council to require new flow standards for the Sacramento and San Joaquin Rivers. Also, the Bay Delta Conservation Plan is planning a new water diversion facility in the north delta. The water diversion would replace pumping at the State and Federal facilities in the South Delta at Tracy for at least a portion of the year. A north delta facility would result in less Sacramento and more San Joaquin River water entering the Delta. This change will alter the major water sources and water residence time in the Delta. More San Joaquin River water may stimulate higher within delta phytoplankton concentrations because of the higher initial seed concentration and a longer within Delta water residence time. In the more distant future, global warming is likely to increase

[12] Dugdale, R. f. Wilkerson, V. Hogue, and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science, 73:17-29.

[13] Wilkerson, F. R. Dugdale, V. Hogue, and A. Marchi, 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29(3):401-416.

[14] Anderson, D. P. Glibbert, and J. Burkholder. 2002. Harmful Algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries 25(4b): 704-726.

Sommer, U. 1993. Phytoplankton competition in PluBsee: A field test of the resource-ratio hypothesis. Limnol Oceanogr 38(4):838-845.

Glibert *et al* 2011. Ecological stoichiometry, biogeochemical cycling, invasive species znd aquatic food webs: San Francisco Estuary and comparative systems. Reviews of Fisheries Science: 19:358-417

[15] Jassby, A. 2008. Phytoplankton in the upper San Francisco Estuary: Recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science 6:1-24

water temperatures, raise sea level and increase salt water intrusion. Turbidity has declined in the Delta over the past 20 years and may continue to do so. The combination of changes in nutrient concentrations and ratios, higher temperature, increased salinity and clearer water may alter pelagic primary production rates and algal species composition. The net effect of these and other unanticipated changes make it impossible to predict pelagic primary production rates in the Delta without a phytoplankton model.

The nutrient research plan should include construction of a nutrient/pelagic primary production model for the delta. The goal of the work would be to produce a model that will accurately predict present and future nutrient and pigment concentrations in the estuary. The model should have the ability to predict primary production rates and standing chlorophyll levels of several key phytoplankton taxa. These should include diatoms and blue-green algae. The model may be a modification of DSM2, the proprietary delta HydroQual model, the salmon SELFE model or some new creation. Criteria for the model will be developed by R5 staff after consultation with the Nutrient TAC and local phytoplankton and modeling experts. Whatever model is selected will need to be in the public domain and be able to interface with watershed models such as WARMF and SPARROW. The latter watershed models are capable of predicting nutrient concentrations and transformations as nitrogen and phosphorus are transported into the estuary from the Central Valley. The new Delta model will also have to be able to interface with the R2 model for nutrients and phytoplankton in Suisun Bay. R5 staff will be responsible for writing the white paper justifying the need for a phytoplankton nutrient model and outlining important model attributes.

Nutrient Data Base Several elements of the nutrient plan may benefit from the compilation of nutrient and related water quality information for the Central Valley and Delta. R5 staff hired a student in 2012 to begin collating that information into an excel spreadsheet for a 10 year time period (2000-2010). However, the student was let go because of a budget shortfall before completing the project.

IEP recently funded David Senn and colleagues to, among other things, collate and synthesize the long term nutrient related monitoring data (1975-2011) for the Delta. Ultimately this data will be available for the nutrient research community. R5 staff will pursue funds to hire a student to complete the compilation of nutrient related data for the Central Valley. The goal being to produce an Excel data base for both the Central Valley and Delta. If all the data is available in time, then R5 staff will summarize key nutrient patterns to help inform development of research solicitation proposals by the fall of 2013.

Low Dissolved Oxygen Concentrations. Thirteen water bodies in the Delta have been placed on the 303(d) list because of periodic low dissolved oxygen levels (Table 3). Ten are creeks and back sloughs that discharge on the eastern and southern sides of the delta. Three are major river channels carrying water across the delta. Together the ten back sloughs constitute the majority of back slough type habitat on the south and east side of the delta. Periodic low oxygen concentrations in all these back sloughs may be ecologically important because it could restrict the use of these areas by aquatic organisms requiring back sloughs to complete a portion of their lifecycle. The

magnitude, duration and frequency of anoxic conditions in back sloughs have not been well characterized and it is possible that anoxic conditions are more common than previously recognized. The primary cause(s) of the low oxygen are not known but it is tempting to surmise that a similar set of factors contribute to the impairment in each back slough. These may include localized runoff of nutrients from agriculture and urban areas that subsequently stimulate algal blooms, runoff of terrestrial BOD that settles locally and decomposes, the presence of dense canopies of SAV and FAV that trap locally produced organic matter that subsequently settles and decomposes. Alternatively, it is possible that the primary source of nutrients fueling the algal blooms is derived from the San Joaquin River. Regardless, all these processes are likely aggravated by poor circulation and long water residence times.

