Macrophyte Knowledge Gap Document[1]

In 2013 the Delta Stewardship Council adopted the Delta Plan. The Plan identified a number of water quality problems that might be the result of excessive nutrient levels in the Delta. One of these problems was the increase in the abundance and distribution of invasive aquatic plants in the Delta. The Plan recommended that the Central Valley Regional Water Board develop and implement a research plan to determine whether nutrient management might reduce the problem. The Regional Water Board commissioned a white paper to determine:

- *How submersed and floating aquatic vegetation support or adversely affect ecosystem services and related beneficial uses*
- *What is known about the spatial and temporal trends in submersed and floating aquatic vegetation in the Delta*
- *What is the relative importance of nutrients versus other factors in promoting observed trends in submersed and floating aquatic vegetation in the Delta*

The Regional Water Board also assembled a Science Work Group composed of macrophyte experts (Appendix A) to review and comment on the white paper[2]. White paper comments and group discussions were used to identify areas of agreement and important information gaps about the state of macrophyte knowledge in the Delta. These discussions were the basis for this document. An important consideration for Regional Board staff was to determine the role that nutrients might play in the abundance and distributions of macrophytes and whether nutrient management might reduce the severity of the problem. Areas of agreement and knowledge gaps have been assembled into a series of tables to inform a Nutrient Research Plan. The Research Plan will be presented to the Regional Water Board and, if requested, the Delta Stewardship Council. The White Paper, Knowledge Gap Report, and Nutrient Research Plan are intended to provide the rationale and roadmap for future research to resolve management issues, including whether nutrient objectives might help control the abundance and distribution of macrophytes.

Table 1 lists areas of agreement among Science Work Group members about macrophytes in the Delta. The consensus of the group is that invasive aquatic plants represent a serious water quality problem that warrants additional research. All the work conducted to date has

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[1] This document was developed after discussions among the Macrophyte Science Work Group and represents their opinion on what is known about invasive aquatic plants and what are critical knowledge gaps that should be the focus of research in the next 3 to 5-year time period.

[2] Boyer, K. and M. Sutula 2015. Factors controlling submersed and floating macrophytes in the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project Technical Report No. 870 October 2015 http://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2015_10_macro_whitepaper.pdf

consisted of periodic remote sensing surveys and a series of one-time special studies. These have been valuable to help define short term trends in the change in abundance and distribution of floating aquatic plants (FAV) but are unreliable to accurately assess changes in submersed aquatic species (SAV). The studies have also not been useful for informing control strategies to arrest and reverse future expansions.

Important findings are that there are nineteen species of submersed (SAV) and floating (FAV) aquatic plants in the Delta. About half of these are native while the rest are invasive. *Egeria densa* (Brazilian waterweed) and *Eichhornia crassipes* (water hyacinth) are the most abundant and problematic introduced macrophyte species in the Delta. *Ludwigia* sp (water primrose) is a third non-native FAV species that has increased in abundance and likely warrants control. *Myriophyllum spicatum* (Euasian watermilfoil), *Potamogeton crispus* (Curly-leaf pondweed), *Cabomba caroliniana* (Carolina fanwort), *Limnobium laevigatum* (South American sponge plant) and *Hydrilla verticillata* (Hydrilla) are non-native aquatic species that are located in or near the Delta and have the potential to become problems in the future. While there is no robust monitoring program, surveys show that in the six year period between 2008 and 2014 there was a two-fold increase in SAV and a five-fold increase in FAV. It is not known whether this rate of increase will continue in the future. The presence of other nearby invasive aquatic plants does increase the likelihood of additional introduced species in the immediate future and emphasizes the need for an early detection and rapid response monitoring program to identify and eradicate new invasive aquatic plants before they become established and difficult to control. A second observation of the Science Work Group is that eradication of one invasive species from an area often leads to the successful colonization by a second species. A successful control program must ensure suppression of all potential colonizer species that can enter and dominate an area.

