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Nutrient Concentrations and Biological Effects in the Sacramento-San Joaquin Delta

July 2010

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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Executive Summary

Nutrient and chlorophyll a concentrations were measured monthly at 21 sites in the Sacramento-San Joaquin Delta (Delta) above and below the Sacramento Regional Wastewater Treatment Plant (SRWTP) between March 2009 and February 2010. The primary purpose of the sampling was to characterize the effect of SRWTP effluent on these concentrations over an annual hydrologic cycle and compare the values with reported toxicity endpoints for sensitive local aquatic organisms.

The SRWTP is the largest Publicly Owned Treatment Plant (POTW) in the Delta's watershed. Water samples were collected above and below the POTW within about an hour of each other. Effluent from the SRWTP increased nutrient concentrations in the Sacramento River. Total particulate and dissolved nitrogen, ammonia, nitrite and nitrate concentrations all increased below the SRWTP ($P<0.001$). The average ammonia level rose 11.5-fold, from 0.04 to 0.46-mg N/l. Likewise, total particulate and dissolved phosphorus and soluble reactive phosphorus increased below the plant ($P<10^{-6}$). Soluble reactive phosphorus concentrations doubled from 0.03 to 0.06-mg P/l.

Nutrient concentrations were measured at nine locations along a major water flow path across the Delta from the City of Sacramento to Chipps Island, a distance of about 77 miles. Total dissolved nitrogen increased below the SRWTP and then remained constant to Chipps Island. Ammonia concentrations decreased down river with most of the loss occurring before Three Mile Slough. There was a corresponding increase in nitrite and nitrate concentrations with most of the change also happening before Three Mile Slough. Ammonia and nitrite/nitrate concentrations were the mirror image of each other, suggesting that there were no other large nitrogen sources or sinks. The microbial transformation of ammonia to nitrite and nitrate appears to be the major biological process occurring in the Delta.

Total dissolved phosphorus (TDP) and soluble reactive phosphorus (PO_4) increased below the SRWTP and remained constant across the Delta to Chipps Island. A stable dissolved PO_4 concentration below the SRWTP also suggested no significant additional sources or sinks of phosphorus.

Chlorophyll concentrations decreased between the City of Sacramento at Tower Bridge and Isleton and then increased as the water mass moved seaward. The average decrease in pigment between Tower Bridge and Isleton was about 60 percent. The decline occurred on 15 of the 16 sampling runs. The cause of the algal decline is not known but deserves additional study.

The Central Valley Regional Water Quality Control Board relies upon U.S. EPA criteria for setting National Pollutant Discharge Elimination System permit limits unless scientifically defensible information exists demonstrating the presence of other more sensitive local aquatic organisms. The lowest recommended U.S. EPA (1999) criteria are chronic endpoints when early life stages of fish are present. In the present study ambient temperature and pH values were collected with each ammonia sample and the U.S. EPA chronic criterion calculated from the formula in U.S. EPA (1999). Three hundred and thirty-four ammonia comparisons were made. The U.S. EPA chronic criterion for early life stages of fish was never exceeded during the year study. Recently, the U.S. EPA (2009) released an updated draft ammonia criterion to protect freshwater mussels. Mussels are more sensitive to ammonia than larval fish. The chronic ammonia criterion for mussels present was also compared against ambient concentrations in the Delta. Ambient concentrations never exceeded the new draft mussel criterion.

A hypothesis at the beginning of the study was that ammonia from the SRWTP was causing acute toxicity to delta smelt *(Hypomesus transpacificus*). The highest un-ionized ammonia levels were measured below the SRWTP at Hood. The mean and 95 percent confidence limits of un-ionized ammonia at Hood were 0.0036±0.0012 mg N/l. The upper 95 percent confidence limit of these values was 19-times lower than the 7-day no observed effect concentration for smelt survival suggesting that ambient ammonia levels in the Delta were not acutely toxic during the study.

There is currently no established bioassay method for assessing chronic toxicity to delta smelt. In such instances, acute to chronic ammonia ratios (ACRs) for other freshwater fish species are used to predict potential chronic toxicological endpoints. The lowest reported 96-hour LC_{50} value for smelt was divided by the highest reported ammonia ACR to estimate a safe chronic concentration. All measured un-ionized ammonia concentrations in the Delta were less than this value suggesting that chronic smelt toxicity did not occur during the study.

A second hypothesis at the beginning of the study was that ammonia from the SRWTP inhibited nitrate uptake and this reduced primary production rates and altered phytoplankton community composition in the river below the POTW. A combination of laboratory and field experiments have demonstrated that ammonia concentrations greater than 0.056-mg N/l shut down nitrate uptake in the Sacramento River but did not reduce primary production when the rate was normalized by the amount of chlorophyll present in the bottle. No information exists on the effect of ambient ammonia concentrations on algal production downstream of Isleton in the Delta. Average annual ammonia concentrations were less than 0.056 mg N/l in the Sacramento River above the SRWTP but greater at 15 of the 19 sites monitored below the SRWTP. The impact of elevated ammonia concentrations on algal species composition in the Delta is also not known but may contribute to the observed shift from ecologically important diatoms to smaller, less desirable flagellates and blue green algae. More research is needed to evaluate the effect of elevated nutrient levels on phytoplankton abundance and species composition in the Delta.

Introduction

The Sacramento-San Joaquin Delta (Delta) is the largest estuary on the west coast of North America. It is home to 230 bird, 45 mammal and 52 species of fish (Department of Water Resources, 1995). The estuary also once supported a commercial fishery including salmon, striped bass, shrimp and bivalves (Smith and Kato, 1979). The natural productivity of its waterways fueled this abundant and diverse wildlife. However, populations of many ecologically and commercially important species have gradually declined over the past century. The cause of the decline has been attributed to multiple causes including the construction of upstream dams, export of water from the Delta, draining wetlands for agriculture in the Delta, and discharge of contaminants from urban and agricultural sources.

A precipitous decline occurred simultaneously for several pelagic fish populations in the freshwater portion of the Delta around the year 2000. The collapse has been termed the pelagic organism decline (POD) (Sommer *et al*., 2007). The POD was not correlated with physical and biological factors previously identified as controlling the abundance of these species. Recognition of the POD led to the development of a conceptual model to inform and guide research to determine its cause (Sommer *et al*., 2007). The conceptual model posits four general areas for investigation. These are top down (water diversions and predation), bottom up (food availability and quality), prior fish abundance, and physical and chemical habitat including contaminants. Nutrient concentrations, and in particular ammonia, have been identified as a potential contaminant of concern.

The Sacramento Regional Wastewater Treatment Plant (SRWTP) is the largest publicly-owned treatment works (POTW) in the Delta's watershed and has been estimated to contribute up to 90 percent of the annual ammonia load (Jassby, 2008). Elevated ammonia[1] concentrations from the SRWTP are hypothesized to cause multiple negative biological impacts. These include acute toxicity to delta smelt *(Hypomesus transpacificus*), one of the POD species, and reductions in phytoplankton primary production downstream of the SRWTP in the Delta.

State Water Resources Control Board Resolution No. 2007-0079 directed "…*Water Board staff… execute contracts to conduct screening studies of potential inhibition of primary production and toxicity to fish associated with ambient ammonia concentrations in the Delta…and implement appropriate regulatory controls to protect beneficial uses*". Contracts were initiated to determine the concentration of ammonia inhibiting primary production in the Sacramento River and causing acute toxicity to delta smelt. A draft final report has been prepared for the phytoplankton work (Parker *et al*., 2010). The study found that ammonia did not inhibit primary production rate measurements in the River below the SRWTP when normalized by the amount of chlorophyll present in the bottles but did identify an ammonia concentration that caused a shift in nitrogen utilization from nitrate to ammonia. Changes in the form of nitrogen being assimilated by algal community may indicate an ammonia-induced competitive shift in the

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[1] Ammonia exists in water in an ionized (NH_4^+) and an un-ionized (NH_3) form. The term ammonia here refers to the sum of the concentration of the two forms.

reproducing portion of the phytoplankton community. Final reports for the first two years of smelt bioassay work have also been received (Werner *et al*, 2008; 2009). The bioassay studies determined the concentration of un-ionized ammonia causing acute toxicity.

Information on ambient nutrient concentrations in the Delta are needed to interpret the phytoplankton and delta smelt toxicity results. This should include widespread, spatial monitoring throughout an annual hydrologic cycle and short-term intensive temporal sampling at key locations to determine whether diel or tidally induced changes in nutrient concentrations occur. The spatial monitoring should ideally be located along the major flow paths of water across the Delta and emphasize locations where other agencies are collecting flow and water quality information. Both the spatial and temporal sampling should also include information on a suite of other water quality parameters, such as temperature and pH, to calculate un-ionized ammonia concentrations and inform future monitoring and hypothesis development.

The California Data Exchange Center (CDEC) operates a series of continuous water quality monitoring sites in the Delta that collect a suite of data on 30 to 60 minute time intervals. The data are available in real time[2]. This high-frequency, long-term data set may be valuable for understanding nutrient transformations and predicting aquatic toxicity between nutrient sampling events. However, before the two data sets can be used interchangeably, both sets of measurements need to be compared to determine whether systematic differences exist.

The purpose of this study was threefold. First, collect nutrient data, including ammonia, at key locations in the Delta for an annual hydrologic cycle to characterize concentrations and compare with reported toxicity endpoints for sensitive local aquatic organisms. Second, determine diel and tidally induced changes in nutrient concentrations at key locations to ascertain short-term variability**.** Third**,** compare water quality measurements collected in this study with remote sensing values reported by CDEC for the same time and place to determine the comparability of the two data sets.

Method and Materials

Spatial monitoring The purpose of the spatial monitoring was to determine nutrient concentrations, including ammonia, across the freshwater Delta through an annual hydrologic cycle. Water samples were collected monthly at 21 sites in the Delta between March 2009 and February 2010 (Table 1, Figure 1). The only exception was March through June of 2009 when two sets of samples were taken monthly as juvenile salmon and delta smelt are present in the Estuary (William, 2006; Bennett, 2005) and both species are reported to be very sensitive to ammonia. All water samples were collected as subsurface grabs in mid channel from bridges or by boat. Samples for nutrient analysis were placed on ice and delivered to Dr. Randy Dahlgren's laboratory at UC Davis on the day of collection. After May samples were also collected for Dr. Carol Kendall's U.S.

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[2] http://cdec.water.ca.gov/

Geological Survey laboratory at Menlo Park for isotope analysis. These were sent by FedEx on the day of collection for next day delivery. The results of the isotope analysis will be reported separately by Dr. Kendall.

Temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and turbidity measurements were made by Regional Board staff in the field during water collection. Hydrogen ion concentration was measured with a Hach HQ30d pH meter, temperature, electrical conductivity and dissolved oxygen with an YSI 556 MPS meter, and turbidity with a Hach 2100P turbidity meter. The pH meter was recalibrated in the field after every four to five samples, dissolved oxygen and turbidity meters were recalibrated at the start of each day. Finally, the EC meter was recalibrated monthly.

Nutrient analysis at UC Davis began the morning after sample collection and was completed within 48 hours. Analytical procedures are described in Dahlgren *et al.* (2010). Briefly, algal pigments were determined using Standard Method 10200-H (Clesceri *et al.,* 1998) after filtering through a Whatman GF/F glass fiber. Water was filtered through a 0.45-µm polycarbonate membrane (Millipore) for quantification of soluble reactive phosphorus (SR-PO_4), nitrate-N (NO_3-N), nitrite-N (NO_2-N), ammonium (NH_4-N), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP). SR-PO_4 was determined using the method of Clesceri *et al*., (1998) while Doane and Horwath (2003) was used to determine NO_3+NO_2-N and NO_2-N; the NO_3-N fraction was calculated by difference: NO_3+NO_2-N minus NO_2-N. Ammonium was determined spectroscopically (Forster 1995). Dissolved organic nitrogen (DON) was estimated from the difference of total dissolved nitrogen minus the sum of the ammonia, nitrite and nitrate values. DOC was measured by EPA Standard Method 5310C. Total dissolved nitrogen and TDP were measured on a filtered sample (Yu *et al*., 1994; SM 45000-N C; Clesceri *et al*., 1998). TN and TP were measured on a non-filtered sample using the same methods. Table 2 is a list of the water quality parameters measured at each site.

Temporal monitoring The purpose of the short-term intensive temporal monitoring was to determine whether there were tidal or diurnally induced variations in nutrient concentrations in the Delta. Sigma samplers were placed on the DWR water quality monitoring piers at Rio Vista (Figure 1, Site 7) and at Antioch (Site 16). The pumps were programmed to collect water samples every two hours for two days (24 samples) in March, April and May 2009. Samples were stored on ice in the Sigma samplers and picked up daily for transport to UC Davis for analysis. Measurements of tidal stage, EC, field pH, chlorophyll, and dissolved oxygen were obtained from the CDEC continuous monitoring meters located at each site[3].

Quality Assurance/Quality Control Program (QA/QC) The program included both a field and laboratory component to determine accuracy and precision. Accuracy was assessed by use of travel blanks, standard reference material and the spike recovery of the addition

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[3] Continuous monitoring data for Rio Vista is from http://cdec.water.ca.gov/cgi-progs/queryF?s=RVB&d=03/09/2010+15:42&span=12hours. Data for Antioch is from: http://cdec.water.ca.gov/cgi-progs/queryF?s=ANH&d=03/09/2010+15:44&span=12hours.

of known amounts of material. Precision was measured by analysis of a duplicate blind field sample on each survey and laboratory replicates. A more detailed description of the QA/QC procedures is contained in Dahlgren *et al* (2010).

Statistics Calculations of t-tests and confidence limits were performed with Microsoft Excel while a Kruskal Wallis multiple comparison test was done with Statistica software[4]. A P-value of 0.05 was used to establish statistical significance although the actual P-values are provided in the text to help the reader evaluate the probability of achieving the results by chance alone.

Results and Discussion

Quality Assurance/Quality Control The program demonstrated that all the analytical results, with the possible exception of chlorophyll, were high quality (Table 3). Four-hundred and eighty field samples were collected and analyzed (Table 1A, Appendix A). Thirty-two of these were travel blanks and field replicates (7 % of the total). Six-thousand four-hundred and ninety-three analytical measurements were made on the field samples. About 19 percent of these or 1,213 measurements were for QA/QC purposes.

The QA/QC program had both an accuracy and precision component (Table 3). Accuracy was assessed by use of travel blanks, analysis of standard reference material and the spike recovery of a known amount of material. Three of the 16 travel blanks were found to contain trace amounts of total and total dissolved nitrogen. Nitrogen concentrations in these blanks were about 1 % of field values collected on the same date and were considered too low to compromise the field results. The mean percent recovery of the addition of known amounts of material into field samples ranged between 99 and 102 percent. The mean percent recovery of standard reference material was between 97 and 103 percent.

Precision was measured by analysis of laboratory replicates and field duplicates. The mean relative percent difference (RPD)[5] of the laboratory replicates was between 1 and 31 percent. Similar values for field duplicates ranged between 2 and 24 percent. Field RPD values were, with the exception of chlorophyll and phaeophytin, consistently 3-7 times greater than laboratory measurements suggesting that most of the variability originated in the field. Chlorophyll and phaeophytin had the highest RPD values. Laboratory and field pigment RPDs values were similar suggesting that much of this variability may have been a laboratory artifact. Care should be exercised in interpreting the chlorophyll results.

The QA program also had an inter-laboratory component (Table 4). On three occasions duplicate water samples were collected at both Garcia Bend and at Hood and were analyzed by both a certified local commercial laboratory[6] and by U.C. Davis. The paired

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[4] Statistica StatSoft, http:// www.statsoft.com

[5] Relative percent difference=((high value-low value)/(high value+ low value)/2)100

[6] California Laboratory Services, 3249 Fitzgerald Road, Rancho Cordova, CA 95742

field samples demonstrate that ammonia, orthophosphate, and total kjeldahl nitrogen concentrations were generally lower above the SRWTP while nitrate and nitrite concentrations were similar above and below it. However, there was often poor agreement on actual concentrations. For example, ammonia concentrations varied between about the same value and a three-fold difference in the six sets of paired samples. A possible explanation for some of the inter laboratory variability is that many of the field measurements were close to the analytical detection limit of the commercial laboratory.

<u>Spatial Monitoring</u> The purpose of the spatial monitoring was to characterize nutrient concentrations in the freshwater portion of the Delta for an annual hydrologic cycle. Of particular importance was the measurement of ammonia concentrations together with the associated pH values to estimate ambient levels of un-ionized ammonia for comparison with recommended U.S. EPA chronic criteria and other toxic values reported for sensitive local organisms. Below, nutrient patterns in the Delta are described and comparisons made between *in situ* concentrations and reported toxic levels.

The SRWTP is the largest POTW in the Delta's watershed and is located on the Sacramento River between Garcia Bend and Hood in a tidal portion of the River (Figure 1). The Sacramento River is the largest source of fresh water to the Delta and typically delivers about 75 to 85 percent of the all the freshwater flow. The SRWTP normally discharges about 141 million gallons per day which averages about 1 to 2 percent of River volume at that location but may on occasion represent up to 7 percent of the Sacramento River's flow because of tidally induced low outflow conditions. The effluent is discharged through a diffuser pipe located on the river bottom running perpendicular to river flow. The effluent is fully mixed in about 4 miles if Sacramento River flow is greater than 1,300 cfs (personal communication, Kathleen Harder). The SRWTP is prohibited from discharging at river velocities less than 1,300 cfs or when the ratio of River flow to effluent is less than 14:1[7]**.** The first sampling location below the SRWTP is at Hood (Site #3 in Figure 1). Hood is seven miles downstream of the SRWTP and the effluent is assumed to be fully mixed by this point.

The SRWTP increased nutrient concentrations in the Sacramento River. Table 5 presents the mean annual nutrient concentrations, pH and dissolved oxygen values from water samples collected above and below the SRWTP at Garcia Bend and at Hood within about an hour of each other. All species of nitrogen and phosphorus, except DON, increased below the SRWTP (two tailed paired t-test, $P<0.001$). DON rose by a factor of 1.4 but the change was not significant ($P<0.06$). The average ammonia concentration increased 11.5 fold, from 0.04 to 0.46-mg N/l. Soluble reactive phosphorus doubled from 0.03 to 0.06-mg P/l. In contrast, the SRWTP reduced river pH and dissolved oxygen concentrations. Dissolved oxygen levels fell from 8.8 to 8.5 mg/l while pH declined from 7.7 to 7.4. The decrease in both dissolved oxygen and pH was significant ($P<0.02$ and $P<10^{-7}$ paired two tailed t-test).

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[7] The discharge permit for the SRWTP may be reviewed at http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/sacramento/5-00-188_npdes.pdf

There are three main flow paths for Sacramento River water across the Delta. The first is along the Sacramento River channel from Tower Bridge (site 1), past Hood (Site 3) and Rio Vista (Site 7) to Chipps Island (site 15) and out into Suisun Bay. The distance between Tower Bridge and Rio Vista and Tower Bridge and Chipps Island is about 61 and 77 miles, respectively. Water velocities are highly variable and depend on river outflow and tidal stage. Travel times between Hood and Rio Vista varied between 2 and 3 days for many of our sampling events (personal communication, Marianne Guerin). Transit times between Hood and Chipps Island are much more variable and may range from 14 to as much as 60 days depending on the volume of Sacramento River inflow and exports at the State and Federal pumps (Kimmerer and Nobriega, 2008).

The second flow path is down the Sacramento River and across a web of channels in the central Delta to the State and Federal pumps at Tracy (Sites 19 and 20). Water leaves the Sacramento River channel for movement across the Delta at the delta cross channel and Georgiana Slough (both near Site 5) and at Three Mile Slough (Site 13). Nutrient data were also collected at a set of key locations along the second flow path and at the State and Federal pumps.

The third flow path is down the Sacramento River to Courtland, through Steamboat and Miners Sloughs to Cache Slough and then joining the Sacramento River channel again at Rio Vista (Figure 1). About half of all the water at Rio Vista travels by this route (personal communication, Carol Kendall). No nutrient monitoring was conducted along this flow path.

For simplicity only changes in nutrient levels along the first flow pathway, Tower Bridge to Chipps Island are discussed below. However, all the nutrient data were evaluated in the toxicological analyses.

Mean annual nutrient levels are summarized for the Delta in Table 6. Nutrient concentrations and water quality data for individual dates are reported in Appendix A, Tables 1A and 1B, respectively. Total dissolved nitrogen (TDN) increased below the SRWTP and then remained constant to Chipps Island ($P>0.15$, Kruskall Wallis test, Figure 2A). Ammonia concentrations decrease down river ($P<0.0001$, Kruskal-Wallis test; Figure 2B) with most of the decrease occurring before Three Mile Slough (Site 13). There was a corresponding increase in nitrite (not shown) and nitrate concentrations with most of the change happening before Three Mile Slough ($P<0.0001$, Kruskal-Wallis test; Figure 2C). Ammonia and nitrite/nitrate concentrations are the mirror image of each other, suggesting that there are no additional large nitrogen sources or sinks below the SRWTP. Microbial transformation of ammonia to nitrite and nitrate appears to be the major biological process at work in the Delta. This conclusion is consistent with the findings of Parker *et al.* (2010).

Total dissolved phosphorus (TDP) and soluble reactive phosphorus (PO_4) increased below the SRWTP and then remained stable down River and across the Delta to Chipps Island ($P>0.2$, Kruskall Wallis test, Figure 3). A stable dissolved PO_4 concentration below the SRWTP also suggests no significant additional sources or sinks of phosphorus, including biological uptake into the phytoplankton community.

Chlorophyll concentrations decreased between Tower Bridge and Isleton ($P<0.0001$, Kruskall-Wallis test; Figure 4a) and then commenced to increase as the water mass continued to move seaward. The average decrease in pigment between Tower and Isleton was about 60 percent. The decline occurred on 15 of the 16 sampling runs (Table 5, Appendix A). Parker *et al*. (2010) also noted a decrease in chlorophyll concentration down river.

The cause of the algal decline is not known. The decline began above the POTW and continued downstream. Parker *et al*. (2010) observed an increase in algal biomass in five-day cubitaner grow out experiments filled with water from above and below the SRWTP and incubated at the Romberg Tiburon Center. The authors also measured primary production in 24-hour C^{13} incubations of water collected at seven locations between Tower Bridge and Rio Vista. This would seem to indicate that the algal community is capable of replicating itself. Zooplankton or clam herbivory would be expected to increase phaeophytin levels. However, phaeophytin concentrations also declined down river with a minimum at Isleton ($P<0.03$, Kruskall-Wallis test; Figure 4B).

The RPD[8] of chlorophyll concentrations at Tower Bridge and Isleton were regressed against the mean daily flow for the Sacramento River at Freeport on the sampling date to better understand the chlorophyll loss. Freeport is located between Garcia Bend and Hood. No flow dependent relationship was observed. Mean daily flow at Freeport was assumed to be a surrogate for water residence time in the channel between Tower Bridge and Isleton. Absence of a relationship suggests that the sum of loss processes is not a rate function. Finally, the RPD was regressed against the instantaneous minimum 15-minute velocity at Freeport for the two days preceding each sampling event. The assumption being that it takes about two days for water to travel between Tower Bridge and Rio Vista. An inverse relationship was observed between the loss of chlorophyll and the instantaneous minimum velocity ($P<0.001$, Figure 5). Pigment loss declined with increasing velocity. The break even point where no loss occurred was about 3 ft/sec. The relationship is still significant with the removal of the single high flow data point in Figure 5. Instantaneous velocity values at Freeport were assumed to be a surrogate for river turbulence. If so, the loss of chlorophyll may be related to settling and the subsequent inability of settled algae to become resuspended when water velocity increases again. Regardless, determining the cause of the loss of chlorophyll in the lower Sacramento River is important because the River is the major source of water to the Delta and should also be an important seed stock. Less incoming algae will result in lower standing stocks for subsequent growth. Algae are the most nutritious form of food in the Delta (Muller *et al*. 2002) and their abundance is important in determining biomasss at higher levels of the aquatic food chain. Low chlorophyll levels are hypothesized to be a potential cause of the POD (Sommer *et al*., 2007).

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[8] RPD or relative percent difference=((high value-low value)/(high value+ low value)/2)100

River pH decreases downstream of the SRWTP (paired t-test, $P<10^{-7}$, Figure 6). The average change is from 7.7 at Garcia Bend to 7.4 at Hood. The pH values rise downstream of Hood and by Rio Vista are not different than above the plant. The pH continues to increase west of Rio Vista and reaches a maximum at Chipps Island.

Hydrogen ion concentration is important in determining ammonia toxicity. Higher pH values result in more un-ionized ammonia. Both the un-ionized and the ionized forms of ammonia are toxic. However, the un-ionized form is the more lethal to fish. So, from a toxicological standpoint, the increased ammonia concentration below the SRWTP is, at least partially, ameliorated by the reduction in pH.

Dissolved oxygen concentrations progressively declined down the Sacramento River between Tower Bridge and Rio Vista. Average annual concentrations at Tower Bridge and Rio Vista were 9.1 and 8.3 mg/l, respectively. Oxygen levels returned to concentrations similar to Tower Bridge by Three Mile Slough. The decrease in oxygen concentrations in the Sacramento River above Rio Vista is consistent with the oxidation of ammonia. However, the annual average decrease in oxygen below Tower Bridge was not statistically significant (Kruskal Wallis test, $P>0.1$). All oxygen concentrations in the River between Tower Bridge and Chipps Island were greater than the Basin Plan Objective of 7.0 mg/l.

<u>Temporal Monitoring</u> Intensive temporal sampling was conducted on three occasions at both Rio Vista and Antioch to determine whether there were diel (day/night) or tidally induced changes in nutrient concentrations (Appendix B, Tables 1B-6B). This was done by collecting water every two hours for two days from each site with an automatic sampler. Diel differences were compared statistically for each date by grouping all samples collected during daylight and nighttime and comparing them with a t-test. Tidally induced differences were evaluated by regressing river stage against nutrient concentrations.

No consistent diel or tidal signal was observed at either location for any of the nutrients or for pH, chlorophyll or dissolved oxygen. For example, results for the 30 March to 1 April 2009 event at Rio Vista are presented in Figure 7. Parker *et al.* (2010) observed significant variation in nutrient concentrations in the Sacramento River below the SRWTP. Our results suggest that the water mass is well mixed and homogenized by tidal action once the water leaves the confines of the Sacramento River channel and enters the more expansive, tidally active Sacramento deepwater ship channel above Rio Vista. There was an inverse relationship between tidal stage and chlorophyll at Rio Vista on the first sampling event (Figure 7B, $P<0.01$) but the relationship was not observed again suggesting that it was not a normal occurrence. Apparently, phytoplankton primary production rates are too low to drive measurable changes in nutrient levels. These conclusions are important because they suggest that nutrient concentrations in the Delta, such as those measured in our spatial sampling, are relatively constant for up to several days.

Comparison of results from this study with CDEC data CDEC maintains a series of continuous water quality monitoring sites in the Delta. Water quality measurements are made on 30 to 60 minute time intervals and the information made available in real time on their website. These data form an invaluable high-frequency record of water quality at key locations throughout the Delta. The CDEC meters are located on channel banks while the results obtained in this study were collected in mid-channel as sub-surface grabs. Four of the locations monitored in this study (Hood, Rio Vista, Chipps Island, and Antioch) were in areas of the Delta dominated by Sacramento River water and near CDEC collection sites.

Water quality data from this study and from CDEC were compared to determine the magnitude of any differences and whether CDEC information might be used during times when no information was available from this study (Table 7). The mean difference in pH values between the two data sets was small and averaged 0.1 pH units. Bias is defined here when one instrument read higher than the other in more than 75 percent of the cases. This frequency was selected as it is different at a P-value of 0.05 with a sign test and a sample size of 16. No bias was observed in the pH data at any location. The average difference in temperature between probes ranged between 0.2 and 0.4^{o}C. Again, there was no bias between the two data sets. Average differences in electrical conductivity (EC) were estimated by calculating the RPD between the two instruments as the absolute magnitude of EC varied greatly at a number of sites over time. The RPD of the EC measurements ranged between 4 and 21 percent with the highest value in the western Delta at Chipps Island. A significant amount of bias was observed in the EC measurements at Rio Vista. On average, CDEC reported higher EC readings than this study. This may result from the CDEC instruments being located on the west side of the channel and water from the Yolo Bypass with higher EC predominately drains down that side. In contrast, our measurements are taken in mid channel. The difference in dissolved oxygen (DO) values ranged between 0.4 and 0.7 mg/l. A significant amount of bias was again observed at Rio Vista where the CDEC probe consistently recorded higher values than measured in this study. Finally, turbidity and chlorophyll were the most variable of the comparisons made. The RPD for turbidity ranged between 20 and 37 percent while a similar value for chlorophyll was between 54 and 73 percent. No bias was observed in either the turbidity or chlorophyll measurements.

Overall, the comparison suggests good agreement in pH and significant differences in turbidity and chlorophyll. Some of the differences in chlorophyll may result from the poor reproducibility of the pigment measurements in the laboratory (see QA/QC discussion), but the results are also likely compounded by difficulty in accurately measuring chlorophyll continuously in the field. The results suggest that care should be exercised when interchangeably using chlorophyll and turbidity measurements recorded by this study and CDEC.

Comparison against toxicity endpoints The final objective of this study was to compare nutrient concentrations measured in the Delta against known toxic endpoints. Three comparisons were made. First, ammonia concentrations were compared against recommended U.S. EPA criteria for the protection of freshwater organisms. Next, ammonia concentrations were compared against values reported to be acutely toxic to delta smelt, a federally listed sensitive local aquatic organism. Finally, the nutrient concentrations are compared against values reported to alter nitrogen uptake and, possibly, algal species composition in the Delta.

U.S. EPA Criteria The U.S. EPA has synthesized the toxicological information for ammonia and developed recommended criteria for the protection of freshwater organisms (U.S. EPA 1999). These criteria are important because the Central Valley Water Board relies upon them for setting National Pollutant Discharge Elimination System permit limits unless scientifically defensible information exists demonstrating the presence of other more sensitive local aquatic organisms.

Ammonia exists in water in two forms: un-ionized ammonia (NH_3) and the charged ammonium ion (NH_4^+). The portion of ammonia in the un-ionized fraction is a positive function of temperature and pH. Both un-ionized and ionized ammonia are toxic but the un-ionized form is usually the more lethal to fish. Therefore, researchers often report toxicological endpoints in terms of un-ionized ammonia. However, the U.S. EPA has chosen to combine the toxicity of both the ionized and un-ionized forms and recommend a safe level in terms of temperature, pH and ammonia concentration.

The U.S. EPA recommended both acute and chronic ammonia criteria in their 1999 document. The lowest values are chronic endpoints when early life stages of fish are present. In the present study ambient temperature and pH values were collected with each ammonia sample and the U.S. EPA chronic criterion calculated from the formula in U.S. EPA (1999). Three-hundred-thirty-four ammonia comparisons were made (Table 8). The U.S. EPA chronic criterion for early life stages of fish present was never exceeded during the year-long study.