R5 staff recommend that the Central Valley Water Board may want to consider developing a single TMDL for all the back sloughs because the impairments may be caused by the same set of physical factors. To my knowledge there has been no systematic investigation of the magnitude, duration and geographic extent of hypoxia in back sloughs. This needs to be undertaken first and once the temporal-spatial nature of the problem determined, then more detailed investigations of the cause(s) can commence. It is beyond the scope of the nutrient study plan to propose to conduct a backslough low dissolved oxygen TMDL. However, if nutrients are found to be a cause, then implementation of a nutrient control plan could be a key implementation action of the low dissolved oxygen TMDL.

The second set of low dissolved oxygen impairments are on Middle, Old and the lower Mokelumne Rivers. Again, the cause of these impairments will not be known until more detailed investigations are undertaken. However, it is again possible that nutrients are a contributory factor. Like with back sloughs, R5 staff assigned to the low dissolved oxygen TMDL and to the nutrient study plan should coordinate activities.

Workshops Two public workshops are planned to help inform the development of the nutrient study plan. The first is a two day conference on the response of aquatic ecosystems to nutrient reductions. Presentations are planned by internationally recognized nutrient and phytoplankton experts. The meeting is scheduled for the summer of 2013 as a Chapman Conference and could provide valuable insights for development of the nutrient study plan. The conference is being organized and funded by the SRWTP and by the State and Federal Contractors Water Agency (SFCWA). R5 staff plan on attending the workshop.

A workshop to discuss the results of ongoing local nutrient and phytoplankton related research would also be valuable. The purpose of this workshop would be to familiarize the Nutrient TAC and stakeholders on the conclusions of ongoing unpublished nutrient related research in the Bay Delta Ecosystem. Presentations may include the results of work by Drs Glibbert and Dugdale on N to P ratios and ammonia inhibition of diatom production, Dr Parker on the role of *microcystis* blooms in the delta foodweb and Dr Lehman on the role of ammonia in stimulating cyanobacterial blooms. The workshop

will also include presentations by Contractors on their two white papers and by R5 staff on the attributes of a delta-wide phytoplankton nutrient model.

Table 1. List of potential water quality impairments that may be caused, at least in part, by elevated nutrient concentrations in the Delta.

Impairment	Location	Contributing Factors
Increased macrophyte colonization	Back sloughs and shallow open water habitat throughout delta	Invasive species with no predators, high nutrients, elevated temperatures, reduced flow
Blue green algae blooms	Central and Western Delta	Elevated temperature, increased water residence time, nutrient including ammonium
Shift in algal community composition	Suisun Bay and delta	Elevated ammonia levels, change in nitrogen to phosphorous ratios, reduced residence time, increased invasive clam feeding
Low dissolved oxygen	Ten back sloughs and three open channels in Delta	Nutrients, hydro modifications, terrestrial BOD, macrophytes

Table 2 Possible next steps for development of nutrient objectives and an implementation plan for the freshwater Delta using the schedule recommended by the Delta Stewardship Council in the final edition of the Delta Plan. The table emphasizes work products needed in 2013 to develop the study plan.

Action	Sub Action	Comments	Completion Date
Coordinate with R2		Recommendation #6 of the Delta Stewardship Council's Delta Plan states that Regions 2 and 5 will work cooperatively in developing a nutrient study plan for Suisun Bay and the Delta.	
	Inter-Regional Board coordination	Karen Taberski and Naomi Feger are the responsible staff at R2. R2 has engaged SCCWRP/SFEI to develop an Assessment Framework and to support implementation of the SF Bay Nutrient Strategy. R2 and R5 will confer regularly and update others at State Board and at the Delta Stewardship Council at the Delta Team meetings	ongoing
	Attend TAC Meetings of other Regional Boards	BACWA has a contract with David Senn, SFEI, to assist R2 in the development of a nutrient science plan for Suisun bay with input from local stakeholders. R5 staff will attend the Suisun Bay stakeholder meetings. Likewise R2 staff will be kept appraised of R5 technical meetings and invited to attend.	ongoing
Assemble Nutrient TAC		R5 staff is responsible for developing and implementing a nutrient study plan for the Delta. R5 staff will assemble a Nutrient TAC and solicit their input on prioritizing and designing study elements, selecting contractors, funding and stakeholder coordination. The Nutrient TAC may continue in later years, if they choose, to help implement study elements, evaluate results, and make recommendations on follow up studies.	2013
	Meetings	The TAC will hold at least three sets of meetings in 2013. The first will be an organizational meeting where the charge of the group is described and stakeholders are invited to send technical experts. The second group of meetings will be with technical experts to discuss the details of the study elements. TAC members will be asked whether they would like to form one or more subgroups to actively design and write study plan elements. A final meeting will be held with the entire TAC and other interested stakeholders to review study plan elements, solicit comments and discuss funding before the research plan is submitted to the Delta Stewardship Council.	2013
	Draft final plan	A draft final study plan incorporating public comments will be prepared and available for discussion at the December 2013 Board meeting before being transmitted to the Delta Stewardship Council	December 2013