E. densa, *E. crassipes* and *Ludwigia* sp are a problem because they are non-native species with no natural biological control. Colonies of all three species have invaded large areas of the Delta and have rapidly increased in biomass. These invasive species tend to occur at high density. In dense beds the colonies of all three species can cause multiple problems. These include decreasing dissolved oxygen to anoxic levels for fish and invertebrates, reducing turbidity and water flow and increasing water temperature. At high density aquatic vegetation can also impede recreation and commercial navigation, clog marinas and domestic and agricultural water feed canals, and obstruct agricultural intake pipes. The density of *E. crassipes* is highest in Delta sloughs and channels with increased residence times. Wind and boat turbulence, among other factors, can cause mats of *E. crassipes* colonies to break from large nursery colonies and migrate into main river channels where they may adjoin other migrating colonies and impede commercial navigation. Native macrophyte species tend to occur in more diffuse, less dense colonies and not cause the same problems. In fact, native macrophyte species are hypothesized to be beneficial for larval and juvenile fish by providing refuge from predators and increased planktonic and epiphytic food resources while maintaining higher dissolved oxygen levels. Research is needed to confirm the beneficial impacts of native species and to determine whether invasive taxa might also provide similar ecological services if they occurred at lower densities. Determining acceptable densities of both native and invasive aquatic plants in different Delta habitats could be valuable as a goal for managing control efforts as it is likely that no control program will be able to completely eliminate all invasive aquatic vegetation.

A number of factors have been identified that may influence the establishment, growth and dispersal of macrophytes in the Delta (Table 1). The factors include light, temperature, salinity, flow, substrate stability, chemical/mechanical control, interspecies competition, and nutrients. Inter-annual production of *E. crassipes* is modulated when there is a sufficient period of sub-freezing air temperatures to bring about senescence of *E. crassipes* colonies in the Delta. Implementing mechanical and chemical control programs earlier in the year and more extensively will target *E. crassipes* nursery areas more effectively following warm winters. Most of these factors have been determined from research conducted elsewhere. Studies are needed to establish their relative importance in determining the seasonal and inter-annual abundance of both native and introduced species in the Delta.

The range of nutrient concentrations that limit macrophyte growth in the Delta are not known. FAV species, like *E. crassipes*, acquire their nutrients from the water column while SAV species, like *E. densa* and *Ludwigia spp*, can obtain nutrients from both the sediment and water column. Therefore, FAV species are hypothetically a more plausible target for a water column nutrient management plan. The Science Work Group cautioned, however, that it was unlikely that nutrient reductions alone would be sufficient to control the abundance and distribution of any macrophyte species. To their knowledge, nutrient reductions have not been effective at eliminating invasive aquatic plants anywhere. The group did acknowledge, though, that were nutrient management able to reduce nutrients to levels that reduce the growth rate and viability of some invasive species, nutrient management might be an option for improving the efficacy of present physical, chemical and biological control actions. The Science Work Group recommended that, if funding was limited, the initial studies should emphasize FAV species that can only acquire nutrients from the water column. Valuable follow up investigations should evaluate whether nutrient management in combination with present control efforts might be a more successful control strategy.

The Macrophyte white paper had three major scientific recommendations. These were to (1) implement routine monitoring of invasive floating and submersed aquatic vegetation (2) develop a biogeochemical model of the Delta, focused on nutrient and organic carbon fate and transport, and (3) review current and potential future control strategies for invasive aquatic macrophytes in the Delta.

The emphasis in the Science Work Group discussions was on implementing a program for routine macrophyte monitoring and linking it with a series of laboratory and field studies to answer specific management questions (Table 2). Previously employed hyperspectral aerial surveillance monitoring has been found to be valuable for measuring the distribution of FAV but is not reliable for SAV. Future monitoring should include a combination of aerial surveillance and field transects. Transects should include measurement of species composition, biomass and a suite of standard water quality measurements including oxygen, salinity, pH, chlorophyll a and ambient nutrient concentrations. One purpose of the surveillance monitoring is to determine annual and inter annual changes in the abundance and distribution of both SAV and FAV in the Bay-Delta. A second goal is to institute an early warning and rapid response program to detect and eradicate new invasive aquatic plants before they can become widespread and difficult to control.

The Science Work Group also recommended that the aquatic plant surveillance monitoring program be used to select sites and determine the relative importance of factors controlling plant growth in different Delta habitats. The primary factors responsible for the growth and distribution of aquatic plants are known. However, less information is available about their relative importance in different habitats and whether any of these factors might be used to control invasive plant abundance and distribution. To accomplish this the Science Work Group recommended that instantaneous, annual and inter annual production rates be measured in different Delta habitats while simultaneously measuring the magnitude of key factors believed to control plant growth. The goal of the surveillance monitoring and special studies is to determine which factors limit plant growth in different Delta habitats.