A safety factor was estimated by dividing ambient ammonia concentrations in the Delta by the calculated site-specific criterion for juvenile fish (Figure 8). A value less than one indicates that the criterion was exceeded and that toxicity may have occurred to juvenile fish. The average safety factor for the Sacramento River at Tower Bridge and at Garcia Bend was about 200 but decreased to 16 at Hood because of the discharge of ammonia from the SRWTP. The safety factor for Hood was the smallest value measured in the study. The margin of safety gradually increased downstream of the SRWTP as ammonia was converted to nitrite and nitrate. The average margin of safety at Rio Vista was about 28.

In 2009 the U.S. EPA released an updated draft ammonia criteria document with lower acute and chronic values (U.S. EPA 2009). The revised criterion is to protect freshwater Unionid mussels. Unionid mussels are more sensitive than larval fish to ammonia. The proposed chronic ammonia criterion for freshwater mussels is about five to ten times lower than the 1999 chronic criterion for juvenile fish.

The freshwater Unionid mussel *Anadonata* sp. is present in the Sacramento watershed above the City of Sacramento and in the Delta (personal communication, Jeanette

Howard). It is not known whether the mussel is in the lower Sacramento River near the SRWTP. However, *Anadonata* disperses by a larval glochidia stage which attaches to passing fish. So, it is possible that *Anadonata* is present in the lower River since it is present both above and below the SRWTP. If so, then the new draft ammonia criteria for protection of mussels may apply.

A site-specific chronic mussel criterion was calculated for each field sample using the formula in U.S. EPA (2009) and compared against ambient ammonia levels in the Delta. Ambient concentrations never exceeded the criterion (Table 8). A safety factor was calculated, like for juvenile fish, by dividing ambient ammonia concentrations by the estimated site specific chronic mussel criteria (Figure 9). The margin of safety for the Sacramento River above the SRWTP (Tower Bridge and at Garcia Bend) was the highest observed in the system and decreased to its lowest level at Hood. Many of the calculated monthly safety factor values for Hood were between one and two indicating a very small margin of safety[9]. Values increased downstream of Hood. The average safety factor for Rio Vista was about six.

Delta Smelt A hypothesis at the beginning of the study was that ammonia from the SRWTP was causing acute toxicity to delta smelt. The State Water Resources Control Board directed staff to execute contracts to evaluate this hypothesis. The 96-hour LC_{50} concentration for larval and juvenile smelt ranged between >0.116 and 0.557 mg N/l un-ionized ammonia in 4 sets of tests with different aged fish (Werner *et al*., 2008; 2009). The 7-day no observed effect concentration (NOEC) for survival was 0.091 mg N/l un-ionized ammonia[10]. In comparison, the highest un-ionized ammonia levels in the Delta were measured below the discharge of the SRWTP at Hood (Figure 10). The mean and 95 percent confidence limits of un-ionized ammonia at Hood were 0.0036±0.0012 mg N/l. The upper 95 percent confidence limit of these values was 19-times lower than the 7-day NOEC suggesting that ambient ammonia levels in the Delta are not causing acute delta smelt toxicity. Werner *et al* (2008, 2009) also concluded that ammonia concentrations in the Delta were not acutely toxic to smelt.

Total and un-ionized ammonia were measured at multiple places in the Delta between 2006 and 2008, including three sites near stations used in this study (as cited in Werner *et al*., 2009). The three common locations were Hood, Rio Vista, and the Deepwater Ship Channel. Ammonia concentrations were similar at all three locations in both studies but pH values were occasionally higher in summer in the Werner study (up to pH=8.3). This resulted in un-ionized ammonia concentrations as high as 0.02 mg N/l or about 4-times greater than the highest value measured in this study. CDEC reports hourly pH measurements for both Hood and Rio Vista. This information was reviewed for our twelve-month study period to determine how common pH values were above 8.0. CDEC reported one 14-hour excursion above a pH of 8.0 at Hood (3 February 2010) and a similar 11-hour event at Rio Vista (5 May 2009). Therefore, pH measurements above 8.0

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[9] Other agencies have collected monitoring data for the river reach between the SRWTP discharge and Hood. Exceedances of the draft US EPA ammonia criteria to protect mussels have been reported for this reach of the river (State Water Contractors letter of 14 June 2010).

[10] The 95 % confidence limits were 0.087 to 0.177 mg N/l.

do occur at sites with high ammonia near the SRWTP but are rare. These conclusions are consistent with the analysis of Engle and Lau (2009, 2010). The authors compiled data for 48 sites in the Bay-Delta between 2000 and 2010. Only on 4 instances were un-ionized ammonia concentrations greater than 0.02 mg N/l in the ten year record.

There is currently no method for assessing chronic delta smelt toxicity. In such instances, acute to chronic ratios (ACRs) for other freshwater fish species are often used to predict potential chronic toxicological endpoints. ACRs are calculated by dividing the 96-hour LC_{50} by the lowest available EC20 concentration. The U.S. EPA (1999) has reported ACR ammonia ratios for six species. The ACR values ranged between 2 and 21. The lowest reported 96-hour LC_{50} for smelt was >0.116 mg N/l un-ionized ammonia (Werner *et al*., 2009). Dividing 0.116 by 21 results in an estimated chronic NOEC for smelt of 0.0055 mg N/l un-ionized ammonia. None of the upper 95 percent confidence limits of un-ionized ammonia in the Delta exceeded 0.0055 mg N/l suggesting that chronic smelt toxicity is unlikely to have occurred during our study (Figure 10). This conclusion is different than that of Werner *et al*. (2008, 2009). Werner *et al*. concluded that chronic smelt toxicity was possible because of the higher pH values measured in summer in their study. In the future it may be possible, assuming that ammonia concentrations from the SRWTP remain constant, to assess whether chronic smelt toxicity is possible by monitoring CDEC pH values for Hood and Rio Vista. Repeated excursions above a pH value of 8.0 would indicate the potential for chronic smelt toxicity. Concurrent measurements of ambient ammonia, pH and temperature would be necessary to determine whether toxicity might be occurring.

In conclusion, un-ionized ammonia concentrations were too low in this study to cause either acute or chronic toxicity to delta smelt at all the sites monitored in the Delta[11]. However, the potential for chronic effects exist if prolonged pH excursions above 8.0 are observed in the Sacramento River between Hood and Rio Vista.

Algal Impairments A second objective of this study was to compare *in situ* nutrient concentrations in the Delta, particularly ammonia, against concentrations reported to impair algal growth or alter phytoplankton species composition. Dugdale *et al* (2007) demonstrated that ammonia concentrations greater than about 0.056 mg N/l inhibited nitrate uptake by diatoms in Suisun Bay. Ammonia induced suppression of nitrate uptake prevented spring algal blooms from developing (Wilkerson *et al*. 2006). Ammonia concentrations in the Sacramento River below the SRWTP are higher than in Suisun Bay. This led to the hypothesis that ammonia from the SRWTP might inhibit nitrate uptake and reduce primary production in the Sacramento River and downstream Delta.

The effect of ammonia on algal performance in the Sacramento River is more ambiguous than in Suisun Bay (Parker *et al*. 2010). Three different types of experiments were conducted. First, four 5-day cubitaner grow out experiments were performed with water collected above and below the SRWTP. The results suggest that algal production in a five

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[11] Our first monitoring site (Hood) is located 8 miles below the SRWTP discharge. Exceedances of the calculated chronic un ionized safe ammonia value for smelt have been reported for the river reach above Hood (State Water Contractor letter of 14 June, 2010).

day test is nitrogen limited in the Sacramento River above the SRWTP once the effect of light limitation is removed. Higher algal biomass was observed in water collected below the SRWTP than above it in three of the four grow-out experiments. Second, primary production was estimated above and below the SRWTP. Twenty-four hour ^{13}C stable isotope incubations were made with water collected at seven locations (three above and four below the SRWTP) on four cruises to determine primary production rates. Primary production rates declined down the river but were constant above and below the SRWTP when normalized by the amount of chlorophyll in the bottles. Finally, on one occasion effluent was amended into upstream Sacramento River water collected at Garcia Bend and primary production measured. Decreases in primary production were observed at environmentally realistic effluent concentrations.

In contrast, ammonium concentrations from the SRWTP did change *in situ* nitrate utilization by river algae (Parker *et al*. 2010). Both ammonium and nitrate uptake rates were measured above and below the SRWTP with 24-hour ^{15}N incubations. On all four cruises nitrate uptake decreased below the SRWTP. In other experiments, the amendment of an increasing amount of ammonium into upstream Garcia Bend water shutdown nitrate uptake at ammonium concentrations above 0.015 mg N/l. This result is consistent with observations from Suisun Bay where similar ammonium concentrations inhibited nitrate uptake by the diatom-dominated community (Dugdale *et al*., 2007).

Ammonium uptake was measured on three of the river cruises. No consistent pattern in ammonium uptake was observed above and below the SRWTP. However, there was a trend for the sum of nitrogen uptake (NO_3+NH_4) to decline downriver. Nitrogen uptake rates at Rio Vista were 30 to 60 percent less than at Hood. The decline in both nitrate and total nitrogen uptake down the Sacramento River was accompanied by a decline in primary production. However, as noted previously, the decline in primary production is most parsimoniously explained by a decline in chlorophyll concentration down the river.

Dugdale *et al* (2007) hypothesize that larger algal cells (diatoms) are favored and grow faster in the nitrate-dominated river above the SRWTP while smaller phytoplankton species (flagellates and bluegreen) are competitively superior and grow faster at the higher ammonia levels present below the SRWTP. A higher growth rate should cause the smaller sized cells to gradually replace the diatom-dominated community. Change in nitrogen utilization from nitrate above the SRWTP to ammonia below it may provide indirect support for this hypothesis. However, water samples were collected on each cruise and size fractionated (greater and smaller than 5-µm) to test this hypothesis. Cells greater than 5-µ were assumed to be diatoms. No consistent change in cell size was noted from above to below the SRWTP (Parker *et al*., 2010). Most of the phytoplankton were larger than 5-µm.

Size fractionation of algal cells above and below the SRWTP may not be a robust test of the Dugdale hypothesis. On average, 60 percent of the chlorophyll was lost between Tower Bridge and Isleton (Figure 4A). About a third of this loss occurred above the SRWTP and likely had nothing to do with the shift in nitrogen utilization. Loss of algal cells down the Sacramento River from some other process may obscure a shift in phytoplankton species composition caused by differential growth on a new nitrogen source.

The SRWTP has transformed the downstream Delta from a nitrate to an ammonia dominated system (Figure 11). The solid horizontal line in Figure 11 marks the ammonia concentration where the local phytoplankton community shifts from preferentially taking up nitrate to becoming ammonium centric. The shift has been documented for both the Sacramento River and for Suisun Bay (Parker *et al*., 2010; Dugdale *et al*., 2007). All sampling locations downstream of the SRWTP, except some sites in the Cache Slough complex and the San Joaquin River at Vernalis, had average annual ammonia concentrations greater than 0.014 mg N/l (Table 6). This represents 15 of 21 sites sampled in the Delta and includes all locations dominated by Sacramento River water (Table 8). At many locations the lower 95 percent confidence limit of the ammonia concentration does not include the 0.014 mg N/l ammonia cut-off value. This is significant because it indicates that at these locations the algal community never experienced a nitrate dominated system during our study as regularly occurred on the Sacramento River upstream of the SRWTP. The upper dashed line is the ammonia concentration that inhibited primary production in Suisun Bay (Dugdale *et al*., 2007). The impact of elevated ammonia concentrations on the algal community downstream of Rio Vista is not known. Lehman (1998; 2000a; 2000b) and Brown (2010) have documented that the algal community in the Delta has changed over the last several decades from diatoms to a flagellate/blue-green algal dominated community as predicted by Dugdale *et al* (2007) for an ammonia rich system. Changes in nitrogen utilization and nitrogen to phosphorus ratios have been observed to change phytoplankton species composition elsewhere (Anderson *et al*., 2002; Sommer, 1993). Diatoms are assumed to be more nutritious to primary consumers like zooplankton than flagellates and bluegreen algae. Changes in algal food availability and its quality or “bottom up” effects is one of the four factors hypothesized to contribute to the POD (Sommer *et al*. 2007) Follow up studies are needed to determine the ecological effect of the change in nutrient concentrations by the SRWTP on phytoplankton community composition in the Delta.

Recommendations for future study. Two recommendations are made for follow up study.

- First, conduct experiments in the Sacramento River above the City of Rio Vista to determine the primary processes responsible for the production and loss of phytoplankton. The studies should also include the River above Tower Bridge.
- Second, conduct experiments in the Sacramento River below the City of Rio Vista to determine the effect of ammonia and other nutrients on primary production rates and algal species composition.

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Table 1. Nutrient sampling locations in the Delta

Location	Site Number	Latitude	Longitude
Sac R @ Tower bridge	1	38.58048	121.50843
Sac R @ Garcia Bend	2	38.47791	121.54431
Sac R @ Hood	3	38.37796	121.52451
Sac R. @ Walnut Grove	5	38.24324	121.51363
Sac R. @ Isleton	6	38.16294	121.60992
Sac R @ Rio Vista	7	38.15745	121.68468
Deep Water Ship Channel @ Cache Sl	8	38.23693	121.67274
Lower flooded Liberty Island	9	38.25601	121.68089
Lindsey Slough	10	38.25798	121.72604
Toe Drain @ Dredger Cut	11	38.35333	121.64323
Mokelumne R @ Georgiana Sl	12	38.12587	121.57983
Three Mile Sl @ Sac R	13	38.10584	121.70021
Sac R @ Point Sacramento	14	38.06194	121.85715
Sac R off Chipps Island	15	38.04633	121.91894
San Joaquin R off Antioch	16	38.01901	121.80289
San Joaquin R @ Turner Cut	17	37.99190	121.40777
Middle R off Bacon Island	18	37.95636	121.52796
Bethany Reservoir	19	37.78398	121.62151
DMC off HWY 4	20	37.81239	121.57887
San Joaquin R @ Vernalis	21	37.67507	121.26692
San Joaquin R @ Jersey Point	24	38.05299	121.69033

Table 2. Water quality parameters and their associated method detection limit (MDL) measured in the nutrient monitoring study.

Constituent	**MDL**	**Responsible party**
Total Nitrogen	0.01 mg/l	UC Davis
Total Dissolved Nitrogen	0.01 mg/l	UC Davis
Ammonia	0.005 mg N/l	UC Davis
Nitrite	0.01 mg N/l	UC Davis
Nitrate	0.01 mg N/l	UC Davis
Dissolved Organic nitrogen	0.01 mg/l	UC Davis
Total Phosphorus	0.005 mg/l	UC Davis
Total dissolved Phosphorus	0.005 mg/l	UC Davis
Soluble Reactive Phosphorus	0.002 mg P/l	UC Davis
Dissolved Organic Carbon	0.1 mg/l	UC Davis
Chlorophyll a	0.5 ug/l	UC Davis
Phaeophytin	0.5 ug/l	UC Davis
EC (25^{0}C)	1 s/cm	Regional Board
Temperature	0.1 ^{0}C	Regional Board
Turbidity	0.1 ntu	Regional Board
Dissolved Oxygen	0.1 mg/l	Regional Board
pH	0.1 pH units	Regional Board

Table 3 Summary of Quality Assurance/Quality Control results for analysis performed at the Dahlgren Laboratory at U.C. Davis.

		TN mg/l	TDN mg/l	NH4-N mg/l	NO_3+NO_2-N mg/l	NO_2-N mg/l	TP mg/l	TDP mg/l	PO_4-P mg/l	DOC mg/l	Chl-a µg/l	Pheophytin µg/l
	MDL	0.01	0.01	0.005	0.01	0.01	0.005	0.005	0.005	0.1	0.5	0.5
Travel Blanks	fraction exceed MDL	3/16	2/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16
	n	16	16	16	16	16	16	16	16	16	16	16
Spike/recovery	Mean % Recovery	99.8	100.1	101.3	100.9	101.6	100.2	100.4	99.3			
	n	36	37	41	43	5	26	19	17			
Lab replicate	Mean % RPD[1/]	0.9	1.1	2.4	1.0	1.3	1.6	1.3	0.7	1.3	12.7	30.7
	N	98	96	99	116	63	81	73	77	61	21	21
Field duplicate	Mean % RPD	6.5	7.7	8.9	4.5	8.2	5.2	4.6	2.1	5.6	16.6	24.0
	N	16	16	16	16	16	16	16	16	16	16	16
Standard Reference Material	Mean % Recovery	99.6	99.8	100.4	99.1	103.0	97.9	97.9	97.4	101.9		
	N	26	22	21	29	5	28	28	19	5		

[1/] Relative percent difference

Table 4. Inter-laboratory comparison of the analytical results of duplicate field samples collected on the Sacramento River above (Garcia Bend) and below (Hood) the Sacramento Regional Wastewater Treatment Plant. Analysis was performed by a certified local commercial laboratory, California Laboratory Services (CLS), and by the Dahlgren Laboratory at the U.C.Davis (UCD).

Date	**Site**	**Lab**	**NH_3 (mg N/l)**	**NO_3 (mgN/l)**	**$N0_2$ (mgN/l)**	**$P0_4$ (mgP/l)**	**DOC (mg/l)**	**TKN[1/] (mg/L)**
5/11/2009	Sacramento R. @ Garcia Bend	CLS	<0.10	0.15	<0.10	<0.15	0.8	0.29
5/11/2009	Sacramento R. @ Garcia Bend	UCD	0.01	0.13	<0.01	0.02	1.9	0.20
5/11/2009	Sacramento R. @ Hood	CLS	<0.10	0.16	<0.10	<0.15	<0.5	0.33
5/11/2009	Sacramento R. @ Hood	UCD	0.28	0.14	<0.01	0.04	2.1	0.60
6/22/2009	Sacramento R. @ Garcia Bend	CLS	0.14	0.12	<0.10	<0.15	2.3	0.21
6/22/2009	Sacramento R. @ Garcia Bend	UCD	0.03	0.08	<0.01	0.02	1.7	0.13
6/22/2009	Sacramento R. @ Hood	CLS	0.49	0.12	<0.10	0.19	1.9	0.70
6/22/2009	Sacramento R. @ Hood	UCD	0.59	0.07	<0.01	0.06	1.9	0.72
11/16/2009	Sacramento R. @ Garcia Bend	CLS	0.11	0.14	<0.10	<0.15	13.0	0.20
11/16/2009	Sacramento R. @ Garcia Bend	UCD	0.03	0.10	<0.01	0.04	2.3	0.41
11/16/2009	Sacramento R. @ Hood	CLS	0.48	0.16	<0.10	0.26	14.0	0.58
11/16/2009	Sacramento R. @ Hood	UCD	0.71	0.13	<0.01	0.08	2.5	1.32

[1/] CLS measured TKN directly by Standard Method 4500 while the UCD value was obtained by subtracting the nitrate and nitrite concentration from the total dissolved nitrogen value.

Table 5. Mean annual nutrient, pH and dissolved oxygen concentrations in the Sacramento River above (Garcia Bend) and below (Hood) the Sacramento Regional Wastewater Treatment Plant between March 2009 and February 2010. Nutrient concentrations, pH and dissolved oxygen (DO) levels between sites were compared with a two tailed paired t-test.

Site	Site #	TN mg/l	TDN mg/l	DON mg/l	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l	TP mg/l	TDP mg/l	PO_4-P mg/l	DO mg/l	pH
Sac R @ Garcia Bend	2	0.41	0.32	0.16	0.04	0.002	0.11	0.08	0.03	0.03	8.8	7.7
Sac R @ Hood	3	0.88	0.82	0.23	0.46	0.004	0.13	0.11	0.07	0.06	8.5	7.4
Sample size		16	16	16	16	16	16	16	16	16	13	16
Increase		2.2X	2.6X	1.4X	11.5X	2X	1.2X	1.4X	2.3X	2X		
P-value		10^{-6}	10^{-7}	NS	10^{-6}	10^{-7}	0.001	10^{-6}	10^{-6}	10^{-6}	0.02	10^{-7}

Table 6. Mean annual nutrient and pH concentrations measured in the Delta between March 2009 and February 2010.

Site	Site #	TN mg/l	TDN mg/l	DON mg/l	NH_4-N mg/l	NO_2-N mg/l	NO_3-N mg/l	TP mg/l	TDP mg/l	PO_4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l	pH
Sac R @ Tower bridge	1	0.39	0.30	0.16	0.02	0.00	0.11	0.08	0.03	0.02	2.18	3.08	1.88	7.7
Sac R @ Garcia Bend	2	0.41	0.32	0.16	0.04	0.00	0.11	0.08	0.03	0.03	2.08	2.48	1.58	7.7
Sac R @ Hood	3	0.88	0.82	0.23	0.46	0.00	0.13	0.11	0.07	0.06	2.21	1.75	1.36	7.4
Sac R. @ Walnut Grove	5	0.80	0.69	0.22	0.32	0.01	0.14	0.10	0.06	0.05	2.19	1.38	1.26	7.5
Sac R. @ Isleton	6	0.87	0.76	0.26	0.31	0.01	0.19	0.11	0.06	0.06	2.25	1.25	1.13	7.5
Sac R @ Rio Vista	7	0.83	0.72	0.21	0.19	0.02	0.30	0.13	0.07	0.06	2.51	1.50	1.33	7.5
Deep Water Ship Channel	8	0.83	0.76	0.26	0.15	0.02	0.33	0.15	0.08	0.08	2.77	2.14	1.37	7.7
Liberty Island	9	0.95	0.83	0.30	0.12	0.02	0.39	0.18	0.09	0.09	3.16	3.68	2.13	7.9
Lindsey Slough	10	0.91	0.78	0.37	0.05	0.02	0.34	0.22	0.13	0.12	4.68	8.85	3.95	7.9
Toe Drain	11	1.21	1.06	0.46	0.06	0.01	0.54	0.39	0.19	0.18	4.64	10.2	5.86	8.0
Mokelumne R	12	0.79	0.72	0.23	0.24	0.02	0.23	0.10	0.06	0.06	2.51	1.04	1.17	7.5
Three Mile Sl	13	0.77	0.69	0.21	0.08	0.01	0.38	0.12	0.06	0.06	2.95	2.33	1.33	7.8
Point Sacramento	14	0.95	0.77	0.28	0.08	0.01	0.39	0.14	0.07	0.07	2.86	2.40	1.62	7.8
Chipps Island	15	0.80	0.71	0.19	0.10	0.01	0.37	0.14	0.07	0.07	2.72	1.75	1.50	7.9
Antioch	16	1.00	0.84	0.29	0.08	0.01	0.46	0.13	0.07	0.07	3.10	3.56	2.68	7.8
Turner Cut	17	1.92	1.84	0.42	0.06	0.02	1.35	0.12	0.10	0.09	4.65	2.57	1.38	7.6
Middle R off Bacon Island	18	0.97	0.89	0.27	0.04	0.01	0.57	0.09	0.07	0.06	4.18	1.79	1.01	7.9
Bethany Reservoir	19	1.04	0.94	0.36	0.06	0.01	0.45	0.12	0.09	0.08	4.41	2.07	2.09	8.0
DMC off HWY 4	20	1.36	1.15	0.35	0.05	0.01	0.74	0.15	0.10	0.09	4.19	4.94	3.41	7.8
Vernalis	21	1.62	1.33	0.25	0.03	0.02	1.04	0.17	0.08	0.07	3.59	34.5	5.15	8.2
Jersey Point	24	0.72	0.65	0.19	0.08	0.01	0.36	0.10	0.06	0.06	2.74	2.72	1.23	7.8

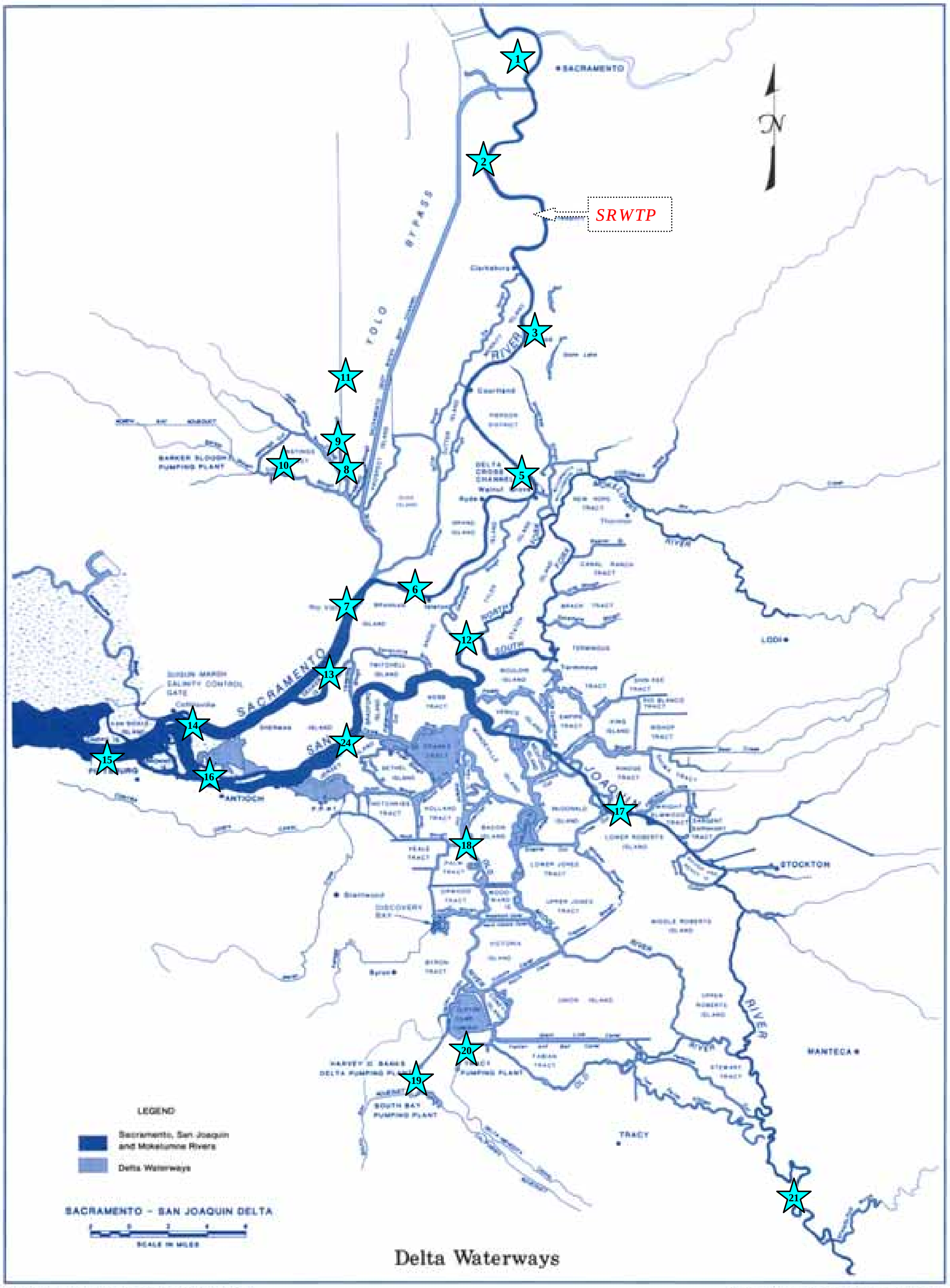
Table 7. Comparison of water quality measurements made by this study and by the California Data Exchange Center. Values from the Center were for the hour closest to when our field measurements were made.

Nutrient Monitoring Study Site	Data Exchange Center Station and Identification code	Statistic	pH	Temp (C)	EC (uS/cm3)	DO (mg/l)	Turbidity (NTU)	Chl (µg/l)
Sac R. @ Hood	Sac R. @ Hood	average difference	0.1	0.2		0.6		3.1
(Site # 3)	(SRH)	average RPD[2/]			4%		37%	63%
		Bias[3/]	no	no	no	no	no	no
		N	16	16	16	13	14	14
Sac R. @ Rio Vista	Sac R. @ Rio Vista	average difference	0.1	0.2		0.6		7.3
(Site #7)	(RVB)	average RPD			6%		25%	73%
		bias	no	no	DWR↑	DWR↑	no	no
		N	17	17		14	15	15
Sac R @ Chipps Is	Sac R @ Mallard Is	average difference	0.1	0.4		0.4		3.0
(Site # 15)	(MAL)	average RPD			21%		29%	69%
		bias	no	no	no	no	no	no
		n	16	16	16	13	16	16
SJR off Antioch	SJR @ Antioch	average difference	0.1	0.4		0.7		2.4
(Site #16)	(ANH)	average RPD			14%		20%	54%
		bias	no	no	no	no	no	no
		N	16	16	16	13	16	14

[1/] No dissolved oxygen or chlorophyll a instrumentation at the Harvey Banks Pumping Plant
[2/] Relative percent difference
[3/] Bias is when one instrument reads higher than the other in more than 75 percent of the measurements.

Table 8. Comparison of ambient ammonia concentrations in the Delta with reported potential toxicological endpoints (see text for details).