Action	Sub Action	Comments	Completion Date
Develop Study Plan		Four potential nutrient related impacts have been identified in delta: increased macrophyte and cyanobacterial production, shift in algal community species composition, and decreased dissolved oxygen. Additional impairments may be identified by the TAC	
	Macrophytes	Study element will be developed after consultation with nutrient TAC and with input from a macrophyte white paper produced by an outside consultant.	2013
	Cyanobacteria	Study element will be developed after consultation with nutrient TAC and with input from a cyanobacteria white paper produced by an outside consultant.	2013
	Shift in algal community	A nutrient phytoplankton model is needed for the delta that will accurately predict the effect of short and longterm changes in temperature, turbidity, salinity, residence time and water sources on algal species composition and biomass. R5 staff will develop a white paper outlining the need and characteristics of a nutrient phytoplankton model for the delta. The white paper would be used as the basis to help focus the development of research solicitation proposals.	2013
	Assemble nutrient data	Assemble nutrient and related water quality data for the Central Valley and freshwater Delta for the past 20 years (1990-2010) for use in future nutrient and phytoplankton modeling.	2013
	Low dissolved oxygen	Nutrient study plan and TMDL staff should coordinate their activities to insure that any nutrient related low dissolved oxygen impacts are addressed by the nutrient basin plan objectives.	.
Conference and Workshop	Nutrient Reduction Conference	SFCWA and Bay Area Dischargers are organizing/sponsoring a two day conference on nutrients. The first day is to be a series of presentations by national experts on aquatic ecosystem responses to nutrient reductions. The second day is to be an invited only meeting between local and national experts on the likely response of the San Franisco Bay Delta to nutrient reductions. Information gained at the two day conference will be used to inform the Nutrient Study Plan	Summer 2013
	Workshop about Delta studies	R5 staff will encourage others to sponsor a workshop on the results of ongoing nutrient and phytoplankton related work in the Delta. Purpose of the workshop would be to inform development of the final nutrient study plan. The workshop may include presentations of ongoing work by Drs. Glibbert, Parker, Dugdale and Lehman. The workshop will also include presentations on key findings of the macrophyte and cyanobacteria white papers and by R5 staff on the attributes of a phytoplankton nutrient model.	Fall 2013

Table 3. List of impaired water bodies located in Delta because of the presence of periodic low dissolved oxygen concentrations. Data is from the 2008-2010 California 303(d) list.

Water Body Segment	Pollutant	Potential Source	Expected TMDL Completion Date
Bear Ck (Eastern Delta)	Low dissolved oxygen	Urban runoff	2021
Calaveras R. (Eastern Delta)	Organic enrichment/low dissolved oxygen	Urban runoff	2012
5-mile Sl (Eastern Delta)	Organic enrichment/low dissolved oxygen	Urban runoff	2019
French Camp Sl. (Eastern Delta)	Low dissolved oxygen	Urban runoff	2021
Kellogg Ck (Western Delta)	Low dissolved oxygen	unknown	2021
Mormon Sl. (Eastern Delta)	Organic enrichment/low dissolved oxygen	Urban runoff	2008
Smith Canal (Eastern Delta)	Organic enrichment/low dissolved oxygen	Urban runoff	2008
Pixley Sl. (Eastern Delta)	Low dissolved oxygen	Urban runoff	2021
Mosher Sl. (Eastern Delta)	Organic enrichment/low dissolved oxygen	Urban runoff	2008
Tom Paine Slough (South Delta)	Low dissolved oxygen	Agriculture	2021
Old River (South Delta)	Low dissolved oxygen	Hydromodification/unknown	2019
Middle River (South Delta)	Low dissolved oxygen	Hydromodification/unknown	2019
Mokelumne River (Eastern Delta)	Low dissolved oxygen	Source Unknown	2021