A second recommendation of the Science Work Group was to use the results of the surveillance monitoring program to select representative habitats in the Delta for a series of special studies. These include determining the extent to which native fish species utilize macrophyte beds. The hypothesis is that dense beds of both native and introduced aquatic plant species reduce dissolved oxygen and restrict the distributions for some fish species, while intermediate densities may be beneficial by providing refuge from predators and increasing planktonic and attached food resources. Periodic fish surveys should be conducted in representative Delta habitats to determine the abundance and community composition of native and non-native fish utilizing the beds. The results would be used to determine whether fish usage is a function of aquatic plant density and/or species composition. The results could then be used to inform an aquatic plant control strategy to reduce the abundance and density of certain floating and submersed aquatic plants in habitats where native fish are present.

An important question for the Regional Board is to determine whether nutrient reductions might decrease the abundance and distribution of invasive aquatic plants. An initial laboratory study should culture aquatic plants in tanks amended with increasing amounts of nutrients while simultaneously measuring growth rates, nutrient uptake rates, and nutrient tissue concentrations. Objectives of the laboratory study are two-fold. First, determine plant growth as a function of ambient nutrient concentrations in water and in sediment. Permitted upgrades to sewage treatment plants are expected to decrease ammonium loads by over 80 percent in the Sacramento River dominated region of the Delta in the next 10-years and decrease dissolved inorganic nitrogen concentrations by 20 to 30 percent[3]. The results of the laboratory nutrient amendment studies should be combined with nutrient surveillance monitoring in the field and modeling (see next section) to evaluate whether present nutrient levels or concentrations expected over the next 10-years are within the range that can be expected to constrain the magnitude and abundance of invasive aquatic plants, based on laboratory experiments. A second objective of the laboratory research should be to ascertain whether nutrient concentrations in plant tissue can be used as a measure of the nutritional status of invasive aquatic plants and a potential indicator of instantaneous growth rates. Similar leaf tissue analysis is routinely used in commercial orchards to determine when and how much fertilizer to apply to maximize yields. It may be that a similar type of leaf tissue analysis can be employed to determine nutrient limitation of aquatic plants in the field. If the results of the laboratory studies are positive then the leaf analysis results should be confirmed with instantaneous growth rate measurements in the field.

The white paper also recommended development of a biogeochemical model of the Delta to inform invasive aquatic plant production. Separately a modeling science work group was formed to provide advice on how a suite of water quality models might be linked through one or more hydrodynamic models. The Modeling Science Work Group was tasked to provide advice on model selection criteria, the characteristics of the institution(s) where the hydrodynamic model(s) and water quality modules would be housed and how development of the models should be phased. The deliberations and recommendations of the work group were captured in a white paper. The white paper did not recommend the preferred suite of models nor the institution responsible for housing and maintaining the models but recommended the criteria that should be considered in selecting models and institutions. Selection of the preferred models and institution would be left to the funding authorities to determine in a competitive bid process. Figure 1 is a conceptual model on how a suite of water quality models might be linked with one or more hydrodynamic models to predict aquatic plant production and biomass in the Delta. More information can be obtained by reading the modeling charge[4] and the completed modeling white paper[5].

The U.S. Department of Agriculture –Agriculture Research Service (USDA-ARS) has funded a 5-year Area-wide pest management project to conduct research to determine how to best control invasive aquatic weeds in the Delta[6]. The project started in 2014. A component of the USDA-ARS effort is to use Soil Water Assessment Tools (SWAT) and make GIS layers of all the key factors controlling aquatic plant development, production and reproduction in the Delta.

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[3] Calculated from http://www.swrcb.ca.gov/centralvalley/board_decisions/adopted_orders/sacramento/r5-2010-0114-03_amend.pdf

[4] http://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/modeling_swg_charge.pdf/

[5] http://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_nutrient_research_plan/science_work_groups/2016_0301_final_modwp_w_appb.pdf