Toxicological Endpoint	**Sample size**	**Exceedance Rate**	**Comment**
U.S. EPA 1999 chronic criterion for early life stage of fish present	334	0/334	No evidence of juvenile fish toxicity
U.S. EPA 2009 chronic criterion for mussels present	334	0/334	No evidence of mussel toxicity
Seven-day NOEC for delta smelt survival	334	0/334	No evidence of acute smelt toxicity
Sampling locations with chronic delta smelt toxicity	21	0/21	No evidence of chronic smelt toxicity
Sampling locations where algal community would preferentially utilize ammonia over nitrate as a nitrogen source	21	15/21	May indicate a shift in algal species composition



Sacramento–San Joaquin Delta Atlas *Department of Water Resources*

Figure 1: Delta Nutrient Sample Sites

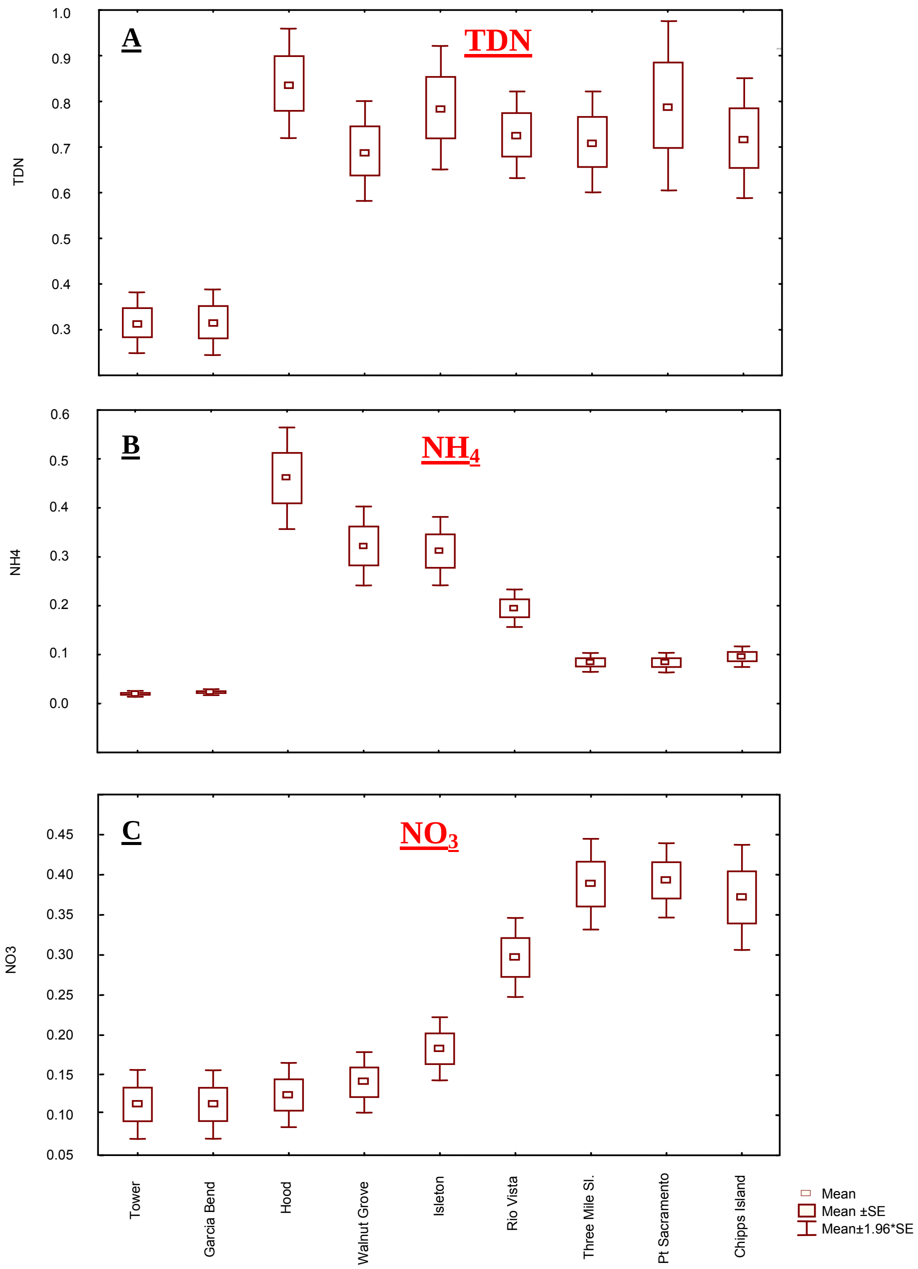


Figure 2. A. Mean annual total dissolved nitrogen (TDN) concentrations on the Sacramento River between Tower Bridge and Chipps Island. The SRWTP discharges between Garcia Bend and Hood. B and C Ammonia (NH_4) and nitrate (NO_3) concentrations over the same river reach. All nitrogen concentrations are as mg N/L

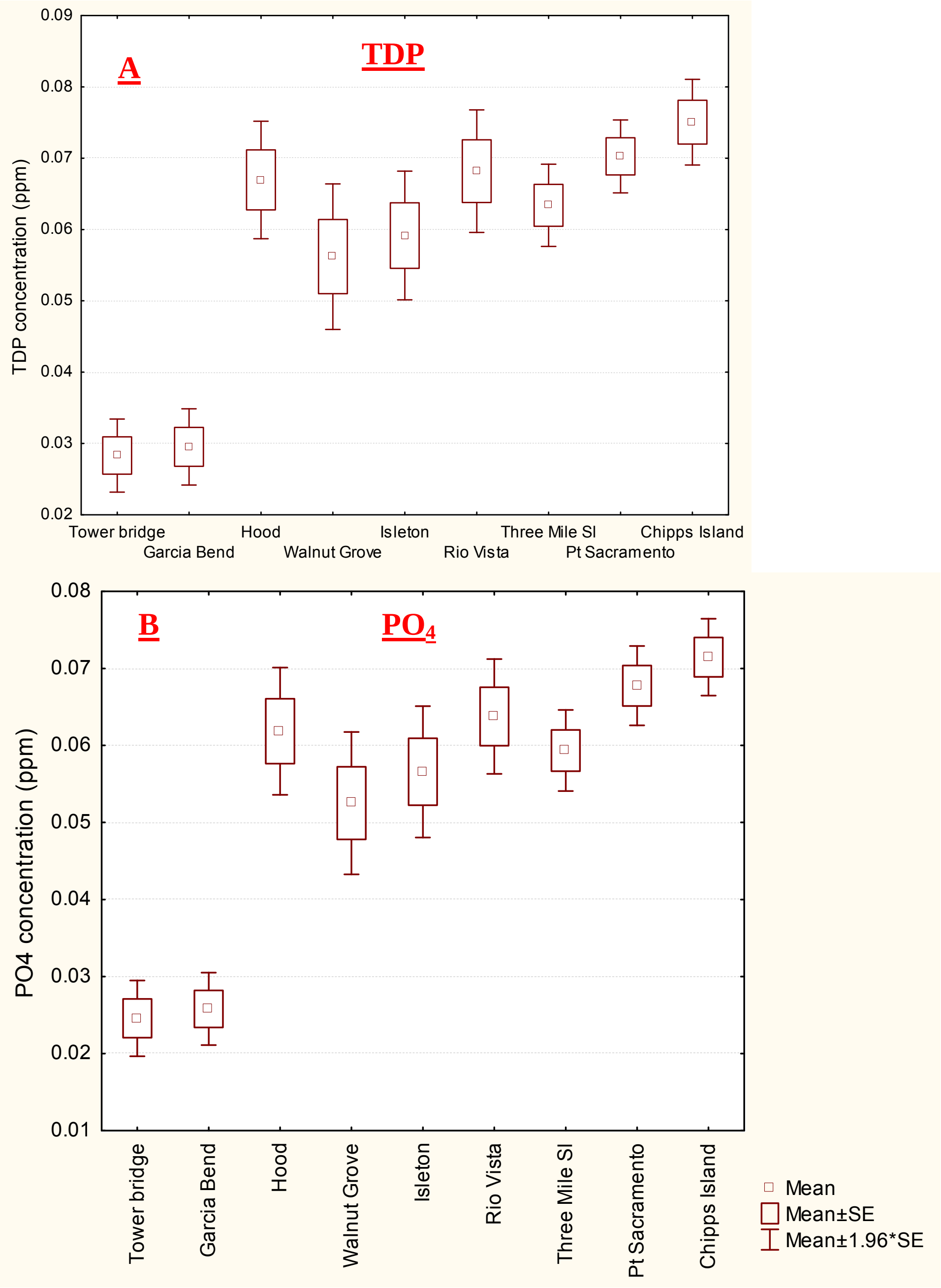


Figure 3A. Mean annual total dissolved phosphorus (TDP) in the Sacramento River and delta. B. Same values for soluble reactive phosphorus (PO_4).

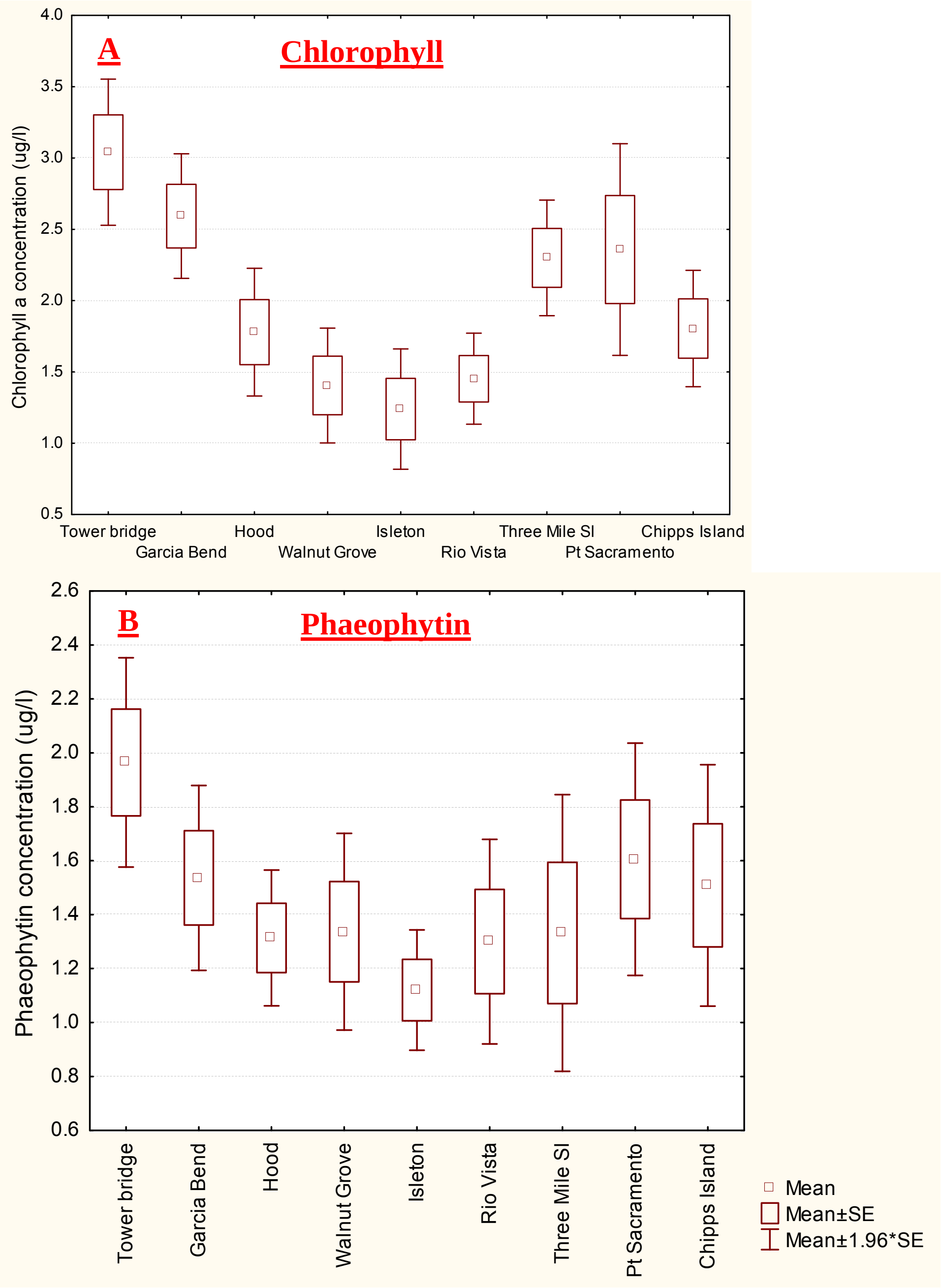


Figure 4A. Mean annual chlorophyll a concentrations in the lower Sacramento River and across the Delta to Chipps Island. B. Same values for phaeophytin.

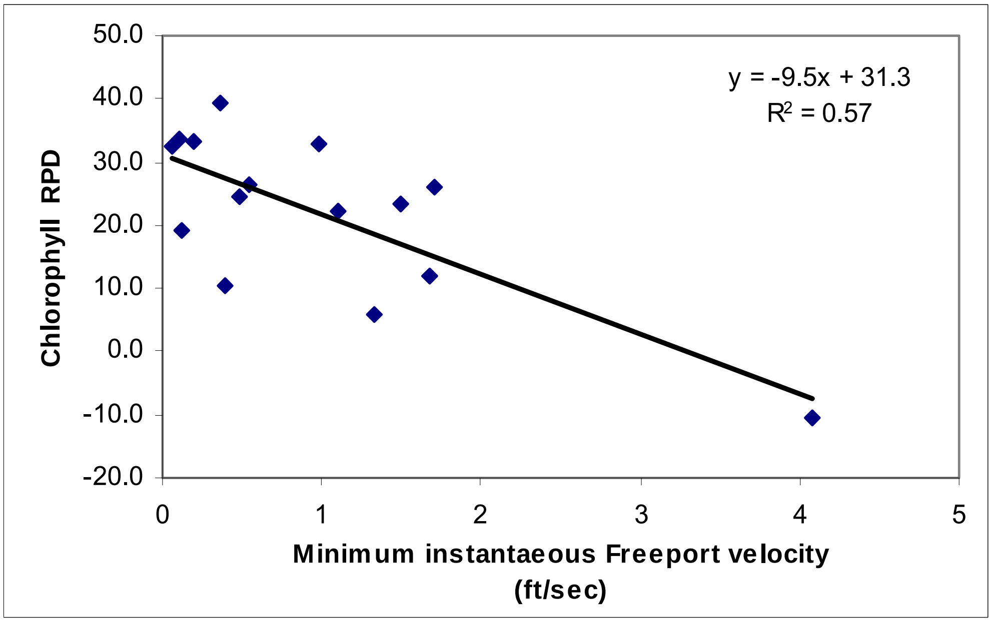


Figure 5. Correlation between the relative percent difference (RPD) in chlorophyll at Tower Bridge and Isleton and the instantaneous minimum velocity measured at Freeport for the two days preceding the sampling event. The correlation is still significant if the single high flow data point is removed.

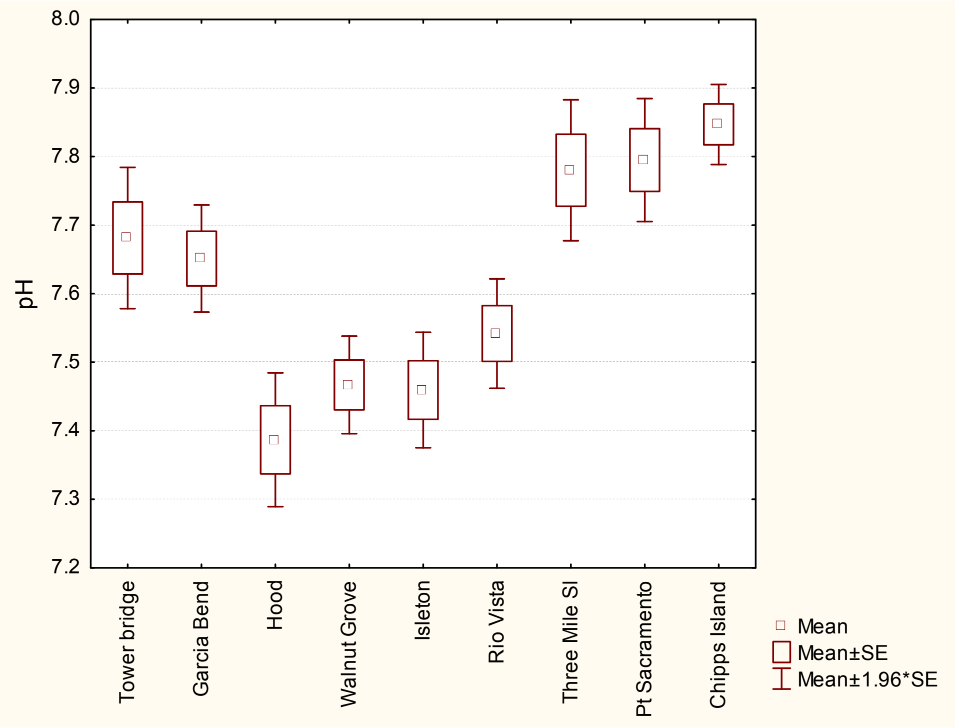


Figure 6. Average pH values down the Sacramento River and across the Delta to Chipps Island. The SRWTP discharges between Garcia Bend and Hood.

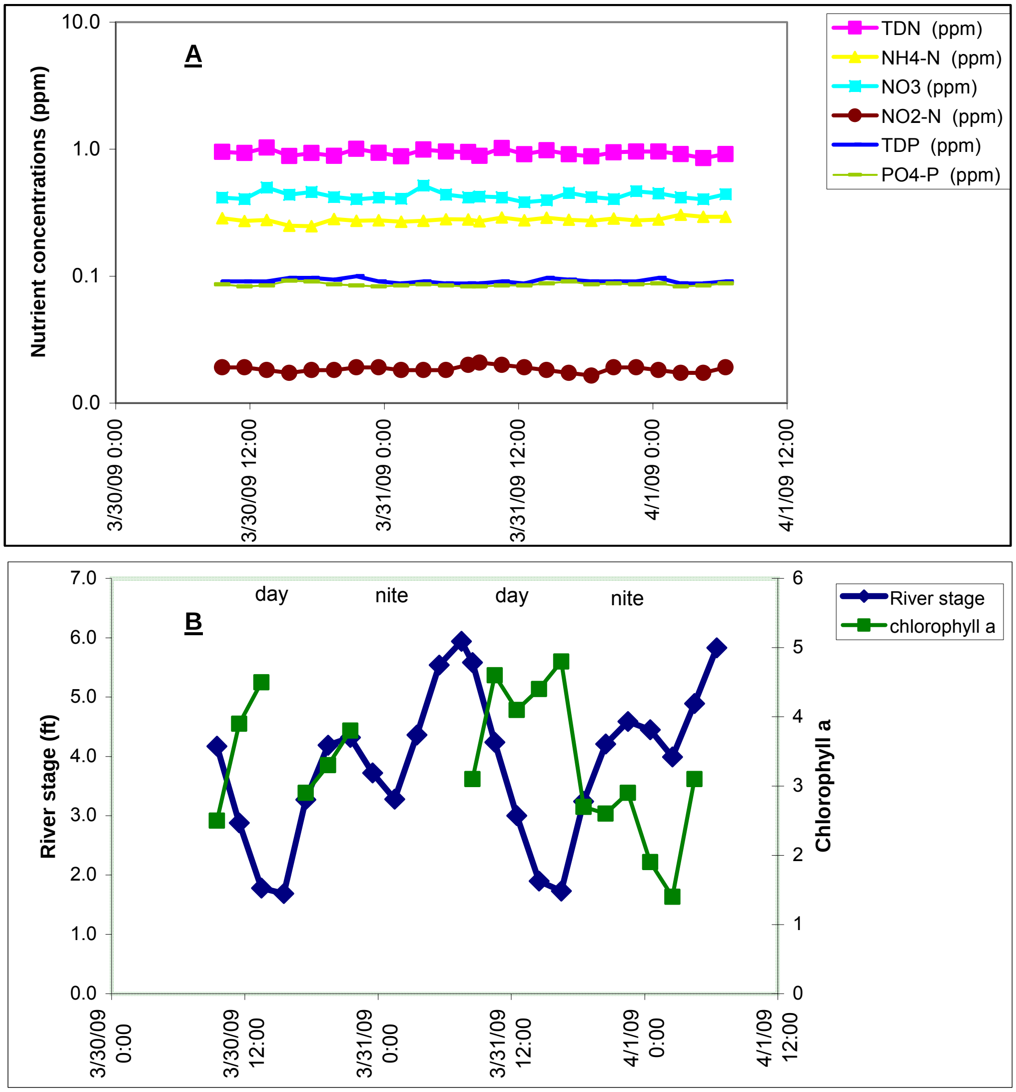


Figure 7. A.Dissolved nutrient concentrations in the Sacramento River at Rio Vista every two hours between 30 March and 1 April 2009. B Day/night, river stage and chlorophyll a concentrations for the same time period. These values are from the continuous DWR meters at Rio Vista. The data show no pattern between nutrient concentrations and either diurnal or river stage. There is an inverse relationship between river stage and chlorophyll a concentration. Actual data is in Table B1 of Appendix B.

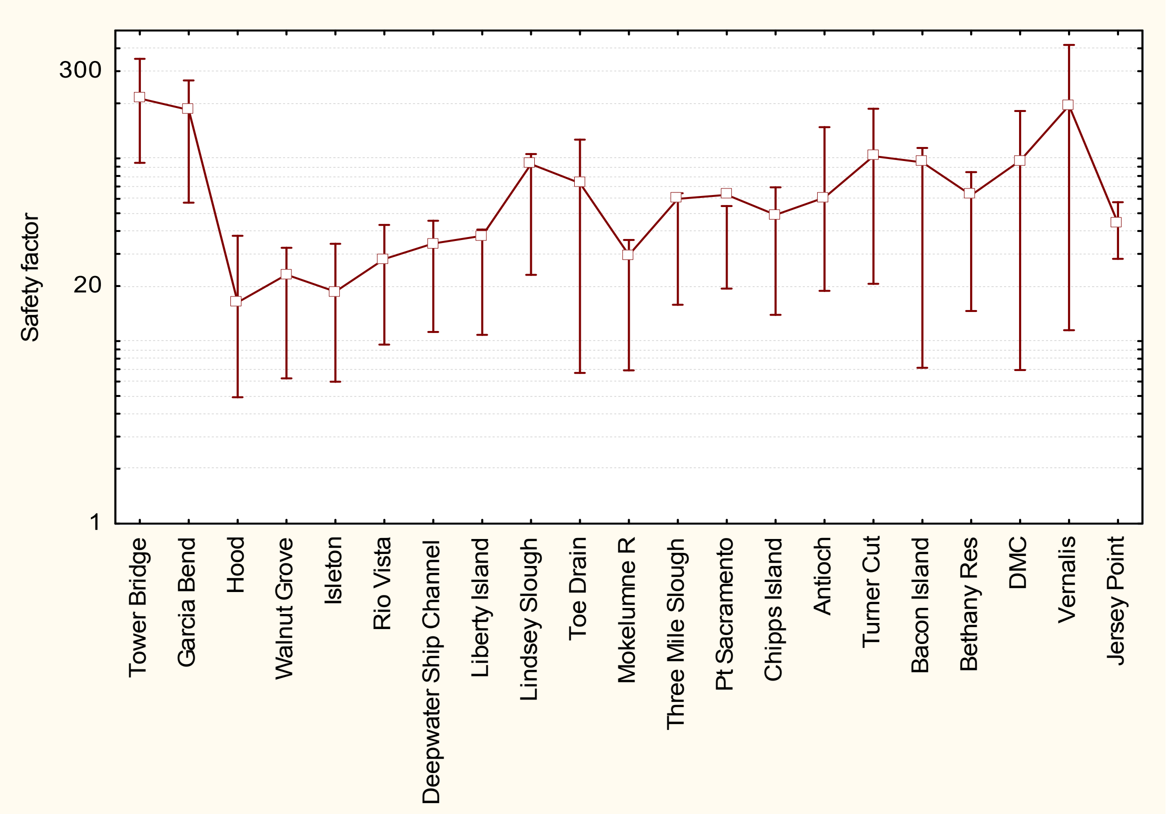


Figure 8. Mean and range of site-specific safety factors for the U.S. EPA (1999) chronic ammonia criterion for juvenile fish present in the Delta. The safety factor was calculated by dividing monthly ambient ammonia concentrations by the recommended criteria after adjusting for temperature and pH. A value greater than one is considered safe for juvenile fish. All safety factors were larger than one.

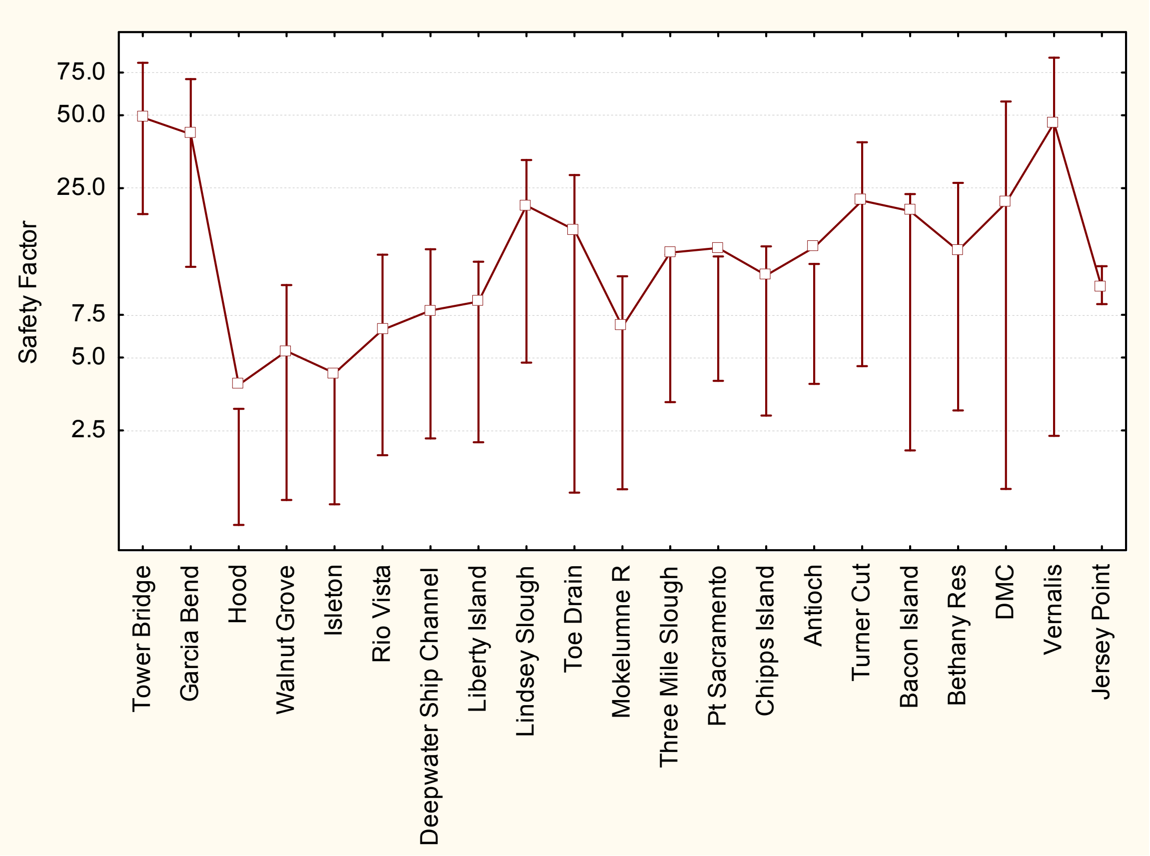


Figure 9. Mean and range of site-specific safety factors for the draft U.S. EPA (2009) chronic ammonia criterion for freshwater mussels present. The safety factor was calculated by dividing ambient ammonia concentrations by the recommended criteria after adjusting for pH and temperature. A value greater than one is considered safe for mussels. All safety factors were greater than one.

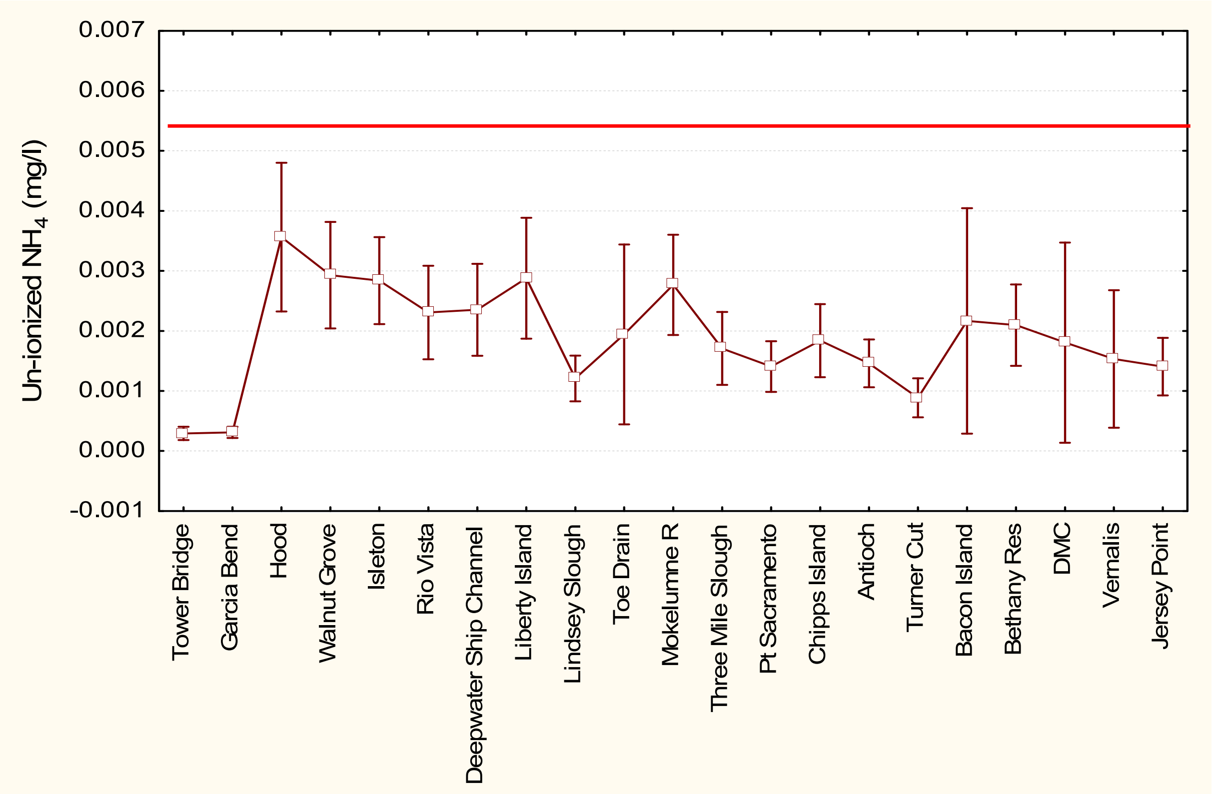


Figure 10. Mean and 95 percent confidence limits for un-ionized ammonia (mg N/l) in the Delta between March 2009 and February 2010. The SRWTP discharges to the river between Garcia Bend and Hood. The solid horizontal line marks the quotient of the lowest 96- hour ammonia LC_{50} concentration for smelt divided by the highest report ammonia ACR value in the literature (see text for details). The line represents a conservative estimate of the chronic no observed effect concentration for smelt.

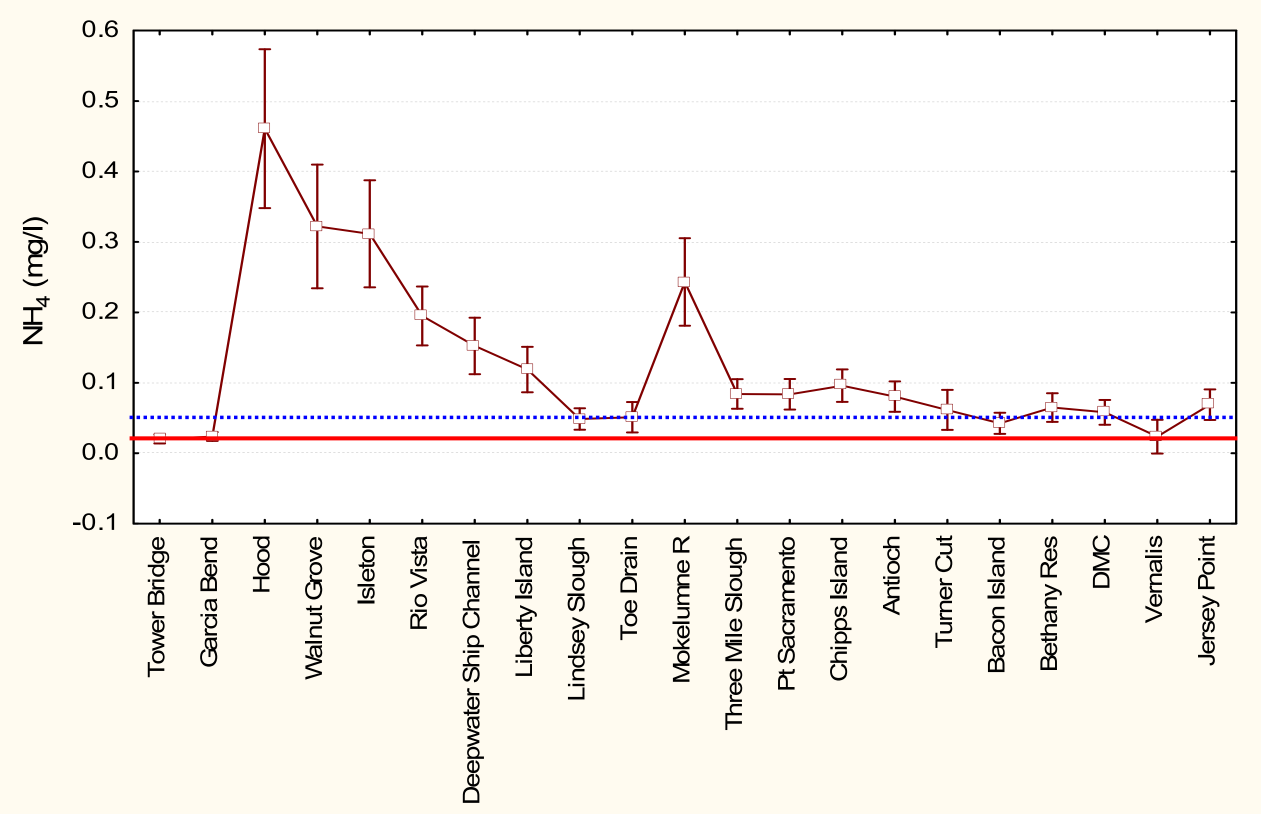


Figure 11. Mean and 95 percent confidence limits of ammonia concentrations in the Delta. The solid horizontal line marks the ammonia concentration (0.014 mg N/l) where algal communities in both the Sacramento River and Suisun Bay cease to take up nitrate and begin satisfying their nitrogen demand with only ammonia. The upper dashed line is the ammonia concentration that arrested diatom primary production in Suisun Bay. The ammonia concentration between the two lines may represent a range causing shifts in the phytoplankton community in the Delta.

APPENDIX A

NUTRIENT MONITORING DATA

Table 1A. Nutrient data for the Sacramento-San Joaquin Delta.

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH_4-N mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Sac R @ Tower bridge	1	3/16/09	0.63	0.20	0.49	0.00	0.29	0.00	0.118	0.036	0.034	2.54	2.44	1.02
Sac R @ Tower bridge	1	3/30/09	0.32	0.10	0.25	0.02	0.13	0.00	0.079	0.027	0.024	1.70	5.15	2.63
Sac R @ Tower bridge	1	4/13/09	0.21	0.09	0.18	0.01	0.08	0.00	0.059	0.019	0.019	1.44	4.78	2.69
Sac R @ Tower bridge	1	4/27/09	0.40	0.25	0.34	0.02	0.07	0.00	0.037	0.017	0.010	1.64	4.05	3.11
Sac R @ Tower bridge	1	5/11/09	0.39	0.22	0.37	0.02	0.13	0.00	0.043	0.019	0.019	2.00	3.46	2.40
Sac R @ Tower bridge	1	5/26/09	0.24	0.19	0.24	0.01	0.05	0.00	0.043	0.024	0.019	1.62	3.31	1.67
Sac R @ Tower bridge	1	6/8/09	0.89	0.24	0.33	0.02	0.07	0.00	0.078	0.029	0.023	2.81		
Sac R @ Tower bridge	1	6/22/09	0.19	0.12	0.20	0.02	0.05	0.00	0.048	0.025	0.013	1.82	3.68	1.30
Sac R @ Tower bridge	1	7/14/09	0.14	0.09	0.12	0.01	0.03	0.00	0.038	0.013	0.013	1.66	2.38	2.37
Sac R @ Tower bridge	1	8/3/09	0.12	0.06	0.10	0.03	0.01	0.00	0.038	0.014	0.012	1.40	1.99	2.13
Sac R @ Tower bridge	1	9/28/09	0.37	0.15	0.24	0.05	0.03	0.00	0.045	0.034	0.028	1.70	2.33	1.28
Sac R @ Tower bridge	1	10/20/09	0.34	0.10	0.30	0.02	0.17	0.00	0.044	0.032	0.032	1.84	1.91	2.54
Sac R @ Tower bridge	1	11/16/09	0.32	0.11	0.26	0.03	0.11	0.00	0.076	0.041	0.037	2.63	2.23	2.22
Sac R @ Tower bridge	1	12/7/09	0.41	0.18	0.30	0.02	0.11	0.00	0.059	0.034	0.030	2.30	2.22	2.32
Sac R @ Tower bridge	1	1/25/10	0.62	0.15	0.48	0.03	0.29	0.01	0.322	0.050	0.041	4.81	2.66	0.23
Sac R @ Tower bridge	1	2/22/10	0.67	0.32	0.60	0.03	0.25	0.01	0.134	0.038	0.039	2.9	3.0	1.6
Sac R @ Garcia Bend	2	3/16/09	0.52	0.11	0.39	0.00	0.28	0.00	0.088	0.042	0.037	2.13	2.37	0.82
Sac R @ Garcia Bend	2	3/30/09	0.32	0.14	0.29	0.02	0.13	0.00	0.057	0.030	0.027	1.61	2.94	1.72
Sac R @ Garcia Bend	2	4/13/09	0.25	0.09	0.19	0.02	0.08	0.00	0.050	0.020	0.019	1.45	2.58	2.09
Sac R @ Garcia Bend	2	4/27/09	0.64	0.22	0.31	0.03	0.06	0.00	0.049	0.012	0.012	1.54	2.21	3.08
Sac R @ Garcia Bend	2	5/11/09	0.36	0.19	0.33	0.01	0.13	0.00	0.056	0.021	0.021	1.93	2.58	1.47
Sac R @ Garcia Bend	2	5/26/09	0.19	0.07	0.13	0.01	0.05	0.00	0.045	0.027	0.027	1.58	3.31	1.36
Sac R @ Garcia Bend	2	6/8/09	0.42	0.25	0.32	0.02	0.05	0.00	0.051	0.029	0.022	2.54	3.68	2.55
Sac R @ Garcia Bend	2	6/22/09	0.23	0.10	0.21	0.03	0.08	0.00	0.050	0.029	0.018	1.65	2.58	1.78
Sac R @ Garcia Bend	2	7/14/09	0.20	0.06	0.10	0.01	0.03	0.00	0.057	0.015	0.013	1.65	2.78	1.98
Sac R @ Garcia Bend	2	8/3/09	0.12	0.06	0.10	0.03	0.01	0.00	0.035	0.014	0.014	1.46	3.18	1.24
Sac R @ Garcia Bend	2	9/28/09	0.36	0.15	0.23	0.05	0.04	0.00	0.047	0.030	0.022	1.58	3.57	1.52
Sac R @ Garcia Bend	2	10/20/09	0.30	0.05	0.26	0.02	0.18	0.00	0.049	0.044	0.037	1.78	0.74	1.43
Sac R @ Garcia Bend	2	11/16/09	0.52	0.38	0.51	0.03	0.10	0.00	0.049	0.037	0.035	2.33	0.79	1.63
Sac R @ Garcia Bend	2	12/7/09	0.35	0.21	0.35	0.02	0.11	0.00	0.053	0.034	0.031	2.27	1.70	0.97
Sac R @ Garcia Bend	2	1/25/10	0.78	0.18	0.53	0.04	0.30	0.01	0.359	0.044	0.039	4.75	2.86	0.65
Sac R @ Garcia Bend	2	2/22/10	0.63	0.30	0.58	0.04	0.23	0.00	0.113	0.044	0.039	3.1	3.6	0.3

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Sac R @ Hood	3	3/16/09	0.99	0.64	0.96	0.04	0.27	0.00	0.106	0.082	0.076	2.31	2.81	0.18
Sac R @ Hood	3	3/30/09	0.96	0.16	0.94	0.61	0.16	0.00	0.103	0.088	0.081	1.77	1.37	1.51
Sac R @ Hood	3	4/13/09	0.69	0.05	0.67	0.53	0.10	0.00	0.092	0.074	0.074	1.60	1.37	1.51
Sac R @ Hood	3	4/27/09	0.93	0.28	0.89	0.54	0.07	0.00	0.095	0.063	0.061	1.61	2.12	2.00
Sac R @ Hood	3	5/11/09	0.78	0.31	0.74	0.28	0.14	0.00	0.083	0.038	0.038	2.05	1.50	1.70
Sac R @ Hood	3	5/26/09	0.80	0.02	0.76	0.65	0.09	0.00	0.078	0.062	0.061	1.78	1.37	1.31
Sac R @ Hood	3	6/8/09	0.88	0.29	0.75	0.40	0.06	0.00	0.072	0.048	0.039	2.34	2.00	2.23
Sac R @ Hood	3	6/22/09	0.80	0.12	0.79	0.59	0.08	0.01	0.091	0.068	0.056	1.91	1.56	1.38
Sac R @ Hood	3	7/14/09	0.40	0.09	0.38	0.24	0.05	0.00	0.075	0.041	0.040	1.80	1.51	1.69
Sac R @ Hood	3	8/3/09	0.43	0.04	0.40	0.34	0.02	0.00	0.078	0.047	0.047	1.56	3.57	1.32
Sac R @ Hood	3	9/28/09	1.08	0.21	0.94	0.67	0.06	0.00	0.093	0.083	0.082	1.88	1.98	1.50
Sac R @ Hood	3	10/20/09	1.16	0.09	0.98	0.69	0.19	0.01	0.100	0.087	0.087	2.12	0.40	1.12
Sac R @ Hood	3	11/16/09	1.45	0.61	1.45	0.71	0.13	0.00	0.101	0.090	0.082	2.52	0.51	1.15
Sac R @ Hood	3	12/7/09	0.98	0.18	0.93	0.63	0.12	0.00	0.077	0.065	0.063	2.28	1.01	0.82
Sac R @ Hood	3	1/25/10	0.87	0.29	0.73	0.14	0.30	0.01	0.371	0.075	0.044	4.78	3.58	0.55
Sac R @ Hood	3	2/22/10	0.96	0.29	0.86	0.33	0.24	0.00	0.116	0.062	0.059	3.0	1.8	1.1
Sac R @ Walnut Grove	5	3/16/09	0.73	0.40	0.72	0.02	0.29	0.00	0.091	0.066	0.063	2.33	0.94	0.92
Sac R @ Walnut Grove	5	3/30/09	0.99	0.20	0.98	0.58	0.19	0.01	0.115	0.097	0.089	1.83	1.12	0.53
Sac R @ Walnut Grove	5	4/13/09	0.61	0.14	0.53	0.29	0.10	0.00	0.080	0.050	0.052	1.62	1.37	1.10
Sac R @ Walnut Grove	5	4/27/09	0.64	0.26	0.63	0.27	0.09	0.00	0.078	0.046	0.043	1.56	1.25	3.67
Sac R @ Walnut Grove	5	5/11/09	0.69	0.25	0.65	0.24	0.15	0.00	0.077	0.033	0.033	2.15	1.62	1.88
Sac R @ Walnut Grove	5	5/26/09	0.47	0.05	0.43	0.29	0.09	0.00	0.064	0.040	0.040	1.66	1.25	1.33
Sac R @ Walnut Grove	5	6/8/09	0.61	0.25	0.51	0.18	0.07	0.00	0.069	0.045	0.038	2.15	1.75	1.24
Sac R @ Walnut Grove	5	6/22/09	0.57	0.06	0.55	0.33	0.16	0.01	0.091	0.056	0.048	1.81	1.75	1.24
Sac R @ Walnut Grove	5	7/14/09	0.46	0.06	0.36	0.25	0.05	0.00	0.072	0.033	0.032	1.71	1.31	1.03
Sac R @ Walnut Grove	5	8/3/09	0.34	0.06	0.33	0.23	0.03	0.00	0.066	0.026	0.026	1.56	1.69	1.98
Sac R @ Walnut Grove	5	9/28/09	0.87	0.23	0.80	0.46	0.10	0.01	0.089	0.076	0.076	1.70	1.16	0.88
Sac R @ Walnut Grove	5	10/20/09	0.95	0.05	0.77	0.53	0.18	0.01	0.097	0.090	0.084	1.93	0.33	1.02
Sac R @ Walnut Grove	5	11/16/09	1.89	0.48	1.12	0.48	0.15	0.00	0.085	0.079	0.066	2.30	0.64	0.95
Sac R @ Walnut Grove	5	12/7/09	0.99	0.17	0.94	0.61	0.16	0.01	0.077	0.065	0.061	2.75	0.78	0.95
Sac R @ Walnut Grove	5	1/25/10	0.96	0.24	0.70	0.16	0.29	0.01	0.377	0.050	0.041	4.96	4.09	0.82
Sac R @ Walnut Grove	5	2/22/10	0.83	0.31	0.79	0.24	0.24	0.01	0.094	0.048	0.048	3.1	1.4	1.9

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Sac R @ Isleton	6	3/16/09	1.09	0.70	1.06	0.04	0.31	0.01	0.112	0.085	0.081	2.45	0.94	0.86
Sac R @ Isleton	6	3/30/09	0.74	0.17	0.70	0.29	0.22	0.01	0.097	0.069	0.065	1.78	0.62	0.82
Sac R @ Isleton	6	4/13/09	0.68	0.11	0.66	0.40	0.14	0.01	0.086	0.062	0.065	1.72	1.00	0.75
Sac R @ Isleton	6	4/27/09	0.62	0.16	0.56	0.29	0.11	0.01	0.069	0.040	0.040	1.56	1.25	1.02
Sac R @ Isleton	6	5/11/09	0.57	0.19	0.55	0.18	0.17	0.00	0.098	0.036	0.036	2.46	1.25	1.43
Sac R @ Isleton	6	5/26/09	0.56	0.06	0.49	0.29	0.13	0.01	0.086	0.045	0.043	1.61	1.12	1.56
Sac R @ Isleton	6	6/8/09	0.76	0.26	0.58	0.20	0.12	0.01	0.078	0.045	0.039	1.90	1.12	1.14
Sac R @ Isleton	6	6/22/09	0.86	0.12	0.77	0.40	0.23	0.02	0.117	0.076	0.063	1.92	1.62	1.16
Sac R @ Isleton	6	7/14/09	0.47	0.07	0.42	0.27	0.07	0.01	0.050	0.036	0.035	1.70	1.47	1.70
Sac R @ Isleton	6	8/3/09	0.40	0.05	0.38	0.26	0.06	0.01	0.072	0.044	0.042	1.62	1.57	2.21
Sac R @ Isleton	6	9/28/09	1.21	0.15	0.89	0.54	0.19	0.01	0.100	0.087	0.085	1.84	1.51	0.53
Sac R @ Isleton	6	10/20/09	1.14	0.10	0.91	0.51	0.28	0.02	0.090	0.079	0.079	2.26	0.38	0.95
Sac R @ Isleton	6	11/16/09	1.54	0.56	1.27	0.46	0.23	0.01	0.091	0.076	0.069	2.20	0.44	0.96
Sac R @ Isleton	6	12/7/09	0.96	0.19	0.90	0.48	0.22	0.01	0.083	0.066	0.066	2.30	0.47	0.67
Sac R @ Isleton	6	1/25/10	1.42	0.77	1.26	0.15	0.33	0.01	0.371	0.038	0.038	4.88	4.09	1.52
Sac R @ Isleton	6	2/22/10	1.03	0.46	0.95	0.22	0.26	0.01	0.094	0.063	0.059	3.1	1.0	0.7
Sac R @ Rio Vista	7	3/16/09	1.09	0.63	1.04	0.02	0.38	0.01	0.133	0.088	0.078	3.15	0.69	0.86
Sac R @ Rio Vista	7	3/30/09	0.97	0.27	0.97	0.30	0.38	0.02	0.167	0.089	0.085	2.50	1.25	1.33
Sac R @ Rio Vista	7	4/13/09	0.73	0.10	0.66	0.27	0.28	0.01	0.107	0.068	0.067	1.96	1.12	0.94
Sac R @ Rio Vista	7	4/27/09	1.22	0.19	0.79	0.32	0.25	0.02	0.133	0.067	0.061	1.80	1.37	1.31
Sac R @ Rio Vista	7	5/11/09	0.68	0.22	0.64	0.16	0.24	0.01	0.089	0.046	0.045	2.31	1.25	1.84
Sac R @ Rio Vista	7	5/26/09	0.57	0.06	0.53	0.18	0.27	0.02	0.106	0.075	0.058	1.85	1.87	1.39
Sac R @ Rio Vista	7	6/8/09	0.86	0.20	0.64	0.18	0.24	0.02	0.120	0.057	0.053	1.97	1.67	1.08
Sac R @ Rio Vista	7	6/22/09	0.70	0.11	0.66	0.19	0.33	0.03	0.125	0.071	0.063	2.01	2.63	1.16
Sac R @ Rio Vista	7	7/14/09	0.41	0.09	0.37	0.13	0.14	0.01	0.069	0.041	0.040	1.83	1.40	1.01
Sac R @ Rio Vista	7	8/3/09	0.35	0.06	0.33	0.13	0.12	0.01	0.087	0.041	0.041	1.69	1.45	1.37
Sac R @ Rio Vista	7	9/28/09	1.04	0.16	0.68	0.17	0.33	0.03	0.093	0.080	0.074	1.99	3.18	0.90
Sac R @ Rio Vista	7	10/20/09	0.77	-0.06	0.72	0.29	0.46	0.03	0.112	0.102	0.091	2.61	0.79	1.13
Sac R @ Rio Vista	7	11/16/09	0.74	0.07	0.74	0.24	0.41	0.02	0.091	0.069	0.068	2.21	0.84	0.84
Sac R @ Rio Vista	7	12/7/09	0.97	0.17	0.88	0.20	0.49	0.02	0.107	0.071	0.070	2.49	1.27	0.80
Sac R @ Rio Vista	7	1/25/10	1.22	0.41	0.91	0.12	0.38	0.01	0.347	0.050	0.050	5.20	1.34	4.03
Sac R @ Rio Vista	7	2/22/10	0.95	0.30	0.83	0.21	0.31	0.01	0.131	0.076	0.075	3.9	1.1	0.8

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Ship Channel	8	3/16/09	0.96	0.49	0.96	0.01	0.44	0.01	0.170	0.109	0.101	4.04	1.75	1.14
Ship Channel	8	3/30/09	0.95	0.24	0.93	0.17	0.51	0.02	0.223	0.106	0.104	3.15	2.54	2.44
Ship Channel	8	4/13/09	0.78	0.20	0.78	0.22	0.34	0.01	0.110	0.080	0.078	2.25	1.62	1.06
Ship Channel	8	4/27/09	0.97	0.27	0.83	0.23	0.32	0.02	0.141	0.078	0.073	2.22	2.25	1.57
Ship Channel	8	5/11/09	0.68	0.19	0.63	0.12	0.31	0.01	0.088	0.060	0.060	2.41	1.96	0.98
Ship Channel	8	5/26/09	0.61	0.09	0.54	0.12	0.32	0.02	0.154	0.073	0.069	1.99	3.33	1.14
Ship Channel	8	6/8/09	0.87	0.31	0.77	0.12	0.32	0.02	0.153	0.072	0.064	2.41	2.50	1.28
Ship Channel	8	6/22/09	0.65	0.12	0.58	0.06	0.37	0.03	0.145	0.082	0.071	2.19	3.89	1.50
Ship Channel	8	7/14/09	0.48	0.07	0.34	0.11	0.15	0.01	0.081	0.044	0.044	1.80	1.98	0.90
Ship Channel	8	8/3/09	0.36	0.07	0.33	0.07	0.18	0.01	0.120	0.054	0.053	1.92	2.67	1.64
Ship Channel	8	9/28/09	0.88	0.25	0.77	0.21	0.29	0.02	0.096	0.074	0.074	1.91	3.38	0.87
Ship Channel	8	10/20/09	0.83	0.08	0.73	0.19	0.43	0.02	0.116	0.090	0.090	2.59	1.38	0.90
Ship Channel	8	11/16/09	0.80	0.11	0.79	0.21	0.45	0.02	0.101	0.079	0.074	2.25	1.38	0.70
Ship Channel	8	12/7/09	1.02	0.16	0.89	0.31	0.40	0.02	0.104	0.077	0.072	2.47	0.80	0.87
Ship Channel	8	1/25/10	1.31	0.76	1.29	0.12	0.40	0.01	0.359	0.053	0.053	5.04	1.43	3.71
Ship Channel	8	2/22/10	0.98	0.40	0.90	0.17	0.32	0.01	0.166	0.094	0.093	4.6	1.9	1.2
Liberty Island	9	3/16/09	1.19	0.61	1.14	0.01	0.51	0.01	0.185	0.126	0.128	5.43	3.12	2.55
Liberty Island	9	3/30/09	2.25	0.26	1.14	0.14	0.72	0.02	0.390	0.129	0.126	3.75	5.89	7.39
Liberty Island	9	4/13/09	0.77	0.10	0.72	0.19	0.41	0.01	0.120	0.089	0.086	2.52	1.69	0.89
Liberty Island	9	4/27/09	0.93	0.35	0.90	0.19	0.34	0.02	0.143	0.086	0.078	2.35	2.32	1.07
Liberty Island	9	5/11/09	0.69	0.24	0.69	0.08	0.35	0.01	0.105	0.068	0.068	2.49	2.08	0.67
Liberty Island	9	5/26/09	0.59	0.08	0.55	0.11	0.34	0.02	0.134	0.075	0.072	2.06	2.71	0.73
Liberty Island	9	6/8/09	0.78	0.29	0.76	0.12	0.33	0.02	0.195	0.071	0.068	2.54	2.87	1.77
Liberty Island	9	6/22/09	0.70	0.12	0.57	0.05	0.38	0.02	0.169	0.076	0.066	2.22	5.31	0.45
Liberty Island	9	7/14/09	0.48	0.09	0.36	0.03	0.23	0.01	0.146	0.063	0.061	2.12	5.20	2.53
Liberty Island	9	8/3/09	0.36	0.07	0.30	0.06	0.17	0.01	0.156	0.054	0.054	1.88	8.44	1.33
Liberty Island	9	9/28/09	0.85	0.23	0.73	0.18	0.30	0.02	0.119	0.080	0.074	2.19	5.56	4.63
Liberty Island	9	10/20/09	0.80	0.09	0.72	0.13	0.48	0.02	0.138	0.108	0.102	2.88	2.12	1.55
Liberty Island	9	11/16/09	1.40	0.65	1.34	0.19	0.47	0.02	0.104	0.073	0.072	2.27	1.38	0.60
Liberty Island	9	12/7/09	0.97	0.19	0.90	0.19	0.50	0.02	0.107	0.078	0.078	2.59	1.32	0.60
Liberty Island	9	1/25/10	1.18	0.46	1.13	0.10	0.55	0.01	0.420	0.118	0.109	5.51	1.43	3.83
Liberty Island	9	2/22/10	1.08	0.52	1.01	0.11	0.37	0.01	0.222	0.140	0.129	5.7	1.3	1.2

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Lindsey Slough	10	3/16/09	1.53	1.14	1.50	0.00	0.34	0.01	0.393	0.278	0.273	10.33	1.77	1.76
Lindsey Slough	10	3/30/09	1.30	0.75	1.21	0.06	0.40	0.01	0.285	0.202	0.200	8.53	5.00	1.39
Lindsey Slough	10	4/13/09	1.13	0.31	0.87	0.02	0.53	0.01	0.233	0.143	0.139	5.99	10.12	2.36
Lindsey Slough	10	4/27/09	0.87	0.40	0.63	0.01	0.21	0.01	0.170	0.092	0.076	4.09	20.85	7.16
Lindsey Slough	10	5/11/09	0.80	0.47	0.65	0.01	0.15	0.01	0.148	0.068	0.066	3.46	44.15	18.09
Lindsey Slough	10	5/26/09	0.73	0.12	0.58	0.09	0.35	0.02	0.226	0.097	0.097	2.84	6.94	1.15
Lindsey Slough	10	6/8/09	0.90	0.35	0.82	0.08	0.38	0.02	0.204	0.108	0.102	3.09	5.55	1.55
Lindsey Slough	10	6/22/09	0.68	0.17	0.56	0.02	0.36	0.02	0.171	0.096	0.086	2.67	9.99	2.91
Lindsey Slough	10	7/14/09	0.65	0.15	0.56	0.05	0.33	0.03	0.209	0.106	0.104	2.99	3.49	4.68
Lindsey Slough	10	8/3/09	0.41	0.12	0.36	0.04	0.19	0.01	0.183	0.078	0.076	2.51	7.94	1.40
Lindsey Slough	10	9/28/09	0.63	0.21	0.52	0.05	0.24	0.01	0.126	0.084	0.081	2.71	15.89	10.33
Lindsey Slough	10	10/20/09	0.84	0.07	0.56	0.06	0.42	0.01	0.164	0.119	0.114	4.51	4.41	2.49
Lindsey Slough	10	11/16/09	0.79	0.07	0.77	0.08	0.60	0.03	0.138	0.079	0.072	2.47	4.40	1.22
Lindsey Slough	10	12/7/09	0.92	0.15	0.85	0.08	0.61	0.01	0.113	0.079	0.079	2.52	2.61	0.89
Lindsey Slough	10	1/25/10	1.52	0.63	1.16	0.05	0.47	0.02	0.433	0.236	0.222	9.86	2.67	6.97
Lindsey Slough	10	2/22/10	1.29	0.73	1.24	0.08	0.43	0.01	0.293	0.180	0.168	7.8	7.4	3.4
Toe Drain	11	3/16/09	1.61	0.68	1.44	0.00	0.74	0.01	0.361	0.182	0.172	6.34	3.68	4.72
Toe Drain	11	3/30/09	1.55	0.50	1.53	0.03	0.99	0.01	0.385	0.267	0.237	5.17	10.30	7.75
Toe Drain	11	4/13/09	1.45	0.36	1.43	0.03	1.01	0.02	0.401	0.272	0.261	5.95	18.40	7.12
Toe Drain	11	4/27/09	2.22	0.51	1.68	0.16	0.98	0.03	0.493	0.281	0.281	5.96	8.32	20.97
Toe Drain	11	5/11/09	1.62	0.40	1.56	0.04	1.10	0.02	0.591	0.463	0.436	5.67	28.07	4.11
Toe Drain	11	5/26/09	0.71	0.18	0.71	0.06	0.47	0.01	0.545	0.186	0.185	3.42	12.93	0.53
Toe Drain	11	6/8/09	1.05	0.35	0.90	0.03	0.50	0.01	0.497	0.183	0.169	3.47	9.00	6.26
Toe Drain	11	6/22/09	0.78	0.19	0.57	0.04	0.33	0.01	0.377	0.134	0.122	2.97	9.68	4.24
Toe Drain	11	7/14/09	0.46	0.16	0.35	0.02	0.17	0.00	0.384	0.106	0.104	2.93	12.71	3.60
Toe Drain	11	8/3/09	0.33	0.13	0.23	0.03	0.07	0.00	0.282	0.078	0.078	2.67	11.92	0.54
Toe Drain	11	9/28/09	0.93	0.63	0.78	0.06	0.09	0.00	0.351	0.222	0.217	4.99	17.21	13.37
Toe Drain	11	10/20/09	1.17	0.75	1.13	0.06	0.31	0.01	0.294	0.175	0.175	3.28	10.59	7.58
Toe Drain	11	11/16/09	1.58	0.77	1.30	0.05	0.47	0.00	0.283	0.154	0.143	5.08	4.33	4.20
Toe Drain	11	12/7/09	1.36	0.42	1.22	0.03	0.76	0.01	0.289	0.204	0.190	6.06	2.93	4.06
Toe Drain	11	1/25/10	1.45	0.72	1.25	0.04	0.48	0.02	0.568	0.106	0.104	6.46	2.34	3.27
Toe Drain	11	2/22/10	1.26	0.68	1.17	0.13	0.33	0.02	0.425	0.198	0.189	7.7	1.7	2.0