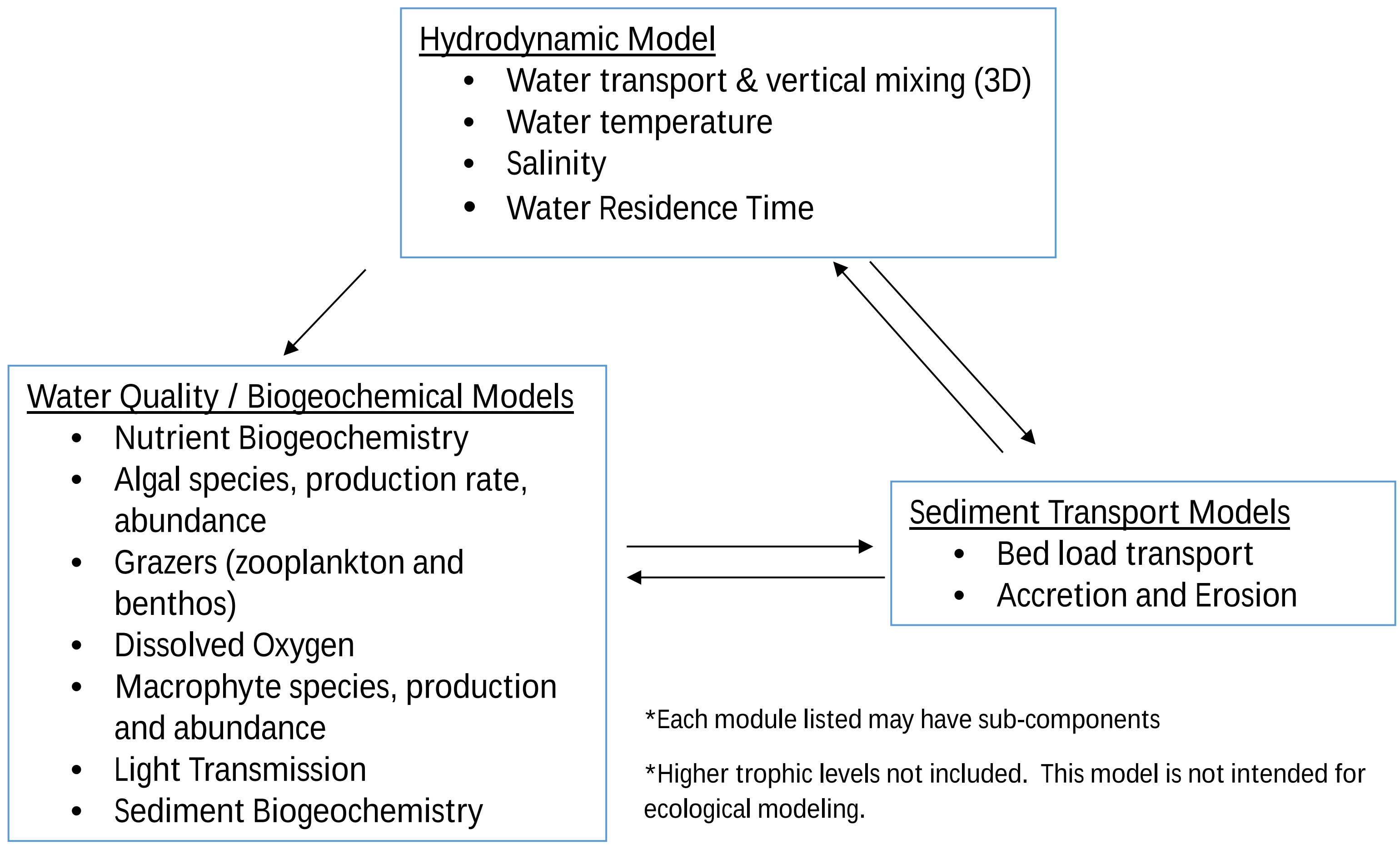
[6] http://www.ars.usda.gov/research/projects/projects.htm?accn_no=427232

These GIS layers would be used in plant response models to better understand factors responsible for plant growth, predict areas at risk for new colonization, and suggest better control strategies.

The Modeling Science Work Group recommended that development of water quality models for the Delta be phased. Early phases should emphasize water quality processes for which models already exist but need to be linked with hydrodynamic models of the Delta. Examples of processes that can be modeled in the initial phase are nutrients, temperature, salinity, dissolved oxygen and light transmission. Many of these processes are factors that are hypothesized to influence macrophyte colonization and production. The Modeling Science Work Group recommended that macrophyte growth and decay be delayed until the last phase of model development because, to the best of their knowledge, no macrophyte production models exist. A cost effective alternative strategy for the State of California may be to coordinate with the USDA-ARS and provide information to populate the SWAT GIS layers and inform the USDA-ARS plant growth response models.