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Mokelumne@ Georgiana	12	3/16/09	1.05	0.52	1.01	0.02	0.46	0.01	0.124	0.088	0.082	4.12	0.50	0.84
Mokelumne@ Georgiana	12	3/30/09	0.75	0.20	0.75	0.29	0.24	0.01	0.094	0.069	0.066	2.31	0.62	0.82
Mokelumne@ Georgiana	12	4/13/09	0.75	0.22	0.71	0.32	0.16	0.01	0.095	0.059	0.058	1.76	0.87	1.50
Mokelumne@ Georgiana	12	4/27/09	1.12	0.20	0.84	0.47	0.15	0.02	0.115	0.058	0.057	1.80	1.12	1.56
Mokelumne@ Georgiana	12	5/11/09	0.53	0.27	0.53	0.12	0.14	0.00	0.056	0.040	0.040	2.47	0.81	1.51
Mokelumne@ Georgiana	12	5/26/09	0.50	0.09	0.48	0.26	0.11	0.01	0.059	0.040	0.038	1.76	0.87	0.57
Mokelumne@ Georgiana	12	6/8/09	0.70	0.25	0.62	0.19	0.15	0.03	0.063	0.048	0.042	2.09	1.12	0.63
Mokelumne@ Georgiana	12	6/22/09	0.75	0.08	0.70	0.30	0.28	0.04	0.088	0.071	0.060	1.90	1.37	0.17
Mokelumne@ Georgiana	12	7/14/09	0.46	0.05	0.36	0.22	0.09	0.01	0.069	0.038	0.037	1.72	0.70	1.70
Mokelumne@ Georgiana	12	8/3/09	0.33	0.05	0.32	0.15	0.10	0.01	0.054	0.036	0.036	1.60	3.57	0.70
Mokelumne@ Georgiana	12	9/29/09	0.81	0.17	0.71	0.21	0.29	0.04	0.092	0.078	0.070	2.00	1.16	1.24
Mokelumne@ Georgiana	12	10/21/09	0.71	0.01	0.64	0.22	0.36	0.04	0.081	0.073	0.070	2.06	0.31	0.67
Mokelumne@ Georgiana	12	11/16/09	0.84	0.04	0.75	0.32	0.36	0.03	0.085	0.069	0.065	2.36	0.42	0.65
Mokelumne@ Georgiana	12	12/7/09	0.96	0.19	0.92	0.45	0.27	0.01	0.077	0.066	0.066	2.50	0.49	0.67
Mokelumne@ Georgiana	12	1/25/10	1.19	0.64	1.16	0.14	0.38	0.01	0.334	0.044	0.038	4.92	1.82	4.61
Mokelumne@ Georgiana	12	2/22/10	1.04	0.41	0.93	0.21	0.30	0.01	0.125	0.060	0.059	3.8	1.1	1.4
Three Mile Sl @ Sac R	13	3/16/09	1.04	0.42	0.97	0.01	0.53	0.01	0.106	0.069	0.064	4.95	2.00	1.71
Three Mile Sl @ Sac R	13	3/30/09	1.03	0.40	1.03	0.09	0.53	0.01	0.127	0.083	0.071	4.13	2.94	1.10
Three Mile Sl @ Sac R	13	4/13/09	0.83	0.16	0.75	0.11	0.47	0.01	0.104	0.069	0.069	3.08	2.87	0.73
Three Mile Sl @ Sac R	13	4/27/09	0.87	0.22	0.65	0.08	0.34	0.01	0.098	0.046	0.039	2.89	2.88	3.31
Three Mile Sl @ Sac R	13	5/11/09	0.65	0.22	0.62	0.06	0.33	0.01	0.068	0.049	0.049	2.60	2.37	1.23
Three Mile Sl @ Sac R	13	5/26/09	0.59	0.10	0.46	0.03	0.32	0.01	0.086	0.053	0.053	2.36	3.00	0.51
Three Mile Sl @ Sac R	13	6/8/09	0.76	0.23	0.62	0.07	0.31	0.01	0.084	0.060	0.052	2.63	2.87	0.84
Three Mile Sl @ Sac R	13	6/22/09	0.57	0.13	0.49	0.04	0.31	0.02	0.096	0.065	0.056	2.29	4.05	0.00
Three Mile Sl @ Sac R	13	7/14/09	0.42	0.08	0.37	0.05	0.23	0.01	0.084	0.055	0.053	2.09	1.86	1.22
Three Mile Sl @ Sac R	13	8/3/09	0.33	0.03	0.31	0.09	0.18	0.01	0.069	0.041	0.041	1.77	1.28	0.40
Three Mile Sl @ Sac R	13	9/28/09	0.84	0.19	0.65	0.07	0.37	0.02	0.094	0.073	0.073	2.27	2.56	1.28
Three Mile Sl @ Sac R	13	10/20/09	0.78	0.05	0.67	0.14	0.45	0.02	0.102	0.078	0.073	2.12	1.17	1.21
Three Mile Sl @ Sac R	13	11/16/09	0.74	0.01	0.71	0.13	0.54	0.02	0.116	0.069	0.066	2.13	1.70	1.07
Three Mile Sl @ Sac R	13	12/7/09	0.89	0.21	0.88	0.13	0.52	0.02	0.095	0.071	0.064	2.60	2.54	1.70
Three Mile Sl @ Sac R	13	1/25/10	1.08	0.23	0.87	0.12	0.51	0.01	0.436	0.062	0.062	5.19	1.79	4.15
Three Mile Sl @ Sac R	13	2/22/10	1.15	0.43	1.07	0.12	0.51	0.02	0.131	0.069	0.064	4.8	0.9	0.8

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Sac R @ Pt Sacramento	14	3/17/09	0.94	0.38	0.87	0.01	0.46	0.02	0.155	0.075	0.072	4.31	1.00	1.68
Sac R @ Pt Sacramento	14	3/31/09	1.01	0.30	0.98	0.14	0.51	0.02	0.148	0.088	0.085	3.42	1.34	1.98
Sac R @ Pt Sacramento	14	4/14/09	0.91	0.17	0.89	0.14	0.55	0.02	0.197	0.083	0.086	3.60	3.29	1.76
Sac R @ Pt Sacramento	14	4/28/09	1.08	0.21	0.75	0.07	0.45	0.02	0.187	0.069	0.069	2.00	5.67	3.69
Sac R @ Pt Sacramento	14	5/12/09	0.75	0.29	0.71	0.07	0.34	0.01	0.105	0.050	0.050	2.56	2.29	2.43
Sac R @ Pt Sacramento	14	5/27/09	0.55	0.01	0.43	0.06	0.36	0.01	0.124	0.062	0.062	2.33	5.52	0.19
Sac R @ Pt Sacramento	14	6/9/09	0.90	0.22	0.65	0.04	0.37	0.01	0.130	0.072	0.064	2.57	3.12	1.69
Sac R @ Pt Sacramento	14	6/23/09	0.50	-0.01	0.38	0.05	0.33	0.01	0.128	0.073	0.063	2.21	2.33	1.38
Sac R @ Pt Sacramento	14	7/15/09	0.37	0.00	0.35	0.05	0.29	0.01	0.123	0.066	0.061	2.12	2.24	1.96
Sac R @ Pt Sacramento	14	8/4/09	0.33	-0.01	0.27	0.05	0.21	0.01	0.096	0.054	0.050	1.99	3.47	1.20
Sac R @ Pt Sacramento	14	9/29/09	1.38	0.16	0.58	0.08	0.32	0.01	0.104	0.078	0.074	2.44	1.51	1.13
Sac R @ Pt Sacramento	14	10/21/09	1.17	0.15	0.64	0.10	0.38	0.01	0.104	0.075	0.075	2.22	0.85	1.23
Sac R @ Pt Sacramento	14	11/17/09	1.62	0.68	1.37	0.13	0.55	0.02	0.120	0.079	0.074	3.16	1.70	0.68
Sac R @ Pt Sacramento	14	12/8/09	0.98	0.29	0.90	0.12	0.48	0.02	0.119	0.072	0.072	2.03	1.01	1.12
Sac R @ Pt Sacramento	14	1/27/10	1.83	1.09	1.72	0.12	0.50	0.01	0.234	0.056	0.056	4.73	1.14	3.07
Sac R @ Pt Sacramento	14	2/23/10	0.98	0.40	0.93	0.11	0.41	0.02	0.146	0.072	0.072	4.0	1.3	0.9
Sac R @ Chipps Is	15	3/17/09	0.93	0.42	0.91	0.01	0.46	0.02	0.161	0.079	0.075	4.41	0.56	0.78
Sac R @ Chipps Is	15	3/31/09	0.99	0.33	0.99	0.13	0.51	0.02	0.164	0.097	0.085	3.02	2.93	0.77
Sac R @ Chipps Is	15	4/14/09	0.95	0.11	0.84	0.12	0.58	0.03	0.134	0.089	0.088	2.92	2.12	1.25
Sac R @ Chipps Is	15	5/12/09	0.66	0.27	0.61	0.03	0.30	0.01	0.148	0.046	0.046	2.97	3.18	3.19
Sac R @ Chipps Is	15	5/27/09	0.54	0.02	0.46	0.06	0.38	0.01	0.103	0.068	0.068	1.89	2.50	1.37
Sac R @ Chipps Is	15	6/9/09	0.59	0.00	0.46	0.06	0.39	0.01	0.145	0.075	0.068	2.62	2.68	2.04
Sac R @ Chipps Is	15	6/23/09	0.35	-0.05	0.35	0.06	0.32	0.01	0.145	0.079	0.069	1.73	1.79	2.04
Sac R @ Chipps Is	15	7/15/09	0.46	0.00	0.44	0.12	0.30	0.01	0.109	0.081	0.075	1.86	1.22	1.30
Sac R @ Chipps Is	15	8/4/09	0.69	0.09	0.53	0.16	0.28	0.01	0.105	0.064	0.064	2.27	2.33	1.79
Sac R @ Chipps Is	15	9/29/09	0.89	0.06	0.50	0.13	0.31	0.01	0.108	0.082	0.076	2.16	1.63	1.13
Sac R @ Chipps Is	15	10/21/09	0.76	0.17	0.66	0.10	0.38	0.01	0.092	0.079	0.079	1.90	1.01	0.82
Sac R @ Chipps Is	15	11/17/09	0.78	0.02	0.68	0.12	0.53	0.01	0.120	0.076	0.072	2.51	0.95	0.73
Sac R @ Chipps Is	15	12/8/09	1.06	0.42	1.01	0.11	0.46	0.02	0.107	0.077	0.075	1.57	0.95	1.12
Sac R @ Chipps Is	15	1/27/10	1.28	0.56	1.23	0.13	0.53	0.01	0.280	0.062	0.062	4.75	1.25	3.57
Sac R @ Chipps Is	15	2/23/10	0.94	0.35	0.88	0.10	0.41	0.02	0.148	0.073	0.072	4.1	2.0	0.7

Table 1A. Continue

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
San Joaquin @ Antioch	16	3/17/09	0.92	0.38	0.89	0.01	0.48	0.02	0.127	0.075	0.070	4.48	0.92	1.15
San Joaquin @ Antioch	16	3/31/09	1.07	0.40	1.07	0.14	0.51	0.02	0.173	0.088	0.081	3.74	2.19	1.27
San Joaquin @ Antioch	16	4/14/09	0.87	0.11	0.80	0.14	0.53	0.02	0.128	0.080	0.080	3.04	2.57	0.97
San Joaquin @ Antioch	16	4/28/09	1.21	0.25	0.75	0.07	0.41	0.01	0.167	0.069	0.060	2.44	9.81	3.67
San Joaquin @ Antioch	16	5/12/09	0.69	0.32	0.70	0.07	0.30	0.01	0.083	0.056	0.053	2.66	20.11	22.56
San Joaquin @ Antioch	16	5/27/09	0.59	0.08	0.50	0.07	0.34	0.01	0.125	0.064	0.061	2.36	4.05	1.55
San Joaquin @ Antioch	16	6/9/09	0.79	0.36	0.78	0.06	0.35	0.01	0.127	0.066	0.060	2.65	3.54	1.44
San Joaquin @ Antioch	16	6/23/09	0.60	0.08	0.46	0.05	0.32	0.01	0.117	0.071	0.060	2.17	3.50	1.17
San Joaquin @ Antioch	16	7/15/09	0.48	0.06	0.43	0.09	0.27	0.01	0.100	0.064	0.064	2.25	1.40	1.73
San Joaquin @ Antioch	16	8/4/09	0.30	0.05	0.29	0.03	0.20	0.01	0.081	0.054	0.050	2.01	1.05	1.11
San Joaquin @ Antioch	16	9/29/09	0.39	0.05	0.35	0.04	0.25	0.01	0.093	0.084	0.071	2.29	1.75	1.14
San Joaquin @ Antioch	16	10/21/09	0.81	0.07	0.55	0.10	0.37	0.01	0.085	0.073	0.073	2.19	1.54	0.69
San Joaquin @ Antioch	16	11/17/09	2.37	1.38	2.02	0.09	0.54	0.01	0.104	0.073	0.069	2.37	1.80	0.97
San Joaquin @ Antioch	16	12/8/09	0.84	0.18	0.78	0.11	0.47	0.01	0.095	0.071	0.069	2.13	1.48	1.19
San Joaquin @ Antioch	16	1/27/10	1.72	0.02	0.85	0.14	0.67	0.02	0.218	0.064	0.064	4.59	1.00	2.60
San Joaquin @ Antioch	16	1/27/10	0.67	0.32	0.60	0.03	0.25	0.01	0.134	0.038	0.039	2.9	3.03	1.56
San Joaquin @ Antioch	16	2/23/10	1.07	0.43	1.01	0.12	0.44	0.02	0.128	0.066	0.070	4.2	1.1	0.5
San Joaquin @ Turner	17	3/17/09	3.42	0.56	3.35	0.01	2.77	0.02	0.148	0.136	0.122	6.27	3.31	1.98
San Joaquin @ Turner	17	3/31/09	3.42	0.63	3.34	0.05	2.64	0.01	0.142	0.112	0.097	6.13	7.73	2.54
San Joaquin @ Turner	17	4/14/09	2.05	0.31	2.06	0.08	1.66	0.01	0.107	0.095	0.083	5.72	1.62	1.16
San Joaquin @ Turner	17	4/28/09	2.69	1.04	2.64	0.12	1.47	0.02	0.133	0.109	0.097	5.50	2.00	1.61
San Joaquin @ Turner	17	5/12/09	1.63	0.23	1.60	0.05	1.30	0.02	0.109	0.091	0.089	4.42	1.87	0.91
San Joaquin @ Turner	17	5/27/09	1.51	0.17	1.42	0.04	1.20	0.01	0.149	0.117	0.116	3.60	2.58	1.78
San Joaquin @ Turner	17	6/9/09	1.84	0.45	1.62	0.04	1.12	0.02	0.148	0.124	0.114	4.13	2.75	0.65
San Joaquin @ Turner	17	6/23/09	1.24	0.27	1.16	0.03	0.84	0.01	0.134	0.105	0.093	3.89	3.31	0.11
San Joaquin @ Turner	17	7/15/09	0.48	0.18	0.42	0.02	0.21	0.01	0.081	0.063	0.060	3.10	4.57	4.10
San Joaquin @ Turner	17	8/4/09	0.39	0.15	0.32	0.01	0.16	0.01	0.084	0.060	0.059	2.98	1.86	1.50
San Joaquin @ Turner	17	9/29/09	2.05	0.48	2.04	0.06	1.48	0.02	0.100	0.087	0.076	3.90	3.37	0.99
San Joaquin @ Turner	17	10/21/09	2.64	0.69	2.54	0.10	1.72	0.02	0.117	0.107	0.100	3.91	1.96	1.15
San Joaquin @ Turner	17	11/17/09	1.10	0.12	0.95	0.03	0.78	0.01	0.082	0.063	0.055	3.24	1.38	0.60
San Joaquin @ Turner	17	12/8/09	1.37	0.16	1.33	0.03	1.12	0.01	0.077	0.065	0.061	3.40	1.17	0.61
San Joaquin @ Turner	17	1/27/10	3.23	0.52	3.19	0.22	2.41	0.04	0.229	0.176	0.176	6.65	0.89	1.82
San Joaquin @ Turner	17	2/23/10	2.64	0.65	2.51	0.10	1.73	0.03	0.174	0.137	0.132	8.5	0.8	0.8

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
Middle R @ Bacon Is	18	3/17/09	1.63	0.52	1.54	0.00	0.99	0.02	0.097	0.075	0.069	6.36	1.12	0.32
Middle R @ Bacon Is	18	3/31/09	1.27	0.37	1.10	0.04	0.68	0.01	0.101	0.069	0.063	5.59	1.25	1.12
Middle R @ Bacon Is	18	4/14/09	1.02	0.21	0.93	0.04	0.67	0.01	0.083	0.068	0.063	4.85	1.25	0.81
Middle R @ Bacon Is	18	4/28/09	0.89	0.31	0.80	0.04	0.44	0.01	0.072	0.049	0.045	4.68	2.00	1.71
Middle R @ Bacon Is	18	5/12/09	1.09	0.42	1.06	0.03	0.60	0.01	0.068	0.068	0.053	4.57	1.37	1.31
Middle R @ Bacon Is	18	5/27/09	0.72	0.20	0.65	0.03	0.41	0.01	0.114	0.062	0.058	3.71	1.62	1.78
Middle R @ Bacon Is	18	6/9/09	0.87	0.39	0.77	0.03	0.33	0.01	0.102	0.081	0.073	3.81	3.00	0.20
Middle R @ Bacon Is	18	6/23/09	0.62	0.27	0.61	0.03	0.30	0.01	0.099	0.079	0.066	3.48	1.62	0.75
Middle R @ Bacon Is	18	7/15/09	0.36	0.11	0.32	0.03	0.17	0.01	0.066	0.057	0.055	2.56	1.75	1.38
Middle R @ Bacon Is	18	8/4/09	0.32	0.12	0.23	0.02	0.09	0.00	0.075	0.054	0.053	2.22	5.16	1.07
Middle R @ Bacon Is	18	9/29/09	0.71	0.19	0.63	0.05	0.39	0.01	0.080	0.063	0.057	2.94	2.33	1.52
Middle R @ Bacon Is	18	10/21/09	0.77	0.03	0.69	0.05	0.60	0.01	0.071	0.061	0.055	2.89	1.38	0.70
Middle R @ Bacon Is	18	11/17/09	0.76	0.09	0.76	0.03	0.63	0.01	0.069	0.057	0.053	3.01	1.17	0.71
Middle R @ Bacon Is	18	12/8/09	0.89	0.21	0.88	0.03	0.62	0.01	0.065	0.053	0.049	2.94	1.01	0.53
Middle R @ Bacon Is	18	1/27/10	1.82	0.25	1.72	0.12	1.31	0.03	0.106	0.075	0.075	5.62	0.75	1.05
Middle R @ Bacon Is	18	2/23/10	1.66	0.52	1.55	0.09	0.91	0.02	0.113	0.072	0.069	7.6	0.8	0.6
Bethany Reservoir	19	3/17/09	1.72	0.58	1.59	0.00	0.99	0.01	0.106	0.079	0.069	6.42	1.10	6.05
Bethany Reservoir	19	3/31/09	1.18	1.02	1.17	0.05	0.09	0.01	0.124	0.080	0.072	5.85	5.15	2.94
Bethany Reservoir	19	4/14/09	1.12	0.28	1.04	0.06	0.69	0.01	0.104	0.084	0.078	5.32	1.25	2.15
Bethany Reservoir	19	4/28/09	1.07	0.54	1.05	0.12	0.38	0.01	0.133	0.098	0.090	4.93	1.00	3.23
Bethany Reservoir	19	5/12/09	1.05	0.39	1.03	0.06	0.57	0.01	0.114	0.095	0.095	4.16	1.25	1.95
Bethany Reservoir	19	5/27/09	0.78	0.22	0.71	0.05	0.43	0.00	0.131	0.097	0.094	4.10	1.75	2.07
Bethany Reservoir	19	6/9/09	0.81	0.35	0.57	0.05	0.17	0.00	0.134	0.120	0.106	4.25	1.00	0.65
Bethany Reservoir	19	6/23/09	0.75	0.32	0.54	0.07	0.14	0.00	0.169	0.117	0.102	4.06	1.75	1.86
Bethany Reservoir	19	7/15/09	0.40	0.17	0.36	0.04	0.15	0.01	0.097	0.074	0.064	2.98	1.45	2.21
Bethany Reservoir	19	8/4/09	0.27	0.12	0.21	0.04	0.05	0.00	0.078	0.057	0.055	2.43	5.76	1.55
Bethany Reservoir	19	9/29/09	0.55	0.26	0.43	0.14	0.03	0.00	0.126	0.099	0.087	3.15	1.16	1.36
Bethany Reservoir	19	10/21/09	0.94	0.30	0.87	0.08	0.47	0.01	0.073	0.058	0.058	3.17	1.06	1.51
Bethany Reservoir	19	11/17/09	1.38	0.49	1.07	0.03	0.54	0.01	0.073	0.051	0.040	3.23	3.49	1.65
Bethany Reservoir	19	12/8/09	1.08	0.18	1.03	0.03	0.81	0.01	0.071	0.059	0.057	2.81	1.59	0.98
Bethany Reservoir	19	1/27/10	1.75	0.31	1.63	0.13	1.16	0.03	0.177	0.109	0.109	6.02	0.92	1.56
Bethany Reservoir	19	2/23/10	1.78	0.49	1.62	0.07	1.03	0.02	0.119	0.079	0.069	7.6	1.8	1.3

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
DMC @ HWY 4	20	3/17/09	1.64	0.65	1.58	0.00	0.91	0.02	0.115	0.069	0.064	6.29	3.79	3.02
DMC @ HWY 4	20	3/31/09	1.15	0.39	1.11	0.05	0.66	0.01	0.118	0.085	0.068	5.56	5.89	1.58
DMC @ HWY 4	20	4/14/09	0.98	0.17	0.96	0.07	0.71	0.01	0.107	0.074	0.070	5.62	1.47	5.06
DMC @ HWY 4	20	4/28/09	1.12	0.37	1.03	0.09	0.56	0.01	0.153	0.115	0.105	4.25	5.70	1.05
DMC @ HWY 4	20	5/12/09	0.94	0.21	0.87	0.06	0.59	0.01	0.141	0.108	0.108	3.22	3.86	2.98
DMC @ HWY 4	20	5/27/09	0.82	0.24	0.70	0.06	0.40	0.01	0.142	0.100	0.093	4.02	2.58	2.40
DMC @ HWY 4	20	6/9/09	1.11	0.44	0.98	0.05	0.48	0.01	0.133	0.108	0.096	4.41	2.00	2.43
DMC @ HWY 4	20	6/23/09	1.06	0.25	0.66	0.04	0.36	0.01	0.128	0.091	0.080	3.71	1.84	3.14
DMC @ HWY 4	20	7/15/09	0.53	0.17	0.44	0.04	0.22	0.01	0.141	0.072	0.069	2.92	3.53	5.15
DMC @ HWY 4	20	8/4/09	0.46	0.12	0.40	0.04	0.22	0.01	0.126	0.075	0.075	2.58	1.16	2.08
DMC @ HWY 4	20	9/29/09	1.45	0.31	1.24	0.09	0.82	0.01	0.178	0.124	0.121	3.09	5.96	4.58
DMC @ HWY 4	20	10/21/09	1.30	0.15	1.00	0.05	0.79	0.01	0.088	0.073	0.065	3.62	1.01	1.81
DMC @ HWY 4	20	11/17/09	2.19	0.76	1.37	0.03	0.58	0.00	0.079	0.063	0.055	3.04	1.06	2.79
DMC @ HWY 4	20	12/8/09	2.04	0.29	1.89	0.02	1.57	0.01	0.174	0.132	0.126	3.10	4.76	3.11
DMC @ HWY 4	20	1/27/10	2.07	0.51	1.74	0.15	1.06	0.03	0.273	0.155	0.150	7.34	1.93	4.45
DMC @ HWY 4	20	2/23/10	1.88	0.48	1.68	0.07	1.10	0.03	0.134	0.085	0.078	7.7	3.4	1.7
San Joaquin @ Vernalis	21	3/17/09	2.31	0.42	2.08	0.00	1.64	0.03	0.305	0.161	0.147	4.98	57.56	11.91
San Joaquin @ Vernalis	21	3/31/09	1.89	0.32	1.60	0.02	1.25	0.02	0.215	0.073	0.077	4.21	52.22	10.02
San Joaquin @ Vernalis	21	4/14/09	1.63	0.16	1.46	0.02	1.27	0.01	0.170	0.074	0.070	3.31	27.96	6.89
San Joaquin @ Vernalis	21	4/28/09	1.19	0.25	0.93	0.01	0.66	0.01	0.112	0.067	0.067	2.59	8.83	2.68
San Joaquin @ Vernalis	21	5/12/09	0.84	0.19	0.75	0.00	0.55	0.01	0.132	0.050	0.050	2.38	10.44	4.28
San Joaquin @ Vernalis	21	5/27/09	0.80	0.11	0.62	0.00	0.50	0.01	0.097	0.035	0.027	2.29	32.38	2.50
San Joaquin @ Vernalis	21	6/9/09	1.65	0.36	1.15	0.00	0.76	0.02	0.171	0.042	0.035	2.83	113.21	3.44
San Joaquin @ Vernalis	21	6/22/09	1.38	0.14	0.90	0.01	0.72	0.02	0.140	0.045	0.033	2.40	67.70	2.01
San Joaquin @ Vernalis	21	7/15/09	1.53	0.14	1.06	0.01	0.86	0.04	0.170	0.029	0.024	1.63	67.52	3.84
San Joaquin @ Vernalis	21	8/4/09	1.41	0.10	1.13	0.02	0.98	0.03	0.168	0.063	0.058	2.65	73.08	13.91
San Joaquin @ Vernalis	21	9/29/09	1.60	0.21	1.48	0.03	1.23	0.01	0.142	0.080	0.078	2.59	15.89	3.14
San Joaquin @ Vernalis	21	10/21/09	1.45	0.10	0.95	0.01	0.84	0.01	0.187	0.116	0.106	4.11	6.35	3.94
San Joaquin @ Vernalis	21	11/17/09	2.67	0.50	2.37	0.02	1.85	0.01	0.165	0.098	0.093	2.95	4.60	2.81
San Joaquin @ Vernalis	21	12/8/09	1.85	0.19	1.84	0.01	1.63	0.01	0.138	0.089	0.081	2.94	6.03	1.84
San Joaquin @ Vernalis	21	1/27/10	2.05	0.03	1.32	0.18	1.09	0.02	0.357	0.160	0.160	8.26	5.89	7.73
San Joaquin @ Vernalis	21	2/23/10	2.82	0.40	2.45	0.01	2.03	0.02	0.248	0.103	0.101	4.2	32.4	8.9

Table 1A. Continued

Site	Site #	Date	TN mg/l	DON mg/l	TDN mg/l	NH4- mg/l	NO3-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Chl µg/l	Pheo µg/l
San Joaquin@ Jersey Pt	24	3/31/09	1.04	0.27	0.92	0.15	0.49	0.02	0.147	0.082	0.077	3.44	2.50	1.21
San Joaquin@ Jersey Pt	24	4/14/09	0.79	0.11	0.73	0.05	0.55	0.01	0.101	0.074	0.070	3.59	2.87	0.63
San Joaquin@ Jersey Pt	24	4/28/09	0.76	0.27	0.67	0.06	0.33	0.01	0.101	0.052	0.045	2.60	10.67	1.78
San Joaquin@ Jersey Pt	24	5/11/09	0.62	0.12	0.58	0.11	0.33	0.01	0.057	0.056	0.056	2.41	2.37	1.03
San Joaquin@ Jersey Pt	24	5/26/09	0.52	0.10	0.47	0.04	0.31	0.01	0.078	0.056	0.053	2.36	2.50	0.80
San Joaquin@ Jersey Pt	24	6/8/09	0.82	0.37	0.74	0.04	0.32	0.01	0.090	0.063	0.054	2.72	2.25	0.64
San Joaquin@ Jersey Pt	24	6/22/09	0.57	0.19	0.54	0.04	0.30	0.01	0.088	0.065	0.054	2.35	3.56	0.20
San Joaquin@ Jersey Pt	24	7/14/09	0.43	0.09	0.35	0.03	0.22	0.01	0.084	0.063	0.062	2.64	2.22	1.44
San Joaquin@ Jersey Pt	24	8/3/09	0.31	0.06	0.28	0.03	0.18	0.01	0.078	0.051	0.047	1.87	3.18	2.94
San Joaquin@ Jersey Pt	24	9/28/09	0.54	0.11	0.41	0.04	0.25	0.01	0.089	0.073	0.068	2.34	1.86	0.90
San Joaquin@ Jersey Pt	24	10/20/09	0.56	0.05	0.47	0.06	0.34	0.01	0.085	0.068	0.066	2.16	1.11	1.11
San Joaquin@ Jersey Pt	24	11/16/09	0.67	0.01	0.60	0.05	0.53	0.01	0.104	0.060	0.055	2.38	1.48	0.79
San Joaquin@ Jersey Pt	24	12/7/09	0.85	0.20	0.83	0.07	0.55	0.01	0.077	0.059	0.058	2.36	1.54	0.59
San Joaquin@ Jersey Pt	24	1/27/10	1.39	0.40	1.24	0.14	0.67	0.02	0.217	0.059	0.059	4.59	1.14	3.33
San Joaquin@ Jersey Pt	24	2/22/10	1.25	0.59	1.23	0.11	0.52	0.02	0.119	0.065	0.058	5.0	0.5	0.8

Table 2A. Water quality measurements taken in the field during the nutrient sampling program.

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm^3)	DO (mg/l)	Turbidity (NTU)
Sac River @ Tower bridge	1	3/16/09	7.9	12.6	195	9.4	
Sac River @ Tower bridge	1	3/30/09	8.0	13.9	178	9.2	15.7
Sac River @ Tower bridge	1	4/13/09	8.0	14.4	148	9.3	12.2
Sac River @ Tower bridge	1	4/27/09	7.8	15.0	155	9.2	8.8
Sac River @ Tower bridge	1	5/11/09	7.7	17.8	121	7.4	24.3
Sac River @ Tower bridge	1	5/26/09	7.7	18.8	141	9.1	
Sac River @ Tower bridge	1	6/8/09	7.8	19.3	178	7.3	15.8
Sac River @ Tower bridge	1	6/22/09	7.8	20.1	130	9.0	6.9
Sac River @ Tower bridge	1	7/14/09	7.7	20.6	108	8.8	13.5
Sac River @ Tower bridge	1	8/3/09	7.5	19.4	123	8.7	8.0
Sac River @ Tower bridge	1	9/28/09	7.6	20.4	144	8.7	7.8
Sac River @ Tower Bridge	1	10/20/09	7.5	15.9	139	9.0	5.8
Sac River @ Tower Bridge	1	11/16/09	7.7	11.2	183	10.8	8.4
Sac River @ Tower Bridge	1	12/7/09	7.7	8.3	225	11.5	0.7
Sac River @ Tower Bridge	1	1/25/10	7.1	8.2	153	9.7	145.0
Sac River @ Tower Bridge	1	2/22/10	7.7	11.7	221		35.3
Sac R @ Garcia Bend	2	3/16/09	7.9	12.7	186	9.9	
Sac R @ Garcia Bend	2	3/30/09	7.8	14.3	161	9.0	8.7
Sac R @ Garcia Bend	2	4/13/09	7.9	14.9	131	9.2	9.3
Sac R @ Garcia Bend	2	4/27/09	7.9	15.7	135	9.1	5.1
Sac R @ Garcia Bend	2	5/11/09	7.6	17.6	111	8.3	14.7
Sac R @ Garcia Bend	2	5/26/09	7.7	18.0	133	8.7	
Sac R @ Garcia Bend	2	6/8/09	7.7	19.5	167	7.3	7.5
Sac R @ Garcia Bend	2	6/22/09	7.6	20.7	124	8.0	9.1
Sac R @ Garcia Bend	2	7/14/09	7.6	20.5	110	8.8	9.9
Sac R @ Garcia Bend	2	8/3/09	7.7	20.6	122	8.4	9.0
Sac R @ Garcia Bend	2	9/28/09	7.5	21.9	136		5.2
Sac R @ Garcia Bend	2	10/20/09	7.4	16.4	143	8.1	4.2
Sac R @ Garcia Bend	2	11/16/09	7.7	12.0	168		5.5
Sac R @ Garcia Bend	2	12/7/09	7.5	8.5	203	10.5	6.4
Sac R @ Garcia Bend	2	1/25/10	7.3	8.3	139	8.7	152.0
Sac R @ Garcia Bend	2	2/22/10	7.6	11.4	218		27.7

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm3)	DO (mg/l)	Turbidity (NTU)
Sac River @ Hood	3	3/16/09	7.7	12.7	185	9.6	
Sac River @ Hood	3	3/30/09	7.8	14.4	177	8.7	6.6
Sac River @ Hood	3	4/13/09	7.6	14.8	143	8.5	6.6
Sac River @ Hood	3	4/27/09	7.4	15.8	130	8.2	7.1
Sac River @ Hood	3	5/11/09	7.3	17.2	111	8.5	16.1
Sac River @ Hood	3	5/26/09	7.3	19.1	145	8.6	
Sac River @ Hood	3	6/8/09	7.5	19.8	157	7.0	6.9
Sac River @ Hood	3	6/22/09	7.3	21.0	133	7.3	9.9
Sac River @ Hood	3	7/14/09	7.3	20.7	120	8.4	7.3
Sac River @ Hood	3	8/3/09	7.4	20.9	136	8.1	8.0
Sac River @ Hood	3	9/28/09	7.2	22.0	160		5.5
Sac River @ Hood	3	10/20/09	6.9	17.2	153	8.3	3.5
Sac River @ Hood	3	11/16/09	7.3	12.8	188		3.4
Sac River @ Hood	3	12/7/09	7.3	9.0	192	10.0	4.5
Sac River @ Hood	3	1/25/10	7.3	8.3	145	9.1	175.0
Sac River @ Hood	3	2/22/10	7.5	12.3	226		22.0
Sac River @ Walnut Grove	5	3/16/09	7.7	12.9	187	9.5	
Sac River @ Walnut Grove	5	3/30/09	7.7	14.9	176	9.5	6.8
Sac River @ Walnut Grove	5	4/13/09	7.8	14.7	139	9.2	7.2
Sac River @ Walnut Grove	5	4/27/09	7.5	16.9	128	8.3	10.1
Sac River @ Walnut Grove	5	5/11/09	7.4	18.2	121	7.4	19.5
Sac River @ Walnut Grove	5	5/26/09	7.4	19.3	134	8.8	
Sac River @ Walnut Grove	5	6/8/09	7.5	20.1	142	7.5	8.1
Sac River @ Walnut Grove	5	6/22/09	7.4	21.7	134	7.4	10.8
Sac River @ Walnut Grove	5	7/14/09	7.3	21.2	111	8.2	9.4
Sac River @ Walnut Grove	5	8/3/09	7.4	21.1	121	8.2	10.0
Sac River @ Walnut Grove	5	9/28/09	7.3	21.9	157		3.7
Sac River @ Walnut Grove	5	10/20/09	7.4	17.2	155	7.9	4.3
Sac River @ Walnut Grove	5	11/16/09	7.5	12.9	182		4.3
Sac River @ Walnut Grove	5	12/7/09	7.4	9.0	194	10.2	4.0
Sac River @ Walnut Grove	5	1/25/10	7.3	8.4	143	8.6	191.0
Sac River @ Walnut Grove	5	2/22/10	7.6	12.4	221		16.4

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
Sac R @ Isleton	6	3/16/09	7.7	12.8	184	9.6	
Sac R @ Isleton	6	3/30/09	7.8	14.3	170	9.7	9.2
Sac R @ Isleton	6	4/13/09	7.6	15.0	138	9.3	6.4
Sac R @ Isleton	6	4/27/09	7.7	17.1	132	8.0	9.0
Sac R @ Isleton	6	5/11/09	7.4	17.8	118	7.9	26.9
Sac R @ Isleton	6	5/26/09	7.4	19.9	131	8.4	
Sac R @ Isleton	6	6/8/09	7.5	20.2	127	7.7	13.6
Sac R @ Isleton	6	6/22/09	7.4	22.5	161	6.5	12.1
Sac R @ Isleton	6	7/14/09	7.2	21.4	107	8.0	6.0
Sac R @ Isleton	6	8/3/09	7.4	21.1	127	8.0	12.0
Sac R @ Isleton	6	9/28/09	7.2	22.3	169		3.0
Sac R @ Isleton	6	10/20/09	7.3	17.5	160	7.6	4.4
Sac R @ Isleton	6	11/16/09	7.5	13.3	170		4.4
Sac R @ Isleton	6	12/7/09	7.5	8.9	194	9.9	3.5
Sac R @ Isleton	6	1/25/10	7.3	8.4	145	8.6	208.0
Sac R @ Isleton	6	2/22/10	7.6	13.0	228		12.7
Sac R @ Rio Vista	7	3/16/09	7.8	12.8	237	9.3	
Sac R @ Rio Vista	7	3/30/09	7.9	14.5	236	8.8	21.9
Sac R @ Rio Vista	7	4/13/09	7.7	15.3	179	9.2	11.8
Sac R @ Rio Vista	7	4/27/09	7.6	17.9	171	7.2	15.7
Sac R @ Rio Vista	7	5/11/09	7.4	18.3	140	7.7	19.2
Sac R @ Rio Vista	7	5/26/09	7.5	19.9	150	7.6	
Sac R @ Rio Vista	7	6/8/09	7.5	19.9	138	8.1	21.9
Sac R @ Rio Vista	7	6/22/09	7.6	21.4	165	7.4	22.1
Sac R @ Rio Vista	7	7/14/09	7.4	22.1	120	8.1	11.7
Sac R @ Rio Vista	7	8/3/09	7.6	20.9	130	8.4	19.0
Sac R @ Rio Vista	7	9/28/09	7.5	22.6	198		3.0
Sac R @ Rio Vista	7	10/20/09	7.3	17.4	169	7.5	14.0
Sac R @ Rio Vista	7	11/16/09	7.5	13.8	183		6.7
Sac R @ Rio Vista	7	12/7/09	7.5	9.5	420	9.4	12.2
Sac R @ Rio Vista	7	1/25/10	7.3	8.4	163	9.0	212.0
Sac R @ Rio Vista	7	2/22/10	7.6	12.9	276		22.3

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
Ship Channel	8	3/16/09	7.9	12.9	335	9.4	
Ship Channel	8	3/30/09	8.1	14.3	362	9.2	47.0
Ship Channel	8	4/13/09	7.8	15.1	239	8.6	14.6
Ship Channel	8	4/27/09	7.9	16.9	252	7.6	24.0
Ship Channel	8	5/11/09	7.6	18.9	206	7.6	21.6
Ship Channel	8	5/26/09	7.8	20.8	204	7.9	
Ship Channel	8	6/8/09	7.8	19.7	193	8.1	40.2
Ship Channel	8	6/22/09	7.9	21.3	250	7.9	34.3
Ship Channel	8	7/14/09	7.4	23.5	132	8.1	14.4
Ship Channel	8	8/3/09	7.9	21.4	192	8.4	32.0
Ship Channel	8	9/28/09	7.5	22.4	185		12.0
Ship Channel	8	10/20/09	7.5	17.5	193	7.5	22.5
Ship Channel	8	11/16/09	7.5	13.6	205		9.2
Ship Channel	8	12/7/09	7.5	9.1	213	9.8	8.0
Ship Channel	8	1/25/10	7.2	8.4	163	8.7	204.0
Ship Channel	8	2/22/10	7.7	13.0	330		25.8
Liberty Island	9	3/16/09	8.1	13.2	454	9.9	
Liberty Island	9	3/30/09	8.3	13.7	416	10.0	172, 166
Liberty Island	9	4/13/09	8.1	14.4	287	9.0	15.5
Liberty Island	9	4/27/09	8.1	16.0	254	8.7	32.0
Liberty Island	9	5/11/09	7.9	18.9	218	8.1	24.8
Liberty Island	9	5/26/09	7.8	18.9	184	9.3	
Liberty Island	9	6/8/09	8.0	19.0	173	9.0	54.9
Liberty Island	9	6/22/09	8.0	21.1	185	8.9	48.7
Liberty Island	9	7/14/09	7.9	26.3	159	8.3	47.0
Liberty Island	9	8/3/09	7.9	20.0	145	8.9	68.0
Liberty Island	9	9/28/09	7.7	22.4	192		20.0
Liberty Island	9	10/20/09	7.6	17.3	201	8.6	36.5
Liberty Island	9	11/16/09	7.7	13.4	204		10.4
Liberty Island	9	12/7/09	7.8	8.9	232	10.3	12.5
Liberty Island	9	1/25/10	7.5	8.5	228	10.4	224.0
Liberty Island	9	2/22/10	7.9	13.0	421		39.7

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
Lindsey Slough	10	3/16/09	7.7	13.1	452	8.5	
Lindsey Slough	10	3/30/09	8.1	14.5	476	9.6	38.9
Lindsey Slough	10	4/13/09	8.4	15.5	443	9.2	26.7
Lindsey Slough	10	4/27/09	8.6	17.1	382	9.4	26.0
Lindsey Slough	10	5/11/09	8.6	20.4	313	9.2	22.2
Lindsey Slough	10	5/26/09	7.7	21.1	236	7.4	
Lindsey Slough	10	6/8/09	8.0	19.5	213	8.6	48.8
Lindsey Slough	10	6/22/09	8.0	21.7	202	7.6	32.4
Lindsey Slough	10	7/14/09	7.8	23.9	193	8.1	44.0
Lindsey Slough	10	8/3/09	7.9	20.5	166	8.7	50.0
Lindsey Slough	10	9/28/09	7.8	21.6	225		39.3
Lindsey Slough	10	10/20/09	7.6	17.3	236	8.2	38.3
Lindsey Slough	10	11/16/09	7.7	13.9	224		26.1
Lindsey Slough	10	12/7/09	7.8	8.4	243	10.7	15.0
Lindsey Slough	10	1/25/10	7.2	8.3	239	8.9	115.0
Lindsey Slough	10	2/22/10	7.6	12.7	410		58.5
Toe Drain	11	3/16/09	8.1	14.3	807	8.2	
Toe Drain	11	3/30/09	8.4	15.8	986	8.3	37.6
Toe Drain	11	4/13/09	8.2	17.1	707	7.4	49.4
Toe Drain	11	4/27/09	8.4	18.6	807	5.6	90.0
Toe Drain	11	5/11/09	8.0	22.1	742	5.8	82.2
Toe Drain	11	5/26/09	7.9	21.9	381	6.7	
Toe Drain	11	6/8/09	7.9	21.3	315	7.4	211.0
Toe Drain	11	6/22/09	7.8	22.8	245	6.5	168.0
Toe Drain	11	7/14/09	7.9	25.4	210	7.4	153.0
Toe Drain	11	8/3/09	7.9	22.2	184	8.1	139.0
Toe Drain	11	9/28/09	8.1	22.9	818		65.7
Toe Drain	11	10/20/09	7.7	17.6	556	5.7	92.4
Toe Drain	11	11/16/09	7.8	12.3	578		59.3
Toe Drain	11	12/7/09	7.9	7.5	622	9.2	29.9
Toe Drain	11	1/25/10	7.4	8.2	301	8.6	378.0
Toe Drain	11	2/22/10	7.7	12.6	598		84.1

Table 2A (Continued)

Site	**Site #**	**Date**	**pH**	**Temp (^{0}C)**	**EC (µmho/cm)**	**DO (mg/l)**	**Turbidity (NTU)**
Mokelumne@ Georgiana	12	3/16/09	7.7	13.1	179	9.6	13.0
Mokelumne@ Georgiana	12	3/30/09	7.7	14.9	171	8.6	10.2
Mokelumne@ Georgiana	12	4/13/09	7.7	15.0	138	8.3	13.1
Mokelumne@ Georgiana	12	4/27/09	7.6	18.0	137	7.4	15.0
Mokelumne@ Georgiana	12	5/11/09	7.4	19.0	103	8.2	17.4
Mokelumne@ Georgiana	12	5/26/09	7.4	20.9	132	8.4	
Mokelumne@ Georgiana	12	6/8/09	7.6	21.0	130	7.7	7.9
Mokelumne@ Georgiana	12	6/22/09	7.5	23.6	159	7.3	5.8
Mokelumne@ Georgiana	12	7/14/09	7.3	22.4	111	8.2	10.0
Mokelumne@ Georgiana	12	8/3/09	7.6	21.8	123	8.7	5.0
Mokelumne@ Georgiana	12	9/29/09	7.7	20.6	164		2.5
Mokelumne@ Georgiana	12	10/21/09	7.4	18.1	154	9.0	2.7
Mokelumne@ Georgiana	12	11/16/09	7.5	13.9	176		2.0
Mokelumne@ Georgiana	12	12/7/09	7.6	9.3	195	9.9	4.2
Mokelumne@ Georgiana	12	1/25/10	7.3	8.6	146	11.3	198.0
Mokelumne@ Georgiana	12	2/22/10	7.5	12.6	224		19.3
Three Mile Sl @ Sac R	13	3/16/09	7.7	12.8	222	10.4	9.5
Three Mile Sl @ Sac R	13	3/30/09	8.0	14.5	249	9.0	18.7
Three Mile Sl @ Sac R	13	4/13/09	8.0	14.8	252	9.1	12.1
Three Mile Sl @ Sac R	13	4/27/09	8.3	17.8	216	8.8	13.0
Three Mile Sl @ Sac R	13	5/11/09	7.8	19.2	184	8.5	10.4
Three Mile Sl @ Sac R	13	5/26/09	7.8	21.3	181	9.3	
Three Mile Sl @ Sac R	13	6/8/09	7.8	20.6	183	7.7	12.4
Three Mile Sl @ Sac R	13	6/22/09	7.9	22.2	199	9.0	12.4
Three Mile Sl @ Sac R	13	7/14/09	7.8	22.9	358	8.6	12.0
Three Mile Sl @ Sac R	13	8/3/09	7.9	21.2	509	8.9	12.0
Three Mile Sl @ Sac R	13	9/28/09	7.8	21.8	954		14.1
Three Mile Sl @ Sac R	13	10/20/09	7.5	17.5	380	9.1	18.3
Three Mile Sl @ Sac R	13	11/16/09	7.6	14.2	579		15.3
Three Mile Sl @ Sac R	13	12/7/09	7.7	9.4	1528	10.8	17.2
Three Mile Sl @ Sac R	13	1/25/10	7.4	8.5	167	10.6	287.0
Three Mile Sl @ Sac R	13	2/22/10	7.6	12.8	258		23.4

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
Sac R @ Pt Sacramento	14	3/17/09	7.9	13.1	283	10.2	27.0
Sac R @ Pt Sacramento	14	3/31/09	7.9	14.5	2051	9.8	34.5
Sac R @ Pt Sacramento	14	4/14/09	7.9	15.1	1150	8.4	42.8
Sac R @ Pt Sacramento	14	4/28/09	7.9	15.9	2885	7.9	61.0
Sac R @ Pt Sacramento	14	5/12/09	7.7	17.3	289	8.0	28.9
Sac R @ Pt Sacramento	14	5/27/09	7.7	19.3	1863	7.8	32.9
Sac R @ Pt Sacramento	14	6/9/09	7.9	18.3	1355	8.8	35.9
Sac R @ Pt Sacramento	14	6/23/09	7.8	20.3	6553	7.6	29.0
Sac R @ Pt Sacramento	14	7/15/09	7.8	21.5	2835	8.3	23.0
Sac R @ Pt Sacramento	14	8/4/09	7.8	19.7	2048	8.9	24.0
Sac R @ Pt Sacramento	14	9/29/09	7.9	20.0	4147		14.3
Sac R @ Pt Sacramento	14	10/21/09	7.6	16.9	5201	8.6	15.9
Sac R @ Pt Sacramento	14	11/17/09	7.8	13.8	5232		16.8
Sac R @ Pt Sacramento	14	12/8/09	7.8	9.1	10877	9.1	22.2
Sac R @ Pt Sacramento	14	1/27/10	7.3	8.6	327	10.1	118.0
Sac R @ Pt Sacramento	14	2/23/10	7.5	12.4	249		22.0
Sac R @ Chipps Is	15	3/17/09	8.0	13.3	328	9.8	32.0
Sac R @ Chipps Is	15	3/31/09	7.9	14.6	2974	10.0	31.2
Sac R @ Chipps Is	15	4/14/09	7.9	15.1	2326	8.4	35.3
Sac R @ Chipps Is	15	5/12/09	7.8	18.1	487	8.6	58.8
Sac R @ Chipps Is	15	5/27/09	7.8	19.0	5440	8.1	28.5
Sac R @ Chipps Is	15	6/9/09	7.9	18.4	3424	8.8	31.9
Sac R @ Chipps Is	15	6/23/09	7.8	20.9	1070	7.2	20.3
Sac R @ Chipps Is	15	7/15/09	7.8	21.4	5984	8.4	15.0
Sac R @ Chipps Is	15	8/4/09	7.8	19.7	6180	8.8	29.0
Sac R @ Chipps Is	15	9/29/09	7.9	20.0	8238		13.6
Sac R @ Chipps Is	15	10/21/09	7.7	16.7	9974	8.7	17.2
Sac R @ Chipps Is	15	11/17/09	7.8	13.7	9793		14.3
Sac R @ Chipps Is	15	12/8/09	7.8	8.7	14595	8.9	25.1
Sac R @ Chipps Is	15	1/27/10	7.7	9.0	419	9.8	140.0
Sac R @ Chipps Is	15	2/23/10	7.7	12.2	227		19.1

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
San Joaquin @ Antioch	16	3/17/09	7.8	13.0	269	10.1	15.4
San Joaquin @ Antioch	16	3/31/09	7.9	14.2	425	10.1	33.1
San Joaquin @ Antioch	16	4/14/09	7.9	15.3	484	8.3	19.9
San Joaquin @ Antioch	16	4/28/09	8.0	16.4	1114	8.2	33.5
San Joaquin @ Antioch	16	5/12/09	7.8	18.2	225	8.3	16.7
San Joaquin @ Antioch	16	5/27/09	7.8	20.0	868	7.0	26.8
San Joaquin @ Antioch	16	6/9/09	7.9	19.2	586	8.6	24.5
San Joaquin @ Antioch	16	6/23/09	7.5	25.2	445	6.3	6.8
San Joaquin @ Antioch	16	7/15/09	7.7	22.0	1617	8.2	17.0
San Joaquin @ Antioch	16	8/4/09	7.9	20.4	1849	8.8	14.0
San Joaquin @ Antioch	16	9/29/09	7.9	21.6	2427		9.3
San Joaquin @ Antioch	16	10/21/09	7.6	17.1	3063	8.6	11.9
San Joaquin @ Antioch	16	11/17/09	7.8	13.8	2523		13.5
San Joaquin @ Antioch	16	12/8/09	7.8	9.3	6598	9.4	17.5
San Joaquin @ Antioch	16	1/27/10	7.6	8.9	605	10.2	63.0
San Joaquin @ Antioch	16	1/27/10	7.6	9.0	619	10.7	
San Joaquin @ Antioch	16	2/23/10	7.6	12.7	243		15.1
San Joaquin @ Turner Cut	17	3/17/09	7.7	15.0	727	9.2	3.2
San Joaquin @ Turner Cut	17	3/31/09	8.0	16.5	839	9.5	8.4
San Joaquin @ Turner Cut	17	4/14/09	7.8	17.4	619	8.0	5.9
San Joaquin @ Turner Cut	17	4/28/09	7.8	18.4	747	6.5	10.4
San Joaquin @ Turner Cut	17	5/12/09	7.8	20.5	540	7.5	5.1
San Joaquin @ Turner Cut	17	5/27/09	7.4	24.5	460	5.8	8.4
San Joaquin @ Turner Cut	17	6/9/09	7.5	22.7	451	6.8	7.4
San Joaquin @ Turner Cut	17	6/23/09	7.7	24.1	253	7.6	4.6
San Joaquin @ Turner Cut	17	7/15/09	7.8	26.4	217	8.5	4.0
San Joaquin @ Turner Cut	17	8/4/09	7.6	25.3	242	7.7	5.0
San Joaquin @ Turner Cut	17	9/29/09	7.4	23.6	467		3.4
San Joaquin @ Turner Cut	17	10/21/09	7.5	19.0	509	7.7	3.5
San Joaquin @ Turner Cut	17	11/17/09	7.7	13.8	306		2.4
San Joaquin @ Turner Cut	17	12/8/09	7.5	9.7	374	9.8	3.8
San Joaquin @ Turner Cut	17	1/27/10	7.5	9.8	520	8.4	21.0
San Joaquin @ Turner Cut	17	2/23/10	7.6	12.7	266		20.7

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
Middle R @ Bacon Is	18	3/17/09	7.6	15.4	366	8.9	5.2
Middle R @ Bacon Is	18	3/31/09	7.9	16.2	291	9.8	6.2
Middle R @ Bacon Is	18	4/14/09	7.8	17.4	300	8.6	4.2
Middle R @ Bacon Is	18	4/28/09	8.0	17.7	310	7.2	6.1
Middle R @ Bacon Is	18	5/12/09	7.8	20.6	356	8.2	3.7
Middle R @ Bacon Is	18	5/27/09	7.6	24.3	318	7.0	5.8
Middle R @ Bacon Is	18	6/9/09	7.6	22.4	286	7.9	4.5
Middle R @ Bacon Is	18	6/23/09	8.1	20.9	395	8.5	18.0
Middle R @ Bacon Is	18	7/15/09	8.2	25.2	171	9.4	2.0
Middle R @ Bacon Is	18	8/4/09	8.9	25.2	275	12.6	3.0
Middle R @ Bacon Is	18	9/29/09	7.6	22.1	399		3.2
Middle R @ Bacon Is	18	10/21/09	7.6	19.2	341	8.8	1.9
Middle R @ Bacon Is	18	11/17/09	7.8	14.5	313		1.8
Middle R @ Bacon Is	18	12/8/09	9.6	9.3	330	9.4	2.6
Middle R @ Bacon Is	18	1/27/10	7.5	9.8	537	8.9	6.0
Middle R @ Bacon Is	18	2/23/10	8.2	12.2	315		31.9
Bethany Reservoir	19	3/17/09	8.0	14.6	456	9.3	7.4
Bethany Reservoir	19	3/31/09	8.2	15.1	372	9.8	11.4
Bethany Reservoir	19	4/14/09	8.2	16.6	356	9.1	7.3
Bethany Reservoir	19	4/28/09	7.9	14.0	442	7.9	13.5
Bethany Reservoir	19	5/12/09	8.1	20.2	395	8.0	7.1
Bethany Reservoir	19	5/27/09	7.9	21.0	371	7.6	13.8
Bethany Reservoir	19	6/9/09	8.5	18.9	394	8.8	7.7
Bethany Reservoir	19	6/23/09	7.8	23.4	294	7.5	12.0
Bethany Reservoir	19	7/15/09	8.0	24.4	232	8.1	7.0
Bethany Reservoir	19	8/4/09	8.1	21.8	420	8.4	6.0
Bethany Reservoir	19	9/29/09	7.9	20.2	557		4.4
Bethany Reservoir	19	10/21/09	7.6	17.5	469	8.9	5.3
Bethany Reservoir	19	11/17/09	8.4	13.2	426		3.8
Bethany Reservoir	19	12/8/09	8.1	8.1	496	11.2	3.2
Bethany Reservoir	19	1/27/10	7.7	9.5	613	8.2	21.0
Bethany Reservoir	19	2/23/10	8.2	12.0	505		35.7

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
DMC @ HWY 4	20	3/17/09	7.6	14.8	372	8.8	15.1
DMC @ HWY 4	20	3/31/09	7.9	16.3	320	9.5	12.4
DMC @ HWY 4	20	4/14/09	7.9	16.7	311	8.1	10.6
DMC @ HWY 4	20	4/28/09	7.8	16.2	393	7.7	12.8
DMC @ HWY 4	20	5/12/09	7.8	20.2	410	7.3	11.6
DMC @ HWY 4	20	5/27/09	7.6	23.4	364	6.1	11.5
DMC @ HWY 4	20	6/9/09	7.8	20.7	356	7.7	10.9
DMC @ HWY 4	20	6/23/09	9.0	23.2	511	10.0	15.5
DMC @ HWY 4	20	7/15/09	7.5	24.7	229	6.9	14.0
DMC @ HWY 4	20	8/4/09	7.5	23.4	405	7.2	14.0
DMC @ HWY 4	20	9/29/09	7.7	20.8	596		13.4
DMC @ HWY 4	20	10/21/09	7.5	18.1	440	8.3	4.9
DMC @ HWY 4	20	11/17/09	7.7	13.9	414		4.9
DMC @ HWY 4	20	12/8/09	7.9	8.1	827	10.4	6.8
DMC @ HWY 4	20	1/27/10	7.5	9.2	548	10.3	37.0
DMC @ HWY 4	20	2/23/10	8.1	12.1	276		25.9
San Joaquin @ Vernalis	21	3/17/09	8.6	18.4	1121	11.6	19.0
San Joaquin @ Vernalis	21	3/31/09	8.7	17.5	951	12.1	20.3
San Joaquin @ Vernalis	21	4/14/09	8.3	18.0	641	9.0	22.4
San Joaquin @ Vernalis	21	4/28/09	8.0	16.7	320	8.8	14.6
San Joaquin @ Vernalis	21	5/12/09	7.9	18.8	254	8.5	24.5
San Joaquin @ Vernalis	21	5/27/09	8.3	24.3	334	8.9	11.5
San Joaquin @ Vernalis	21	6/9/09	9.3	22.3	487	12.4	19.4
San Joaquin @ Vernalis	21	7/15/09	9.1	27.6	633	14.3	12.0
San Joaquin @ Vernalis	21	8/4/09	8.9	24.8	528	11.3	16.0
San Joaquin @ Vernalis	21	9/29/09	7.8	18.6	466		7.7
San Joaquin @ Vernalis	21	10/21/09	7.5	16.5	361	9.3	12.7
San Joaquin @ Vernalis	21	11/17/09	7.8	12.4	734		7.2
San Joaquin @ Vernalis	21	12/8/09	7.7	7.2	772	10.0	7.1
San Joaquin @ Vernalis	21	1/27/10	7.7	10.5	630	9.1	71.0
San Joaquin @ Vernalis	21	2/23/10	7.4	12.4	526		9.8

Table 2A (Continued)

Site	Site #	Date	pH	Temp (^{0}C)	EC (µmho/cm)	DO (mg/l)	Turbidity (NTU)
San Joaquin@ Jersey Pt	24	3/31/09	7.9	14.3	253	10.0	23.0
San Joaquin@ Jersey Pt	24	4/14/09	8.0	15.3	302	8.8	11.6
San Joaquin@ Jersey Pt	24	4/28/09	8.2	16.8	259	8.0	17.8
San Joaquin@ Jersey Pt	24	5/11/09	7.9	19.8	198	8.8	6.5
San Joaquin@ Jersey Pt	24	5/26/09	7.7	21.1	175	8.3	
San Joaquin@ Jersey Pt	24	6/8/09	7.9	20.3	183	8.6	8.8
San Joaquin@ Jersey Pt	24	6/22/09	7.9	22.1	194	8.1	9.3
San Joaquin@ Jersey Pt	24	7/14/09	7.9	23.2	395	8.5	7.0
San Joaquin@ Jersey Pt	24	8/3/09	7.9	21.2	1110	8.7	11.0
San Joaquin@ Jersey Pt	24	9/28/09	7.9	22.5	2015		6.7
San Joaquin@ Jersey Pt	24	10/20/09	7.7	17.6	1238	9.0	9.5
San Joaquin@ Jersey Pt	24	11/16/09	7.6	14.3	1494		9.5
San Joaquin@ Jersey Pt	24	12/7/09	7.6	9.5	1312	10.1	6.1
San Joaquin@ Jersey Pt	24	1/27/10	7.6	9.0	499	11.0	67.0
San Joaquin@ Jersey Pt	24	2/22/10	7.5	12.4	418		12.3

APPENDIX B

INTENSIVE TEMPORAL MONITORING DATA FOR RIO VISTA AND ANTIOCH.

Table 1B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Rio Vista during the 30 March to 1 April 2009 intensive temporal sampling event. Nutrient data are from Dahlgren *et al*. (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the radio telemetered continuous DWR meters.

Date	**Time**	**TN mg/l**	**TDN mg/l**	**NH4-N mg/l**	**NO3+NO2-N mg/l**	**NO2-N mg/l**	**TP mg/l**	**TDP mg/l**	**PO4-P mg/l**	**DOC mg/l**	**Tidal height (ft)**	**EC**	**Chl (µ g/)**	**pH**	**DO (mg/l)**
3/30/2009	930	0.952	0.952	0.285	0.434	0.019	0.148	0.091	0.086	2.515	4.2	239	3.6	7.7	9.7
3/30/2009	1130	1.041	0.931	0.271	0.424	0.019	0.176	0.091	0.083	2.639	2.9	241	2.5	7.7	9.6
3/30/2009	1330	1.045	1.030	0.277	0.517	0.018	0.176	0.091	0.085	2.859	1.8	251	3.9	7.7	9.6
3/30/2009	1530	0.941	0.883	0.249	0.455	0.017	0.206	0.097	0.092	2.793	1.7	280	4.5	7.8	9.7
3/30/2009	1730	0.936	0.932	0.247	0.477	0.018	0.194	0.097	0.091	2.667	3.3				
3/30/2009	1930	0.960	0.886	0.282	0.438	0.018	0.161	0.094	0.086	2.566	4.2	261	2.9	7.7	9.6
3/30/2009	2130	1.006	1.006	0.273	0.422	0.019	0.136	0.100	0.085	2.595	4.3	249	3.3	7.7	9.4
3/30/2009	2330	0.934	0.934	0.276	0.434	0.019	0.145	0.091	0.083	2.567	3.7	248	3.8	7.7	9.7
3/31/2009	130	0.888	0.877	0.268	0.425	0.018	0.148	0.088	0.085	2.570	3.3				
3/31/2009	330	0.996	0.992	0.273	0.534	0.018	0.145	0.091	0.086	2.554	4.4				
3/31/2009	530	0.997	0.955	0.280	0.457	0.018	0.148	0.088	0.085	2.520	5.5				
3/31/2009	730	0.969	0.949	0.279	0.438	0.020	0.118	0.088	0.083	2.614	5.9				
3/31/2009	830	0.894	0.888	0.270	0.444	0.021	0.124	0.088	0.083	2.721	5.6				
3/31/2009	1030	1.036	1.022	0.290	0.438	0.020	0.155	0.091	0.085	2.687	4.2	244	3.1	7.7	9.7
3/31/2009	1230	0.912	0.912	0.276	0.401	0.019	0.176	0.088	0.085	2.759	3.0	244	4.6	7.7	9.6
3/31/2009	1430	0.983	0.979	0.288	0.414	0.018	0.182	0.097	0.088	2.882	1.9	260	4.1	7.7	9.6
3/31/2009	1630	1.014	0.911	0.278	0.472	0.017	0.182	0.094	0.091	2.750	1.7	279	4.4	7.7	9.6
3/31/2009	1830	0.885	0.878	0.273	0.437	0.016	0.155	0.091	0.086	2.844	3.2	278	4.8	7.8	9.6
3/31/2009	2030	0.976	0.946	0.284	0.425	0.019	0.176	0.091	0.088	2.673	4.2	269	2.7	7.7	9.5
3/31/2009	2230	0.960	0.955	0.274	0.485	0.019	0.145	0.091	0.086	2.807	4.6	261	2.6	7.7	9.5
4/1/2009	2430	0.995	0.955	0.279	0.468	0.018	0.152	0.097	0.088	2.787	4.5	257	2.9	7.6	9.6
4/1/2009	230	0.992	0.914	0.304	0.436	0.017	0.130	0.088	0.083	2.669	4.0	244	1.9	7.6	9.5
4/1/2009	430	0.878	0.851	0.293	0.421	0.017	0.133	0.088	0.085	2.655	4.9	248	1.4	7.7	9.5
4/1/2009	630	1.027	0.914	0.293	0.460	0.019	0.148	0.091	0.088	2.591	5.8	252	3.1	7.7	9.4
mean		**0.967**	**0.935**	**0.278**	**0.448**	**0.019**	**0.157**	**0.091**	**0.086**	**2.678**		**256**	**3.3**	**7.7**	**9.6**
n		**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**		**18**	**18**	**18**	**18**

Table 2B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Rio Vista between 27 and 29 April 2009. Nutrient data are from Dahlgren *et al.* (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the continuous DWR on site meters.