The Modeling Science Work Group recommended that monitoring and special studies also include the collection of information needed by modelers to develop, calibrate and validate aquatic plant models. Likewise, the modelers recommended consultation with nutrient managers and aquatic plant researchers to determine high priority questions for evaluation. This exchange will require active collaboration between the macrophyte research and ecosystem modeling communities whether this is the USDA-ARS group or some other modeling institution selected by the State of California for development of water quality models. Funding authorities should look for ways to encourage this exchange, including requiring periodic annual workshops where each group informs the other of their findings and research needs. The funding authorities should also set aside money to fund high priority follow up studies as identified by both groups.

In summary, the Macrophyte Science Work Group's research recommendations for the next three to five year period are listed in Table 2. An important issue for the Central Valley Water Board is to determine whether nutrient management might be employed to significantly reduce the abundance and distribution of invasive aquatic vegetation in the Delta. The Science Work Group cautioned that no work conducted elsewhere, to their knowledge, has shown that nutrient reductions can be used alone to control invasive aquatic plants. Nonetheless, laboratory and field research should be conducted in the Bay-Delta Estuary to confirm these findings. The Science Work Group also noted that answering the management questions in Table 2 is not an intractable exercise. A well designed and coordinated set of field and laboratory studies could inform all these management questions in three to five years.



*Each module listed may have sub-components

*Higher trophic levels not included. This model is not intended for ecological modeling.

*See Figure 3 for an outline of important factors and variables for the models.

Figure 1. Preliminary framework for the hydrodynamic, water quality/biogeochemical, and sediment transport models and sub-models needed to inform nutrient related questions. Other researchers may use the model to investigate non-nutrient related issues. (Figure is from the charge to the modeling science work group).

Table 1. Summary of the areas of agreement among the Science Work Group about macrophytes in the Delta. The list was developed by members after review and discussion of the white paper.

Issue #	Topic	Agreement
1	Macrophyte species	*Egeria densa* (brazilian waterweed) and *Eichhornia crassipes* (water hyacinth) are currently widely distributed, dominant, non-native macrophytes in the Delta. *Ludwigia* spp. (water primrose) is another invasive aquatic weed that has increased in biomass and distribution. Other invasive species [*Cabomba caroliniana* (Carolina fanwort), *Limnobium laevigatum* (South American sponge plant), *Myriophyllum spicatum* (Eurasian watermilfoil), *Potamogeton crispus* (curly leaf pondweed), and *Hydrilla verticillata* (hydrilla)] are located in or near the Delta and have the potential to become future problems.
2	Impacts to physical & chemical environment	Invasive macrophytes have the potential to deplete oxygen, reduce turbidity and water flow, increase water temperature, and cause wide pH fluctuations in the beds and surrounding water.
3	Economic impacts	At high biomass macrophyte colonies obstruct water conveyance for agricultural, industrial, and domestic use; impede recreational and commercial navigation, obstruct agricultural and drinking water intake pipes, and can impede flood control channels.
4	Trends in biomass & distribution	*E. densa, E. crassipes, and Ludwigia* spp. have increased in abundance since the middle of the last century in the Delta. The two most recent UC Davis aquatic vegetation surveys in the Delta showed that between 2008 and 2014 there has been a two-fold increase in submersed aquatic vegetation (SAV) and a five-fold increase in floating aquatic vegetation (FAV).
5	Drivers	Several factors have been identified that likely influence the abundance and distribution of *E. densa* and *E. crassipes* in the Delta, although these are based mostly on studies conducted elsewhere. They are light, temperature, salinity, flow, residence time, water velocity, nutrients and chemical/mechanical control efforts. Less is known about the factors controlling populations of other species.
6	Control	Present control methods (mechanical, herbicide and biological) are useful for reducing the annual size of macrophyte colonies but have not kept up with inter annual population increases.
7	Nutrient Management	The Science Work Group is unsure whether nutrient management can control macrophytes. There is no precedent from other ecosystems that nutrient management alone will be an effective control option. Hypothetically, though, if nutrient management were able to reduce nutrients to levels that reduce the growth rate and viability of some invasive species, nutrient management might be an option for improving the efficacy of present chemical and mechanical control actions.

Table 2. Summary of knowledge gaps identified by the Macrophyte Science Work Group after review and discussion of the white paper. Issues 1 to 6 might best be addressed by a combination of monitoring and special studies that should be closely coordinated to simultaneously address multiple issues at the same time.
Note: These management questions have not been prioritized and the order does not imply a ranking of the importance of knowledge gaps.

Issues #	Management Question	Knowledge Gap	Research Recommendation
1	Have all macrophyte species causing water quality problems in the Delta been identified?	Yes, but other invasive aquatic plant species have colonized nearby waters and may successfully invade the Delta. No comprehensive early detection and rapid response monitoring program exists to identify new invasive species before they become a problem.	Implement a comprehensive multi-year monitoring program to detect new aquatic plants before they become widespread and conduct studies to evaluate whether early control is feasible and desirable.
2	Is the abundance and distribution of *E. crassipes*, *E. densa* and *Ludwigia* spp. increasing in different Delta habitats and will it continue to expand in the future?	Uncertain as no comprehensive monitoring program exists that measures change in biomass and distribution on a reoccurring annual basis.	Implement a comprehensive multi-year monitoring program in a variety of sites and Delta habitats to determine changes in seasonal and annual biomass of all dominant macrophyte species.
3	Should the State promote native macrophytes and reduce non-native invasive species abundance? What is the effect of native and non-native macrophyte species on pelagic and littoral fish abundance?	Limited information exists about the effect of macrophyte species composition and abundance on fish species composition and abundance.	Conduct a targeted study identifying the relationship between aquatic macrophyte species composition and biomass density and fish species composition and densities. This type of study could provide information on the general relationship between macrophytes and the fish assemblage. In the absence of such information, a synthesis of existing fish survey data to highlight key areas of native and listed fish abundance could provide information on general Delta regions that deserve focus for invasive macrophyte control.
4	What factors limit the growth and maximum size of	Most of the primary factors controlling macrophyte production and distribution are	Measure instantaneous, annual & inter annual production rates in representative Delta

	macrophyte beds on a seasonal, annual and inter-annual basis? Are any of these factors controllable?	known. Less information is available about their relative importance in different Delta habitats.	habitats. Simultaneously, assess the magnitude of all factors thought responsible for controlling production to determine their relative importance. Conduct manipulation studies to confirm key factors controlling production.
5	Can nutrient analyses of macrophyte tissue be used as a cost-effective method for assessing the nutrient status of plants in the field?	At present there is no robust method for rapidly assessing *in situ* nutrient limitation in the field. A novel method would be valuable for ascertaining nutrient limitation of both FAV and SAV in the Delta.	Culture macrophytes in the laboratory at varying nutrient levels to determine growth rates as a function of ambient nutrient levels in water and sediment. Simultaneously collect and analyze tissue to determine whether there is a predicable relationship between tissue growth, nutrient uptake rates & nutrient concentrations. Confirm relationships in the field by simultaneously measuring tissue growth, nutrient status and ambient nutrient concentrations.
6	Can nutrient management alone, including the lower concentrations expected in the future as a result of revised NPDES permits, reduce/control the abundance of macrophyte species?	Limited information exists on the range of ambient nutrient concentration in water and sediment that might restrict or control macrophyte growth in the Delta.	Conduct field experiments to determine nutrient concentrations at increasing distance from & into macrophyte beds. Use this data in combination with results from Issue #5 to determine seasons and locations in the Delta when nutrient concentrations might be restricting growth. If funding is limited, initial evaluations should emphasize FAV species. Use biogeochemical models (Issue #8 below) to forecast future nutrient concentrations after implementation of revised NPDES permits. Apply models to determine whether future nutrient levels will reduce aquatic plant tissue growth. If not, predict nutrient levels that might do so.
7A	What are the major factors that influence the efficacy of	The factors that promote or hinder the efficacy of the mechanical, herbicide, and biological control	Collaborate with agencies involved in the USDA-ARS Delta Area wide project and use their data