Date	Time	TN mg/l	TDN mg/l	NH4-N mg/l	NO3+NO2-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Tidal height (ft)	EC	Chl (µ g/)	pH	DO (mg/l)
4/27/2009	1330	0.902	0.880	0.311	0.276	0.019	0.130	0.078	0.073	2.450	1.6	185		7.3	8.6
4/27/2009	1530	0.907	0.885	0.296	0.279	0.019	0.124	0.069	0.066	2.058	2.8	187		7.3	8.8
4/27/2009	1730	1.019	0.907	0.310	0.278	0.019	0.109	0.072	0.066	2.048	4.1	184		7.3	8.7
4/27/2009	1930	0.876	0.876	0.299	0.283	0.020	0.118	0.066	0.066	2.070	4.9	182		7.3	8.7
4/27/2009	2130	0.908	0.834	0.308	0.276	0.020	0.109	0.063	0.064	2.006	4.6	176		7.3	8.7
4/27/2009	2330	1.068	0.931	0.309	0.269	0.019	0.118	0.066	0.064	2.202	3.9	175		7.3	8.8
4/28/2009	130	0.948	0.838	0.297	0.263	0.019	0.118	0.063	0.063	2.087	4.4	175		7.3	8.8
4/28/2009	330	0.875	0.825	0.302	0.274	0.019	0.107	0.066	0.063	2.057	5.6	173		7.4	8.8
4/28/2009	530	0.891	0.761	0.297	0.293	0.021	0.121	0.066	0.064	2.147	6.4	178		7.4	8.7
4/28/2009	730	0.898	0.867	0.278	0.293	0.021	0.115	0.064	0.064	2.255	5.9	179		7.4	8.8
4/28/2009	930	1.012	0.858	0.287	0.276	0.023	0.124	0.063	0.063	2.055	4.5	180		7.4	9.0
4/28/2009	1130	0.869	0.775	0.305	0.264	0.019	0.124	0.064	0.064	1.988	3.3	174		7.3	8.8
4/28/2009	1230	0.881	0.873	0.275	0.273	0.019	0.127	0.066	0.063	2.021	2.7	171		7.3	8.8
4/28/2009	1430	0.997	0.879	0.271	0.265	0.019	0.118	0.063	0.063	1.984	1.7	176		7.3	8.9
4/28/2009	1630	0.927	0.841	0.283	0.264	0.019	0.101	0.066	0.061	1.960	2.7	182		7.4	9.0
4/28/2009	1830	0.870	0.765	0.275	0.263	0.019	0.109	0.063	0.061	1.982	4.0	183		7.5	8.9
4/28/2009	2030	0.914	0.867	0.278	0.252	0.018	0.101	0.060	0.060	1.982	4.7	178		7.4	8.8
4/28/2009	2230	0.916	0.747	0.277	0.259	0.019	0.107	0.060	0.060	1.961	4.4	172		7.4	8.8
4/29/2009	2430	0.860	0.826	0.277	0.271	0.020	0.109	0.061	0.061	1.940	3.6	173		7.3	8.9
4/29/2009	230	1.004	0.879	0.257	0.284	0.020	0.112	0.061	0.061	1.948	4.1	171		7.3	8.9
4/29/2009	430	0.826	0.826	0.261	0.264	0.019	0.112	0.060	0.060	1.994	5.3	171		7.4	8.9
4/29/2009	630	0.899	0.823	0.293	0.259	0.019	0.115	0.063	0.060	2.285	6.0	171		7.5	8.8
4/29/2009	830	0.939	0.808	0.286	0.262	0.019	0.133	0.063	0.061	2.243	5.3	175		7.3	8.9
4/29/2009	1030	0.941	0.893	0.273	0.265	0.019	0.115	0.075	0.063	2.262	4.0	170		7.3	9.0
mean		**0.923**	**0.845**	**0.288**	**0.271**	**0.020**	**0.116**	**0.065**	**0.063**	**2.083**		**177**		**7.4**	**8.8**
n		**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**		**24**		**24**	**24**

Table 3B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Rio Vista between 11 and 13 May 2009. Nutrient data are from Dahlgren et al. (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the continuous DWR on site meters.

Date	**Time**	**TN mg/l**	**TDN mg/l**	**NH4-N mg/l**	**NO3+NO2-N mg/l**	**NO2-N mg/l**	**TP mg/l**	**TDP mg/l**	**PO4-P mg/l**	**DOC mg/l**	**Tidal height (ft)**	**EC**	**Chl (µ g/)**	**pH**	**DO (mg/l)**
5/11/2009	1130	0.583	0.564	0.136	0.268	0.011	0.080	0.057	0.050	2.486	2.5	140	2.2	7.7	8.7
5/11/2009	1330	0.573	0.559	0.146	0.261	0.011	0.065	0.055	0.048	2.150	1.7	149	2.6	7.7	8.7
5/11/2009	1530	0.644	0.568	0.149	0.257	0.011	0.083	0.058	0.048	2.289	2.9	152	2.4	7.7	8.8
5/11/2009	1730	0.575	0.565	0.152	0.231	0.009	0.080	0.055	0.045	2.461	4.2	150	1.8	7.7	8.8
5/11/2009	1930	0.505	0.505	0.156	0.238	0.010	0.080	0.061	0.046	2.490	4.8	145	2.7	7.7	8.7
5/11/2009	2130	0.590	0.536	0.157	0.236	0.009	0.074	0.060	0.046	2.551	4.6	142	2.1	7.7	8.8
5/11/2009	2330	0.613	0.587	0.136	0.256	0.011	0.077	0.058	0.048	2.516	4.0	136	1.3	7.7	8.9
5/12/2009	130	0.646	0.626	0.153	0.257	0.011	0.080	0.059	0.049	2.583	4.5	138	1.3	7.7	8.9
5/12/2009	330	0.675	0.540	0.162	0.243	0.010	0.098	0.059	0.046	2.546	5.5	138	1.9	7.7	8.9
5/12/2009	530	0.606	0.551	0.153	0.246	0.011	0.111	0.051	0.042	2.567	6.0	143	1.4	7.7	8.8
5/12/2009	730	0.701	0.609	0.140	0.262	0.011	0.098	0.059	0.049	2.560	5.3	145	1.7	7.7	8.8
5/12/2009	930	0.649	0.605	0.141	0.268	0.011	0.074	0.057	0.050	2.568	4.0	138	1.9	7.7	9
5/12/2009	1100	0.693	0.595	0.133	0.271	0.011	0.077	0.054	0.052	2.462	3.1	138	2.2	7.7	8.9
5/12/2009	1300	0.699	0.646	0.145	0.267	0.012	0.074	0.053	0.050	2.517	2.0	143	1.6	7.7	8.9
5/12/2009	1500	0.677	0.620	0.145	0.262	0.012	0.074	0.057	0.048	2.491	1.8	153	1.9	7.7	8.9
5/12/2009	1700	0.573	0.534	0.136	0.260	0.011	0.074	0.059	0.049	2.467	3.3	153	1.3	7.7	8.9
5/12/2009	1900	0.605	0.511	0.170	0.231	0.009	0.068	0.057	0.046	2.260	4.3	150	1.9	7.7	8.8
5/12/2009	2100	0.506	0.476	0.162	0.242	0.009	0.062	0.059	0.049	2.304	4.6	144	1.5	7.7	8.8
5/12/2009	2300	0.605	0.520	0.162	0.242	0.011	0.065	0.053	0.050	2.392	4.1	144	1.6	7.7	8.9
5/13/2009	100	0.625	0.485	0.160	0.261	0.011	0.071	0.059	0.049	2.351	3.8	133	2.6	7.6	8.9
5/13/2009	300	0.636	0.482	0.156	0.249	0.010	0.089	0.056	0.049	2.293	4.5	137	2.1	7.7	8.9
5/13/2009	500	0.600	0.506	0.152	0.240	0.010	0.083	0.060	0.046	2.342	5.3	136	1.3	7.7	8.8
5/13/2009	700	0.696	0.500	0.152	0.257	0.011	0.108	0.059	0.048	2.382	5.4	141	1.4	7.7	8.7
5/13/2009	900	0.600	0.497	0.127	0.237	0.011	0.089	0.056	0.052	2.556	4.3	138	2.3	7.7	8.8
mean		**0.620**	**0.550**	**0.149**	**0.252**	**0.010**	**0.081**	**0.057**	**0.048**	**2.441**		**143**	**1.9**	**7.7**	**8.8**
N		**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**		**24**	**24**	**24**	**24**

Table 4B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Antioch between 30 March and 1April 2009. Nutrient data are from Dahlgren *et al* (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the continuous DWR on site meters.

Date	**TN mg/l**	**TDN mg/l**	**NH4-N mg/l**	**NO3+NO2-N mg/l**	**NO2-N mg/l**	**TP mg/l**	**TDP mg/l**	**PO4-P mg/l**	**DOC mg/l**	**Tidal height (ft)**	**EC**	**Chl (μ g/)**	**pH**
3/30/09 10:30	1.098	1.014	0.160	0.594	0.017	0.161	0.088	0.078	4.051	3.1	407	1.9	8.1
3/30/09 12:30	1.206	1.135	0.079	0.596	0.013	0.179	0.085	0.068	4.441	2.1	300	2.3	8.1
3/30/09 14:30	1.067	1.042	0.066	0.612	0.013	0.164	0.075	0.065	4.552	1.7	287	2.4	8.1
3/30/09 16:30	1.020	0.941	0.065	0.596	0.014	0.139	0.079	0.068	4.454	3.4	291	2.7	8.1
3/30/09 18:30	1.162	1.162	0.101	0.553	0.015	0.148	0.091	0.071	4.422	4.2	305	2.4	8.1
3/30/09 20:30	1.070	1.070	0.116	0.580	0.016	0.148	0.091	0.072	4.263	4.4	340	2.1	8.0
3/30/09 22:30	1.061	1.045	0.113	0.639	0.015	0.130	0.082	0.072	4.191	3.7	354	2.6	8.0
3/31/09 0:30	1.011	0.958	0.116	0.556	0.016	0.142	0.082	0.074	4.145	3.3	367	2.1	8.0
3/31/09 2:30	1.023	1.019	0.121	0.589	0.015	0.139	0.082	0.074	4.106	4.4	365	1.8	8.0
3/31/09 4:30	1.084	1.000	0.124	0.553	0.016	0.167	0.085	0.080	4.051	5.6	405	2.1	8.0
3/31/09 6:30	1.181	1.069	0.163	0.544	0.018	0.179	0.085	0.080	3.828	6.1	468	1.9	8.0
3/31/09 8:30	1.008	0.988	0.136	0.575	0.019	0.164	0.088	0.080	3.769	5.2	635	2.4	8.0
3/31/09 11:15	0.964	0.951	0.155	0.538	0.019	0.161	0.091	0.081	3.857	3.2	507	2.1	8.0
3/31/09 13:15	0.941	0.941	0.085	0.580	0.014	0.152	0.079	0.068	4.381	2.2	330	2.4	8.0
3/31/09 15:15	1.034	0.903	0.066	0.579	0.013	0.136	0.075	0.066	4.505	1.7	296	2.5	8.0
3/31/09 17:15	0.980	0.924	0.065	0.590	0.013	0.124	0.075	0.066	4.384	3.2	311	2.0	8.1
3/31/09 19:15	0.985	0.878	0.086	0.565	0.015	0.152	0.079	0.071	4.231	4.2	315	1.9	8.1
3/31/09 21:15	1.103	0.977	0.118	0.570	0.016	0.158	0.085	0.074	4.129	4.6	363	1.8	8.0
3/31/09 23:15	1.055	0.940	0.105	0.570	0.016	0.133	0.082	0.075	4.065	4.3	447	1.9	8.0
mean	**1.055**	**0.998**	**0.107**	**0.578**	**0.015**	**0.151**	**0.083**	**0.073**	**4.201**		**373**	**2.2**	**8.0**
n	**19**	**19**	**19**	**19**	**19**	**19**	**19**	**19**	**19**		**19**	**19**	**19**

Table 5B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Antioch between 27 and 28 April 2009. Nutrient data are from Dahlgren *et al* (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the continuous DWR on site meters.

Date	**TN mg/l**	**TDN mg/l**	**NH4-N mg/l**	**NO3+NO2-N mg/l**	**NO2-N mg/l**	**TP mg/l**	**TDP mg/l**	**PO4-P mg/l**	**DOC mg/l**	**Tidal height (ft)**	**EC**	**Chl (µ g/)**	**pH**
4/27/09 14:15	0.706	0.691	0.029	0.279	0.009	0.098	0.052	0.048	3.190	2.0	285	4.6	8.4
4/27/09 16:15	0.750	0.638	0.033	0.292	0.008	0.101	0.046	0.042	3.140	3.8	289	5.2	8.5
4/27/09 18:15	0.697	0.675	0.021	0.341	0.009	0.118	0.049	0.048	3.030	4.5	415	6.3	8.4
4/27/09 20:15	0.765	0.737	0.046	0.384	0.012	0.130	0.055	0.055	2.804	4.5	747	4.9	8.2
4/27/09 22:15	0.991	0.787	0.059	0.396	0.013	0.115	0.063	0.057	2.633	3.7	895	5.2	8.2
4/28/09 0:15	0.774	0.700	0.034	0.381	0.011	0.098	0.055	0.054	2.782	3.8	731	6.2	8.2
4/28/09 2:15	0.775	0.718	0.023	0.373	0.011	0.101	0.055	0.052	2.695	5.3	619	4.8	8.3
4/28/09 4:15	0.817	0.781	0.058	0.393	0.013	0.124	0.063	0.057	2.634	6.2	1065	5.1	8.1
4/28/09 6:15	1.022	0.786	0.085	0.430	0.017	0.130	0.063	0.063	2.211	6.2	1966	4.3	8.1
4/28/09 8:15	1.202	0.777	0.083	0.441	0.017	0.176	0.069	0.069	2.085	4.6	2260	3.6	8.1
4/28/09 10:15	0.957	0.774	0.083	0.407	0.014	0.153	0.060	0.060	2.538	3.4	1166	5.2	8.1
4/28/09 12:15	0.732	0.720	0.017	0.320	0.009	0.112	0.046	0.046	3.004	2.2	478	4.6	8.4
4/28/09 13:30	0.766	0.617	0.012	0.314	0.009	0.107	0.046	0.042	3.037	1.6	396	6.1	8.5
4/28/09 15:30	0.701	0.553	0.007	0.278	0.008	0.092	0.040	0.040	3.134	2.3	294	3.7	8.6
4/28/09 17:30	0.775	0.602	0.009	0.310	0.010	0.095	0.043	0.040	2.949	3.9	300	5.5	8.7
4/28/09 19:30	0.849	0.682	0.017	0.328	0.011	0.109	0.046	0.043	2.988	4.5	446	5.4	8.6
4/28/09 21:30	1.032	0.752	0.033	0.366	0.011	0.112	0.052	0.048	2.871	4.3	672	4.9	8.4
4/28/09 23:30	0.765	0.756	0.036	0.369	0.011	0.109	0.052	0.049	2.807	3.5	754	5.0	8.4
4/29/09 1:30	0.792	0.749	0.023	0.356	0.010	0.107	0.052	0.045	2.952	3.8	599	5.8	8.4
4/29/09 3:30	0.750	0.657	0.034	0.353	0.011	0.107	0.055	0.046	2.754	5.2	531	5.1	8.4
mean	**0.831**	**0.708**	**0.037**	**0.356**	**0.011**	**0.115**	**0.053**	**0.050**	**2.812**		**745**	**5.1**	**8.4**
n	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**		**20**	**20**	**20**

Table 6B. Nutrient and water quality concentrations at the DWR water quality monitoring pier at Antioch between 12 and 13 May 2009. Nutrient data are from Dahlgren *et al* (2010) while tidal height, EC, chlorophyll, pH and dissolved oxygen (DO) are from the continuous DWR on site meters.

Date	TN mg/l	TDN mg/l	NH4-N mg/l	NO3+NO2-N mg/l	NO2-N mg/l	TP mg/l	TDP mg/l	PO4-P mg/l	DOC mg/l	Tidal height (ft)	EC	Chl (μ g/)	pH
5/11/09 12:30	0.677	0.573	0.045	0.293	0.007	0.080	0.054	0.052	2.799	1.9	228	3.1	7.7
5/11/09 14:30	0.682	0.583	0.043	0.293	0.007	0.102	0.057	0.054	2.797	2.8	240	3.4	7.8
5/11/09 16:30	0.700	0.542	0.036	0.298	0.007	0.086	0.054	0.050	2.789	4.3	216	2.5	7.8
5/11/09 18:30	0.732	0.558	0.062	0.309	0.008	0.083	0.054	0.053	2.737	4.9	233	3.2	7.8
5/11/09 20:30	0.673	0.670	0.076	0.311	0.008	0.086	0.054	0.054	2.656	4.8	251	2.4	7.7
5/11/09 22:30	0.706	0.630	0.093	0.313	0.009	0.085	0.057	0.056	2.611	4.2	254	2.5	7.7
5/12/09 0:30	0.731	0.681	0.092	0.314	0.009	0.083	0.057	0.056	2.622	4.5	251	3.0	7.7
5/12/09 2:30	0.633	0.558	0.088	0.307	0.010	0.089	0.057	0.057	2.688	5.6	253	3.1	7.7
5/12/09 4:30	0.651	0.631	0.131	0.311	0.010	0.102	0.066	0.058	2.560	6.2	250	2.9	7.7
5/12/09 6:30	0.659	0.603	0.121	0.315	0.010	0.089	0.057	0.058	2.526	5.6	251	2.5	7.7
5/12/09 8:30	0.659	0.598	0.132	0.312	0.010	0.089	0.060	0.060	2.520	4.2	251	2.6	7.7
5/12/09 10:30	0.595	0.551	0.077	0.315	0.010	0.089	0.060	0.057	2.696	3.0	243	2.4	7.7
5/12/09 12:30	0.630	0.620	0.052	0.303	0.009	0.077	0.054	0.053	2.993	2.0	223	3.1	7.8
5/12/09 14:30	0.674	0.630	0.036	0.280	0.007	0.067	0.060	0.050	3.031	2.1	212	3.8	7.8
5/12/09 16:30	0.716	0.636	0.038	0.298	0.008	0.068	0.051	0.050	2.995	3.8	207	2.4	7.9
5/12/09 18:30	0.806	0.721	0.058	0.306	0.008	0.077	0.054	0.052	2.911	4.6	217	3.7	7.8
5/12/09 20:30	0.623	0.581	0.081	0.318	0.009	0.077	0.063	0.056	2.737	4.7	238	3.1	7.8
5/12/09 22:30	0.649	0.607	0.078	0.313	0.009	0.083	0.057	0.056	2.710	4.1	238	2.7	7.8
5/13/09 0:30	0.747	0.630	0.078	0.314	0.009	0.080	0.063	0.056	2.728	4.1	238	3.1	7.7
5/13/09 2:30	0.664	0.618	0.082	0.312	0.009	0.086	0.057	0.056	2.693	5.0	239	2.3	7.8
5/13/09 4:30	0.703	0.616	0.086	0.314	0.009	0.083	0.060	0.056	2.650	5.6	237	2.9	7.7
5/13/09 6:30	0.676	0.652	0.144	0.318	0.011	0.098	0.063	0.060	2.609	5.5	242	2.5	7.7
5/13/09 8:30	0.683	0.650	0.131	0.315	0.012	0.092	0.069	0.060	2.814	4.2	241	2.5	7.7
5/13/09 10:30	0.698	0.648	0.076	0.312	0.010	0.077	0.057	0.056	2.749	3.0	235	2.7	7.7
mean	**0.682**	**0.616**	**0.081**	**0.308**	**0.009**	**0.085**	**0.058**	**0.055**	**2.734**		**237**	**2.9**	**7.7**
n	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**		**24**	**24**	**24**

APPENDIX C

REVIEWER COMMENTS

Dr Carol Kendall, U.S. Geological Survey

Comment #1 I appreciated having a chance to read your well-written and timely report. You folks did an especially thorough job of summarizing the important points of your report in the executive summary and in the algal impairment section near the end of the report. I think your "lumped" or "big picture" approach to data analysis (where you mostly compare average values at the various sites) is a nice complement to my more nitty-gritty approach (which focuses on site-to-site downstream differences on the various sampling dates). Below are some comments, keyed to the page (P#) and paragraph (p#). I hope you find them useful. My main criticism is the first one listed below; the rest are minor suggestions for improvement.

P2, p2: I have always liked your poetic statement about [NH4] and [NO3] being "the mirror images of each other". But I think this simplification hides the fact that there are significant discrepancies between the changes in [NH4] and [NO3] between (1) adjacent sites on the different collection dates (e.g., Isleton and Rio Vista), and (2) between the average values for sites (e.g., Hood and Chipps). So while at first glance it appears that the decreases in [NH4] are mirrored by corresponding (but negative) changes in [NO3], in detail the changes do NOT agree. This is clear when you compare the changes in the average [NH4] and [NO3] for paired upstream and downstream sites (e.g., Hood vs Chipps) on your Figure 2.

Remember the weird "cumulative concentration" plots I circulated last fall? These were a first attempt to compare how [NO3] changed with changes in [NH4] as the water flowed from Hood downstream into the Delta on different sampling dates. Guerin and I have now moved to comparing calculated nitrification rates for NH4 and NO3 as an improved way to deal with these discrepancies.

In general, there is a lot more loss of NH4 than gain in NO3 (or NO3+NO2) between adjacent sites in the upstream part of the transects (this is especially obvious with the more detailed sampling done as part of Parker's two 25-site transects last year). A good question is whether the nutrient ratio discrepancy (which I often calculate as Δ[NH3]/Δ[NO3]) between sites "mostly" reflects (1) NH4 that is lost by processes other than nitrification (i.e., uptake by algae and/or bacteria, or other processes), (2) NO3 that is lost by uptake or other processes, or (3) oscillations in chemistry and resultant poor mixing caused by frequent temporal changes in effluent loads. Of course, in places where there are significant inputs of new water (e.g., between Isleton and Rio Vista, or near Pt Sacto), some of the discrepancy is certainly caused by the different nutrient concentration ratios in the new water being added to the river. We are using our recent isotope data to account for the discrepancies, both in terms of processes (uptake of NH4 vs NO3) and in terms of amounts of new water in the channel (e.g., how much NH4 could be contributed between Isleton and Rio Vista).

In short, your "mirror" simplification leads you to make conclusion statements like "suggesting that there were no other large nitrogen sources or sinks" -- that I am not so sure is true. But maybe we are arguing about how large is large? The nutrient ratio discrepancies between some sites on the transect seems pretty big to me. Nitrification is certainly the major process that affects nutrient speciation and concentrations in the Sacramento River, but I think it is too early to dismiss the possible importance of other factors.

Response #1. The main question here appears to be why there is a lot more loss of NH4 than gain in NO3 (or NO3+NO2) between adjacent sites in the upstream part of the transects if nitrification is the main process. I think a large part of the variation in nutrient concentrations in the river between Hood and Isleton is being driven by the fact that the river is tidal. Effluent loads from the SRWTP are reasonably constant but the amount of River water moving past the plant into which the effluent is being mixed varies through the tidal cycle. Sacramento River flow rates at Freeport are low at high tide and high at low tide. This produces a natural twice a day sinusoidal oscillation in the effluent signal in the river. Of coarse, ammonia varies more than nitrate because the SRWTP effluent contains little nitrate but lots of ammonia. For example, on our second sampling event on 29-30 March 2009 River discharge at Freeport varied from 3,363 to 15,335-cfs. This would produce a 4.6-fold change in ambient ammonia concentrations but not nitrate down the river. The Regional Board sampling may not have picked up much of this variability as we collected the river samples over a couple of hours. This was part of the reason why we did the high frequency temporal sampling at Rio Vista. We wanted to see whether tidal mixing in the Sacramento deepwater ship channel had homogenized the signal by Rio Vista. The answer appears to be affirmative.

On the importance of nitrification, our data are clear that nitrogen inputs from the SRWTP and subsequent nitrification is the primary nitrogen cycling process in the Delta. The evidence is that TDN (DON+NH4+NO2+NO3) increases 2.6X between Garcia Bend and Hood, above and below the SRWTP (Table 5). The increase is statistically significant at a $P<10^{-7}$. TDN concentrations do not exhibit a change of this magnitude anywhere elsewhere in the Delta suggesting that this is the major nitrogen source. TDN concentrations are similar between Hood and Chipps Island (P>0.15, Figure 2A) again suggesting no additional large sources or sinks of dissolved nitrogen. The diurnal data is also consistent with this conclusion. TDN sampling at Rio Vista and Antioch do not reveal large tidal or day/night cycling (Figure 7A). This does not mean that other nitrogen cycling processes are not at work in the Delta, including those listed by the SRCSD, however, our data suggest these processes are quantitatively less important. The Carol Kendall isotope data analysis should confirm or refute the Regional Board hypothesis.

Minor comments:

P5, p2: **Comment #2**. You might give more specific recommendations about numbers of sites, locations, specific measurements, etc. I would, of course, add isotope samples of various kinds to any future monitoring plan. Other items on my "monitoring program" wish list are NBOD measurements, measurement of additional conservative tracers like sulfate and chloride, more detailed sampling over the WWTP plume, avoidance of seemingly weird sites like Parker's DCC site and your Walnut Grove site where we usually see a dip in [NH4], careful attention to tide levels during sampling, sampling of all important input waters (like Miner and Steamboat Sloughs, and the SJR), getting more information on hourly changes in effluent loads and quality from SRWTP to match the dates and times of future transects, etc. **Response #2** I have added a short section at the end of the report recommending some follow up actions. I hope this will become the beginning of the discussion about next steps.

P6, p4: I think additional temporal sampling is especially critical at upstream locations. The report prepared by SRCSD last fall (and distributed to the NH4 CWT) has a table showing lots of downstream oscillations in [NH4] that the authors attribute to oscillations in effluent loading. Is this the cause of weird oscillations in chemistry often seen at Walnut Grove (and at the CRS (i.e., DCC) site sampled by Parker)?

P9, p2: **Comment #3** You should include a third important flowpath: down the SR to Courtland, down thru Steamboat and Miner Sloughs to Cache Slough, and then joining the main channel at Rio Vista. Roughly half the water at Rio Vista gets there via this important and under-sampled flowpath. **Response #3**. Text changed

P9, p3: **Comment #4** see the comments for P2, p2 above. See **Response #1**

P10, p2, 4th sentence: **Comment #5** could you explain this statement a bit more? I didn't understand. **Response #4** No change in text. Mean daily flow is loosely correlated with water velocity because the channel cross section is fixed. Higher daily flow result in faster water travel rates and a lower residence time.

P11, p3: **Comment #6**. I think there are much larger diel and tidal effects in the river (especially upstream of Pt Sacto) than your figure 7B would suggest. We don't have a lot of data (mostly sampled by Parker) for sites that were sampled at different stage levels on the same day (or next day), but the data we have suggests substantially different chemistries for the paired samples. This has made me very nervous about comparing the chemistry of samples collected on different tidal cycles. Also, the detailed [NH4] data in the fall 2009 SRCSD report show large oscillations in downstream values for samples collected on the outgoing tide. More data needed! **Response #5**. Comment noted

P14, p2:**Comment #7** replace XXX with correct date. **Response #6** Text changed.

P15-16: great summary of findings.

P18, p5: **Comment #8** is Randy writing a report of some sort? **Response #7** Dr. Dahlgren will provide a final data report summarizing analytical methods and QA/QC.

Figure 2: **Comment #9** need to specify that the units for the NH4 and NO3 plots are ppm-N. **Response #8** Text changed

Figure 3: **Comment #10** I think the PO4 units are ppm-P. **Response #9** Text changed.

Figure 7A: **Comment #11** Is this really ppm NO3 -- or is it ppm NO3-N? I think probably the latter. **Response #10** Text changed

Table 2: **Comment #12** are these MDLs for mg/L for all constituents, or are some of them for mg-N/L or mg-P/L ? The units for EC are usually µS/cm3, not what you have here. **Response #10** Text changed.

Table 4: **Comment #13** are all these mg/L or are some of them mg-N/L or mg-P/L ? **Response #11** Text changed

Table 5: **Comment #14** would flow-weighted averages be more useful? **Response #12** It depends on what you want to use the table for. A flow weighted table would change the average concentration at each site but not the average change in nutrient levels or their associated p-value. My purpose for including Table 5 was to document the change in ambient nutrient concentrations caused by the introduction of waste from the SRWTP.

Table 1A: **Comment #15** I was sorry you rounded the data off to 0.01. A lot of my calculations needed the 0.001 detail of the original dataset. **Response #13.** I will provide the original data set to anyone wishing to have it. I have rounded the values off consistent with the reported U.C. Davis MDL values.

Table 2A: **Comment #16** Could you add the sampling times to the table? Given the importance of tidal cycle on effluent flow and chemistry, collection times are essential. **Response #14** See response #13. I will include the actual sampling time with the raw data.

Dr Randy Dahlgren, UC Davis

I have reviewed your report and made a few minor suggestions using track changes in the attached doc.

<u>Comment #17</u> I don't like the use of "toxic endpoints". I suggest "toxicity criteria" instead. If you agree, you should check the entire document for this wording. **<u>Response #15</u>**. I do not like "toxicity criteria" for use with individual species as it may be confused the reader with recommended U.S. EPA criteria values. I have changed the document to "toxicity endpoints".

<u>Comment #18</u> I also suggest using "an annual hydrologic cycle" or "hydrologic year" to specify the temporal aspect of the hydrologic cycle. **<u>Response #16</u>** Text changed.

<u>Comment #19</u> In table 3, the mean value for NH4 spike/recovery should be "101.3%" not 123.4%. **<u>Response #17</u>** Text and Table changed.

<u>Comment #20</u> Table 4, the DOC values for 11/16 are very high (13 and 14 mg/L). Did these values get transposed correctly? It almost appears that these were the sample identification numbers (#13 and #14). These are delta peat soil DOC values. **<u>Response #18</u>** Values confirmed, no changes made.