	current mechanical, herbicide, and biological control practices? Can these control practices be modified to more effectively control production in the Delta?	program were not reviewed for the white paper. However, the USDA-ARS Delta Area wide aquatic weed control project is conducting a number of special studies to determine if mechanical, herbicide, and biological control practices can be modified for a greater level of efficacy.	from special studies to determine if mechanical, herbicide, and biological control practices could be modified for a greater level of efficacy. Barriers to modifying current control efforts should be identified, and actions should be proposed to address these barriers.
7B	Can nutrient management improve the efficacy of mechanical, herbicide, and biological control practices in the Delta? What is the optimal nutrient range for each aquatic plant species?	It is uncertain whether nutrient management might increase the effectiveness of present mechanical, herbicide, and biological control practices.	If nutrient management is demonstrated to be a viable option for reducing macrophyte growth (Issues #5 and #6), then mesocosm studies or pilot work conducted in the field should be undertaken to determine whether the results of mechanical, herbicide & biological control would be enhanced at lower nutrient levels. Studies should be conducted to determine optimal nutrient ranges for each aquatic plant species.
8	How important are aquatic plants in the nutrient and carbon cycle in the Delta?	It is unclear how much of the reduced carbon in the Delta is from aquatic plant production. It is also unknown what the rate of carbon, nitrogen and phosphorus turnover from aquatic plants is in the Delta.	Use surveillance monitoring results of aquatic plant biomass (issue #2), nutrient content, and instantaneous and net tissue growth rates (issue #5) to estimate production and cycling rates for both nutrients and carbon. Compare these values with similar estimates for pelagic and benthic algae to determine the relative importance of aquatic vegetation processes in the Delta.
9	Can biogeochemical models help evaluate the relative importance of different macrophyte drivers, test management scenarios & evaluate the redirected negative effects of nutrient management?	Ecosystem water quality models are not available for the Delta although a Modeling Science Work Group is being formed to make recommendations on model development. The proposed model should include nutrient and macrophyte sub models.	Develop an ecosystem model that includes both a nutrient and macrophyte sub model. Macrophyte monitoring and modeling should be closely coordinated with model development to provide model coefficients and inform model calibration and validation efforts. Conversely, modelers should attempt to develop models that will inform critical questions posed by macrophyte researchers.

Table 3. Management questions were identified by STAG members after review and discussion of the white paper. These questions were posed to the Macrophyte Science Work Group and they were asked to provide suggestions on the knowledge gaps and recommended research.

Issues #	Management Question	Knowledge Gap	Research Recommendation
1	What are the potential impacts on water quality and other aquatic species (e.g., plant, animal, and cellular organisms, etc.) when increasing the use of herbicides (e.g., acres sprayed) as a management strategy?	New herbicides permitted (NPDES) for aquatic uses are planned for the Delta in future years (Penoxsulam, Imazamox, and possibly others), and should be the focus of water quality studies. Effects of these new herbicides and adjuvants, mediated through the decline and death of the targeted weed, on dissolved oxygen, nutrient content, and population sizes of organisms living in targeted weed beds are unknown.	Examine the effects of new herbicides and adjuvants on key water quality parameters and juvenile fish survival in tanks, and determine impacts on water quality, invertebrates, fish and non-target plants in field plots. Conduct mesocosm studies to evaluate the impacts of expected environmental concentrations of herbicides on other aquatic species.
2	What is an appropriate amount of macrophyte growth needed for beneficial ecological services in the Delta?	Limited information exists on the optimal growth and density of macrophytes necessary for ecological benefits. The USDA-ARS Delta Area wide Project is conducting a special study on water hyacinth and invertebrate communities in the roots but the study is limited to only five sites in the Central Delta. A larger study is needed across other areas of the Delta.	Examine the communities of invertebrate and vertebrate animals in mixed beds of invasive and native macrophytes at varying bed water coverage levels.
3	This question relates to Issue #7b in Table 2. If other more prominent factors that impact macrophyte growth (e.g., temperature and flow) are controlled, will nutrient management make a substantial difference?	**Science Work Group members did not provide any knowledge gaps in response to this management question.*	**Science Work Group members did not respond with any research recommendations. A few members indicated that this question could be assessed under question 7b by performing control studies with and without nutrient management in conjunction with controlling other drivers to assess whether nutrient management made a substantial difference in controlling macrophyte production.*

Appendix A

Macrophyte Science Work Group members

Individual	Agency
Martha Sutula (Facilitator)	Southern California Coastal Water Research Project
Kathy Boyer (White Paper Author)	San Francisco State University
Louise Conrad	Department of Water Resources
Jeff Cornwell	Horn Point Laboratory, U Maryland
John Durand	U.C. Davis
Diana Engle	Larry Walker Associates
Shruti Khanna	LAWR, U C Davis
Angela Llaban	CA Dept. Parks & Recreation, Div. Boating & Waterways
Patrick Moran	USDA, Agricultural Research Service
John Madsen	U.C. Davis/USDA, Agricultural Research Service