<u>Comment #21</u> In looking at figures such as Figure 3, do you think the river is completely mixed at the Hood sampling point? The P values especially drop at Walnut Grove leaving me searching for a mechanism. My thought is that the river is not completely mixed yet. The pH is low relative to WG as well. **<u>Response #19</u>**. I agree that the mean of both TDN and TDP appear low at Walnut Grove. The river is supposed to be fully mixed by there. Part of the variation in nutrient levels is undoubtedly being caused by the fact that the river is tidal, see my **<u>response #1</u>**, but this does not explain why values are consistently lower at Walnut Grove.

<u>Comment #22</u> Table 2A page 57: Are the EC values of 10 to 14 dS/m correct here on 12/8? This is approaching 50% seawater? **<u>Response #20</u>**. The value is correct. This was before there was a strong river outflow and there was considerable seawater intrusion.

State Water Contractors and Delta Mendota Water Authority

(Figures in Comment letter not included)

GENERAL COMMENTS:

<u>Comment #23</u> ***The Statement that the Sacramento Regional Wastewater Treatment Plant (Treatment Plant) Discharge is not Causing Algal Toxicity is Not Supported by the Data.***

The Water Agencies strongly disagree with the conclusion stated in the report that "algal induced toxicity from the Treatment Plant does not appear to be the cause [of chlorophyll declines in the Sacramento River] as the chlorophyll decline consistently began above the POTW." This statement is based on the erroneous observation that chlorophyll consistently declines between Tower Bridge and Garcia Bend, upstream of the Treatment Plant. In fact, chlorophyll only declined between these two stations during 60% of the surveys, and as apparent in overlapping error bars in Figure 4A of the report, the difference between Tower Bridge and Garcia Bend chlorophyll data is not statistically significant. **Response #21** I stand by my observation that chlorophyll levels began to decline above the SRWTP. I reanalyzed the Tower Bridge and Garcia Bend data with a 2-tailed paired t-test. The decline in both chlorophyll and phaeophytin are statistically significant ($P<0.037$ and $P<0.046$). Chlorophyll and phaeophytin declined by 22 and 19 percent, respectively. I would not expect much growth in such a deep turbid river but remain surprised and perplexed that chlorophyll levels would decline by a 1/5th in a 7-mile river reach.

Comment #24 Second, the data also indicate that the chlorophyll decline between Tower Bridge and Garcia Bend is due to continued mixing and dilution with high quality American River water down this reach. Several pieces of evidence support this hypothesis. Salinity at Garcia Bend is lower than salinity at Tower Bridge. The most likely reason salinity would drop from upstream to downstream is if there is dilution from another source of water. The only other major source of water in this area is the American River.

There is also a strong association between the difference in salinity between Garcia Bend and Tower Bridge and the difference in chlorophyll *a* at these locations . The more that the salinity drops from Tower Bridge to Garcia Bend, apparently due to dilution with American River water, the more the chlorophyll *a* drops between these two stations. **Response #22.** This is a great observation. I had not noticed the consistent drop in EC between Tower and Garcia Bend. I have tried to make a rough estimate of how much of the drop in chlorophyll a could be accounted for by having an unmixed sample at Tower Bridge. I did this by combining our data with that of Randy Dahlgren. Randy collected 102 EC and chlorophyll samples on the American River at Discovery Park between October 99 and September 03. Average EC and chlorophyll at Discovery Park were 58 $\mu mho/cm^3$ and 1.0 ug/l. First I did a mass balance using the EC at Tower, Garcia Bend and Discovery Park to calculate how much unmixed American River water, on average, was at Tower. The answer was 11%. Next, I used the chlorophyll levels at Tower and Discovery Park to estimate what chlorophyll levels should have been in a fully mixed Tower sample and compared this with the measured value at Garcia Bend. The American River could account for about a third of the drop in chlorophyll between Tower and Garcia Bend. While important, this does not appear to be sufficient large to explain the drop in concentration. The detailed calculations are available should anyone wish to review them.

Comment #25 Third, as the report states, "*care should be exercised in interpreting the chlorophyll results*" due to the high relative percent differences in the laboratory and field duplicates. The chlorophyll concentrations are all very low (<1 to 5 µg/L) and near the laboratory detection limit of 0.5 µg/L. The average difference in chlorophyll between Tower Bridge and Garcia Bend is less than 1.0 µg/L. Given all these factors, it is clearly too strong a conclusion that the Treatment Plant does not induce algal toxicity downstream of the discharge. **Response #23** I agree that the lack of precision in chlorophyll measurements makes it difficult to estimate differences between any two stations but the drop between Tower Bridge and Isleton is about 60 percent. That is clearly real and deserves follow up.

Comment #26 In fact, the data further support that the Treatment Plant does contribute to declines in algal biomass downstream of its discharge. Figure 4 (not included here but available upon request) presents the relationship between the changes in chlorophyll and ammonium levels above and below the Treatment Plant. When the Treatment Plant discharge increases Sacramento River ammonium levels by more than 0.3 mg/l-N of ammonium, chlorophyll drops by a factor of one half to three quarters compared to chlorophyll above the Treatment Plant. When the ammonium increase is smaller, chlorophyll decreases by a smaller amount and can even increase. **Response #24**. This is an interesting observation and perhaps you are right that the SRWTP is, at least partially, responsible for the loss in chlorophyll down the river. However, Parker et al., (2010) do not observe a decrease in primary production above and below the SRWTP when their rates are corrected for the amount of chlorophyll in the sample. Theoretically, I can understand how a chemical in the effluent might damage algal cell integrity and this would manifest itself as a loss in primary production or even in chlorophyll concentration but I cannot understand why we do not measure a concomitant increase in phaeophytin. The distances used in your analysis are about 25 miles (Tower Bridge to Walnut Grove) or about 1 days travel time. Phaeophytin should be stable for this length of time. Regardless, I have amended the text to indicate that a loss in chlorophyll is observed down river and the cause is not known. I do not feel comfortable at this time ascribing the cause of the decline to any one or combination of factors.

Comment #27 *Hood is too Far Downstream of the Treatment Plant Discharge to Adequately Assess the Impacts on Aquatic Life.*
Conclusions about the impacts of the Treatment Plant discharge on water quality and aquatic life cannot be based solely on monitoring at Hood. The Sacramento River at Hood is monitored frequently by the Department of Water Resources as representative of the quality of water in the Sacramento River in the eastern Delta, and it is a good location to determine far-field impacts of the discharge. It is, however; too far downstream from the Treatment Plant discharge to measure the near-field effects of the discharge on river water quality and aquatic life. Monitoring should be conducted immediately downstream of the discharge to evaluate the impacts of the discharge on nutrient concentrations and toxicity in the river. The Water Agencies urge you to include a discussion in the report about the distance of Hood from the Treatment Plant discharge and that conclusions about effects in the immediate vicinity of the discharge cannot be drawn from this study.

In order to address the near-field effects of the Treatment Plant discharge on river water quality and aquatic life, the Water Agencies suggest you inquire if receiving water data exist during the timeframe of your study from either the Sacramento Regional County Sanitation District compliance monitoring reports and/or from the Sacramento Coordinated Monitoring Program. **Response #25**. The Water Agencies are correct that other ambient water quality data exist, including information for the river between the SRWTP discharge and Hood. I have not reviewed this information as part of this report as I do not know how the information was collected and cannot speak to its accuracy and precision. I have amended the text in several places to indicate that the conclusions of this report are not to be extended to the river reach between the discharge point and eight miles downstream at Hood.

Comment #28 *Toxic Conditions May Exist Immediately Downstream of the Treatment Plant Discharge.*

The toxicity discussion in the Executive Summary should be expanded to include a discussion of the safety factors. The report should disclose that Hood is eight miles downstream of the Treatment Plant discharge and no data were collected immediately downstream of the discharge. The ammonia toxicity analysis showed an average safety factor for juvenile fish of 16 at Hood. What did the individual monthly results show? What was the lowest safety factor at Hood? It can be presumed that the toxicity safety factor immediately downstream of the discharge is substantially lower. It may even be possible that chronic toxicity conditions exist immediately downstream of the discharge for juvenile fish. The mussel results are even more startling, with safety factors between 1 and 2 at Hood. This indicates that ammonia toxicity to mussels may occur in the river immediately downstream of the discharge. In fact, based on data reported to the Regional Board by the Treatment Plant, ammonia levels at R3 exceeded the draft EPA criteria with mussels present in 41% of the samples analyzed in 2008. Similarly, the data presented on delta smelt toxicity indicate there is a potential for toxicity, particularly chronic toxicity, immediately downstream of the discharge. In fact, based on data reported to the Regional Board by the Treatment Plant, un-ionized ammonia levels at R3 exceeded the estimated chronic NOEC of 0.0055 mg/L in 35% of the samples analyzed in 2008.

US Fish and Wildlife Service (USFWS) beach seine monitoring caught delta smelt both upstream and downstream of the Treatment Plant. In fact, delta smelt can be found in the area of the Sacramento River up to and above the Treatment Plant's discharge from December through June. However, the survival or the length of stay of individual delta smelt in this area is unknown. (*Three figures were included in comment letter documenting existence of smelt above and below the SRWTP that are not reproduced here but are available upon request)*

In addition, this year's USFWS beach seine surveys also caught delta smelt at Garcia Bend and at Clarksburg, which are approximately three miles upstream and downstream of the Treatment Plant.4 The fact that delta smelt have been found upstream and downstream of the Treatment Plant suggests that delta smelt are passing through the discharge area multiple times and may also reside for periods of time near the discharge. While the USFWS beach seine surveys are generally undertaken along the shore, delta smelt also reside mid-channel in deeper open water. **Response** See **response #25** above and I again reiterate, *no exceedance of the chronic US EPA criteria for juvenile fish or mussel was observed anywhere downstream of Hood..*

Comment #28 *Phytoplankton Community Composition Data are Needed.*

The Water Agencies concur with your recommendation on page 16 that follow-up studies are needed to continue assessing the ecological effect of the changes in nutrient concentrations by the Treatment Plant on phytoplankton community composition in the Delta. However, the Water Agencies disagree with the statement on page 3 of the draft report that "[t]he impact of elevated ammonia concentrations on algal species composition in the Delta is not known…". The recent work by Dr. Patricia Glibert has shown a link between the ammonia discharged from the Treatment Plant, the switch from a diatom-based phytoplankton community to a flagellate/cyanobacteria-based community in the lower Sacramento River, and the decline in delta smelt. There is also a wealth of published studies from other freshwater, estuarine and marine systems around the world that document the impact of elevated ammonium concentrations, changes in N:P ratios, and changes in NH_4:NO_3 ratios on algal species composition. Please refer to pages 15-20 of the Water Agencies' *Comments on Aquatic Life and Wildlife Preservation Issues Concerning the Sacramento Regional Wastewater Treatment Plant NPDES Permit Renewal* (attached) for a sampling of these other studies.

We urge you to also recommend that follow-up studies include phytoplankton, including picoplankton, identification and enumeration along the entire Sacramento River transect below the Treatment Plant as well as immediately upstream and downstream of the Treatment Plant discharge. Species identification is needed to determine if the size fractionation of water samples actually distinguishes between diatoms and flagellates and cyanobacteria. **Response #27**. Noted

Comment #29 *Report Should Include a Conclusions and Recommendations Section*
A succinct discussion of the key findings and recommendations for future studies would assist decision-makers in understanding the results of this study. **Response #28**. I have included a short section at the end of the report recommending some follow up studies.

Sacramento Regional County Sanitation District

(Figures in Comment letter not included)

Comment #30 This Nutrient Report identifies the primary focus for future research is evaluating nutrient level effects on phytoplankton abundance and species composition in the Delta. SRCSD supports research in the area of determining what is driving phytoplankton biomass and composition, but believes that other environmental factors, such as hydrologic residence time, temperature, benthic grazing, etc., which has changed over time, should be considered in addition to nutrients. **Response.** See response #27 above

SRCSDs comments provided below are to assist Central Valley Regional Water Quality Control Board staff in generating a final report. The comments are divided into three areas: general comments on the Executive Summary, specific comments on the content of the report, and minor edits. The general comments on the Executive Summary primarily cover language that could easily be misinterpreted, while the specific comments are more technical in nature and are intended to help the scientific understanding of nutrients role in the Bay-Delta.

General Comments on Executive Summary

Comment #31 Risk evaluation methods used in this report are extremely conservative and agree with multiple study findings by Werner et al. (2009a,b) and with National Recommended Water Quality Criteria (EPA 1999, 2009). The ambient concentrations of ammonia were lower than a conservative benchmark where there is no effect – the No Observed Effect Concentration (NOEC) for delta smelt - rather than one that causes threshold effects and would signify the presence of risk. The Executive Summary, Page 3, 2nd paragraph states that "The upper 95 percent confidence limit of these values was 19-times lower than the 7-day no observed effect concentration for smelt survival **suggesting** [emphasis added] that ambient ammonia levels in the Delta were not acutely toxic during the study." We suggest you change this conclusion to be more definite, such as "the data indicate that there is no potential for risk due to the acute toxicity of ambient ammonia to delta smelt within the area studied." **Response #29** We agree that a 19-fold safety factor is quite large. However, the Delta is large and includes over 1,100 miles of channels and backwaters. This study did not sample at all locations and times in the Delta. So, it is impossible to definitely say that not toxicity occurred. Also, please see **response #25** above. No change in text.

Comment #32 All three purposes of the study (as described on page 4) should be included in the Executive Summary. Currently only collecting nutrient data at key locations in the Delta to characterize concentrations and compare with reported toxic endpoints for sensitive local aquatic organisms is included in the Executive Summary. The following two purposed should also be stated in the Executive Summary:

1. Determining diurnal and tidally induced changes in nutrient concentrations at key locations to ascertain short-term variability,

2. Comparing water quality measurements collected in this study with remote sensing values reported by CDEC to determine the comparability of the two data sets.

Response # 30 No change in text. All three objectives are fully discussed in the text but only the most important conclusions are described in the Executive Summary. All the information provided in the Executive Summary is entirely consistent with the conclusions for objectives #2 and #3.

The Executive Summary contains some statements that potentially could easily be misinterpreted. One example is the final paragraph of the Executive Summary:

"Other research has now demonstrat[ed] that ammonia concentrations greater than 0.056 mg [N]/L prevent development of algal blooms in Suisun Bay but not in the Sacramento River below the SRWTP. No information presently exists on the effect of this concentration of ammonia on algal production in the Delta."

There are 3 elements of this passage which are potentially misinterpreted:

Comment #33. The first sentence of the passage promotes a common misconception that ammonia concentrations below 4 µM (0.056 mg/L ammonia-N) are a predictor of algal blooms in Suisun Bay. In the ambient time series for Suisun Bay presented in Dugdale et al. 2007[1], algal blooms occurred only twice out of five periods when ammonium concentrations fell below 4 µM (Figure omitted here). This amply illustrates that other factors frequently prevent blooms in Suisun Bay even when ammonium concentrations are below the "Dugdale" threshold.

These factors may vary seasonally (temperature, residence time, turbidity, salinity stratification, benthic grazing), but the pattern indicates that it may not be reasonable to expect large dividends in phytoplankton biomass if ammonium concentrations are reduced in the brackish Delta. The fact that low ammonium periods in Dugdale's time series were not always within the April-May spring bloom window does not diminish the significance of non-nutrient-based regulation of phytoplankton biomass.

The large June-September phytoplankton biomass observed in the confluence zone and Suisun Bay prior to the arrival of *Corbula* (Figure omitted here) illustrates that summer was historically a period of greater algal abundance than spring in Suisun Bay. Spring diatom blooms did not historically dominate annual production in Suisun Bay, and as Dugdale's time series illustrates, ammonium levels are an inadequate explanation for the current dearth of phytoplankton in summer in the brackish Delta. **Response #31**. Your comment is no longer germane as I changed the text to address Dr Dugdale **comment #47**.

Comment #34 The first sentence should be modified to say "...but not in the Sacramento River *between the SRWTP and Suisun Bay*." The sentence as written can incorrectly imply that different growth responses to ammonium in the Sacramento River, compared to Suisun Bay, were only observed immediately downstream of the SRWTP. However, the available datasets (in the Regional Board report and in an SFSU report and 2009 poster)[2] indicate that the relationships between ammonium uptake and phytoplankton biomass and growth rates differ from those in Suisun Bay along the full extent of the Sacramento River within the Delta. **Response #33**. I have changed the text in response to Dr Dugdale **comment #47**. Dr Dugdale indicates that he has a manuscript in preparation that addresses your comment (comment #47). However, we have not had an opportunity to review the manuscript and so still maintain that the response of the phytoplankton community to ammonia is not known for the River reach between Rio Vista and Suisun Bay.

Comment #35 The sentence *"No information presently exists on the effect of this concentration of ammonia on algal production in the Delta"* could easily be misinterpreted or taken out of context. The Sacramento River between the American River and Suisun Bay is an important part of the Delta, and as indicated above, the SFSU study now provides information about algal production in the Sacramento River throughout its course within the Delta. Given that Sacramento River water is diverted into the central and south Delta by export operations, it is not unreasonable to hypothesize that relationships between phytoplankton and ammonium observed downstream of SRWTP within the main Sacramento River channel may also apply to riverine phytoplankton that are transported out of the main channel into the interior Delta. See **response #33** above.

Comment #36 In the Executive Summary and on page 9, it is stated "*Microbial transformation of ammonia to nitrite and nitrate appears to be the major biological* *process at work in the Delta.*" This is a gross overstatement that could be used out of context by readers less familiar with the available research. Aquatic nitrogen transformations include (at minimum) nitrogen fixation, nitrification, denitrification, dissimilatory nitrate reduction to ammonia (DNRA), anaerobic ammonia oxidation (annamox), assimilation by phytoplankton, aquatic plants, *and* bacteria, excretion by pelagic and benthic biota, and microbial remineralization. Except for the N uptake rates measured in one study by Parker et al. (2010) along the Sacramento River, genuine rate measurements (such as direct measurements of transfer of ^{15}N between compartments) have not been reported from the freshwater Delta for the myriad routine pathways by which nitrogen is used and re-used in aquatic systems - *including nitrification*. In many settings, rapid recyling of nitrogen between grazers and microbes in the water column (nutrient regeneration) means that patterns in bulk concentrations of nutrients (such as observed by grab sample surveys) do not reflect underlying turnover rates. Although stable isotope analyses of bulk N pools (currently underway by C. Kendall, USGS, and colleagues) can reveal information about sources and transformations, they do not result in rate measurements. Almost nothing is known about the use and cycling of dissolved organic nitrogen in this system, although there is growing evidence that marine and freshwater phytoplankton utilize amino acids, amides, urea, humic substances, and other dissolved organic nitrogen compounds as sources of nitrogen (recently reviewed in Bronk et al. 2007)[3]. See second part of **response # 1**.

The cross comparison between grab sample and CDEC data was useful information and will hopefully spur additional cross comparisons.

Specific Comments on Content

Page 7, Results and Discussion: **Comment #37** It would be helpful to identify or report the river flows during this study and how they compare with long-term averages. This information will help place the monitoring conditions in context of a wet vs. dry year. Measurements made in a dry year (lower than average flows) would represent conservative estimates of the potential for risks while wet weather measurements would likely be less conservative. This is relevant because the report makes risk estimates based on the measured concentrations of ammonia. **Response #34** It is not straightforward to predict the effect of water years types and their associated flow rates on ammonia concentrations in the Delta. A wet year with its higher flow will act to dilute the initial nitrogen concentration at Hood and this will reduce the concentration moving downstream into the Delta. However, the higher water velocities will also reduce the time available for nitrification to occur. This will act to maintain a more constant ammonia concentration across the Delta. It will take modeling to tease out the effect of these two conflicting factors. The study provides sampling dates. Others can determine the specific Sacramento River discharge rates should they wish to model the results. No change in text.

Page 14, Results and Discussion, first paragraph: **Comment #38** It would be helpful to add that the 7-day NOEC concentrations reported by Werner et al. (2009a,b) range from 0.087 – 0.177 mg/L NH_3, although only the NOEC value reported here (0.091 mg/L) represents a bounded NOEC where there was an effect observed at a higher tested concentration. The other NOECs reported were unbounded, because there were no effects at the highest tested concentrations. **Response #35**. Text added

Page 10: Comment #39 The possibility that current speed and/or residence time are directly affecting the biomass of phytoplankton which remains in suspension in the Sacramento River is investigated by correlating the percent decline in chlorophyll concentrations between Tower Bridge and Isleton with (a) Sacramento River flow at Freeport and (b) minimum velocity at Freeport (for 2 days prior). This type of analysis is welcome, because the roles of residence time, turbulence, and other physical processes in shaping riverine phytoplankton communities deserve more attention than they have received in Delta food web discussions.

Freeport flow and current speed are probably reasonable proxies for these two parameters between Freeport and Walnut Grove. However, depending on season and year, between 15-60% of Sacramento River flow exits the main channel near Walnut Grove on a monthly basis through Georgiana Slough and the Delta Cross Channel (Figure 3). Especially during months when high percentages of river flow exit the main river channel at Walnut Grove, it might be better to compare Freeport flow and current speed to chlorophyll decline between Tower Bridge and Walnut Grove only, rather than chlorophyll decline between Tower Bridge and Isleton. **Response #36**. Interesting observation. The analysis was provided in the text to help develop alternate hypothesis for the loss in chlorophyll down the river. All hypotheses should be rigorously tested and eliminated. This should include the Dugdale and State Water Contractor hypothesis that either the effluent or ammonia is responsible for the decrease in chlorophyll **(Comment # 26 and # 50).** No change in test.

Page 14: Comment #40 Werner's 2006-2008 survey of un-ionized ammonia concentrations is referenced to provide context for the results of the Regional Board survey. In doing so, attention is called to un-ionized ammonia concentrations in the Werner dataset that approached 0.02 mg N/L. Additional context could be provided by referencing the multi-agency dataset analyzed by Engle & Lau (2009, 2010)[4], which provides un-ionized ammonia concentrations for the period 2000-2010 for stations spanning the brackish (18 stations) and freshwater Delta (30 stations)[5]. In this larger dataset (which includes Werner's 2006-2008 survey data), un-ionized ammonia was ≥ 0.02 mg N/L in only 4 water samples, and the 99th percentile concentrations for un-ionized ammonia at freshwater sites and brackish sites were 0.014 and 0.0063 mg N/L, respectively. **Response #37**. Text added.

Page 14, paragraph 3: Comment #41 The method for calculating ACRs is incorrect. USEPA does not calculate ACRs for ammonia by dividing 96-h LC50s by "lowest chronic NOEC values". USEPA calculates ACRs for ammonia by dividing the 96-h LC50 from acute tests by the EC20 from comparable chronic tests. The USEPA uses specific criteria for determining which LC50s and EC20s are suitable for pairing for purposes of ACR calculation[6] **Response #38** Text changed.

Comment #42 The footnote on page 14 incorrectly describes how an ACR of 20.7 was calculated by USEPA from the life cycle test of Thurston et al. (1986). The ACR was calculated using an EC20 based on an endpoint of *percent hatch* (not a NOEC related to histopathologic effects)[7]. The USEPA does not use chronic values obtained using histopathologic endpoints to calculate criteria or ACRs for a host of reasons which are detailed in USEPA (1999). **Response #39**. Text changed

Comment #43 Additionally while it is a positive result that the Regional Board did not find evidence for chronic toxicity after applying an ACR of 21 to the LC50 for Delta smelt, this particular ACR is a biased screening tool. USEPA (1999) provides three ACR's for fathead minnow: 20.7, 9.7, 6.5[8]. There is no justification for singling out the highest of 3 independently determined ACRs for fathead minnow to derive a hypothetical chronic threshold for Delta smelt.

As is customary, the USEPA uses a Genus Mean ACR (GMACR) to characterize the acute:chronic sensitivity of fathead minnow, not the highest of the available ACRs. Following USEPA procedures, the GMACR for fathead minnow is calculated in the 1999 criterion document as the *geometric mean* of the three available ACRs (see p. 136 in 1999 criterion document). The resulting GMACR of 10.9 is one of five GMACRs for fish genera that have survived vetting by the USEPA and which were published in both the 1999 and 2009 USEPA ammonia criteria documents (the latter being a draft update):

Pimephales	10.86
Catostomus	<8.33
Ictaluris	2.712
Lepomis	7.671
Micropterus	7.688

Singling out the 20.7 ACR for fathead minnow to derive a screening threshold is especially inappropriate considering that it is derived from a chronic test that the USEPA considers problematic, as indicated by the following passage from the "Review and Analysis of Chronic Data" in the 1999 criteria document:

> "*Thurston et al. (1986) reported similar results from two life-cycle tests that started with 3 to 5-day-old fry and ended with 60-day-old offspring....However, there are concerns about this test:*
>
> *1. Effects on survival and weight of F1 fry were uncertain due to high mortality attributed to handling during cleaning.*
>
> *2. The eggs were dipped in malachite green daily.*
>
> *3. Hatchability of the controls was about 50 percent.*
>
> *4. There was a large difference between the replicate test chambers in the control-adjusted percent hatch at 0.09 mg NH3/L."* (USEPA 1999, p. 53)

The other two ACRs for fathead minnow were derived from tests which did not raise any concerns (Swigert & Spacie 1983, Mayes et al. 1986)[9]. In fact, USEPA purposely averaged the chronic values from the latter two tests with the chronic value from Thurston et al. (1986) to derive the species mean chronic value (SMCV) for fathead minnow owing to concerns about the validity of the Thurston et al. test:

"In the present case, however, because of the concerns about the life-cycle test [Thurston et al. 1986]*, the SMCV for the fathead minnow at pH=8 is set equal to 3.09 mg N/L, which is the geometric mean of the three EC20s from Thurston et al. (1986), Swigert and Spacie (1983), and Mayes et al. (1986).." (USEPA 1999, p. 54)* **Response # 40**. No change in text as the ACR value of 20.7 is described in Table 7 (Appendix 7) of U.S. EPA 1999 as an ACR value.

Page 14: **Comment #44** It is suggested that CDEC pH values above 8.0 might be used as a potential indicator of chronic toxicity for Delta smelt at Hood and Rio Vista. There is large risk for this remark to be misconstrued as an endorsement of the use of pH as a screening tool in the Delta, generally. Because total ammonia concentrations and water temperature vary widely within pH strata across the estuary, ambient pH is a terrible generalized basis for gauging whether un-ionized ammonia concentrations are of concern. Data for 2000-2010 illustrate the wide range of un-ionized ammonia concentrations that occur when pH is greater than 8.0 at stations in the brackish Delta (Figure not included here) and the freshwater Delta (Figure not included here). **Response #41**. text changed.

On page 16, paragraph 2, **Comment #45** it is stated "*The impact of elevated ammonia concentrations on the algal community downstream of Rio Vista is not known.*" This remark is somewhat misleading, as there has been research on the effects of ammonia on the algal community in the Sacramento River downstream of Rio Vista. As explained above (see footnote 2), longitudinal transects by the Parker/Dugdale team during their 2008-2009 project included descriptive sampling and rate measurements at 11 stations extending from Rio Vista well into Suisun Bay. This work, which was not included in the Parker et al. (2010) draft report, indicates that increases in primary production and biomass of several phytoplankton groups (greens, diatoms, and Cryptophytes) can occur in the Sacramento River between Rio Vista and Suisun Bay even when nitrogen uptake is dominated by ammonium. These results are particularly important to reference because the lower reach of the Sacramento River is more important habitat for pelagic fish than the reach between the SRWTP and Isleton. See **response # 33**

Minor Edits

- The following bullets are some minor editorial suggestions to make the report consistent and figures easier to read. **Response #46**. Some text changes made

  - Ammonia and nitrate concentrations are referred to throughout the report and on graph axes using "mg/L" which can be interpreted by readers as mg NH4/L and mg NO3/L, rather than mg/L ammonia-N or mg/L nitrate-N. The units should be consistently labeled mg N/L, if that is what is meant.

- Figure 2. No units are provided for the y axis.
- X axis labels are missing or only partially visible in most of the figures.
- Y axis units are jumbled in Figures 10 and 11.
- Figure 7B. The yellow masking obscures the daytime values in Figure 7B. The y axes should be labeled (which y axis is chl? which is river stage?)

Conclusions

Overall the Nutrient Report is fairly balanced. The recommendations for changes to the Executive Summary will help readers that only read the Executive Summary have a comprehensive understanding of the information in the report, without misinterpretation. The changes requested for the acute to chronic ratio, will correct the way in which this ratio should be derived in accordance with USEPA guidance. We hope the minor editorial changes enhance the thoroughness of this report.

[1] The same Suisun Bay time series is included in Wilkerson et al. (2006). Full citations are in the Regional Board report.

[2] Although the Parker et al. (2010) draft report for the Central Valley Regional Board only shows transect results between I-80 and Rio Vista, sampling during at least one of the transects extended past Rio Vista well into into Suisun Bay. Results for the longer transect from March 2009 were presented in Parker et al. (2009) *Transport and Fate of Ammonium Supply from a Major Urban Wastewater Treatment Facility in the Sacramento River, CA. 9th Biennial State of the San Francisco Estuary Conference, Oakland, CA, September 29-October 1, 2009.* The poster results show increases in primary production and biomass of several phytoplankton groups (greens, diatoms, and Cryptophytes) starting in the river well upstream from Suisun Bay in a reach where nitrogen uptake was dominated by ammonium.

[3] Bronk, D. A., J. H. See, P. Bradley, and L. Killberg. 2007. DON as a source of bioavailable nitrogen for phytoplankton. Biogeosciences 4: 283-296.

[4] Engle, D.L., & G. Lau (2009) *Total and Un-ionized Ammonia Concentrations in the Upper San Francisco Estuary: A Comparison of Ambient Data and Toxicity Thresholds*. 9th Biennial State of the San Francisco Estuary Conference, Oakland, CA, September 29-October 1, 2009

Engle, D.L., & G. Lau (2010) Does Ammonia Exceed Toxicity Thresholds in the Upper San Francisco Estuary? A Comparison of Ambient Data and Toxicity Thresholds for 1974-2010. Interagency Ecological Program (IEP) Annual Workshop, Sacramento, CA, May 25-26, 2010.

[5] USGS, IEP, DWR, SRCSD, and UC Davis ATL POD monitoring programs

[6] USEPA (1985) *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*, outlines the following steps for producing an ACR from a chronic value:

1. The numerator for the ACR should be the geometric mean of the acute values for that species from all acceptable flow-through acute tests in the same dilution water.
2. For fish, the acute tests should have been conducted with juveniles.
3. The acute tests should have been (a) a part of the same study as the chronic tests, (b) from different studies but from the same laboratory and dilution water, or (c) from studies at different laboratories using the same dilution water.
4. If no such acute tests are available, an ACR should not be calculated.

[7] See Table 5 and text on page 53, in USEPA (1999).

[8] See Table 7, p. 136, in USEPA (1999).

[9] Full citations are available in USEPA (1999).

Dr Richard Dugdale, Romberg Tiburon Center

Executive Summary 4th paragraph page 2. **Comment #46** The cause of the algal decline is not known. However, algal induced toxicity from the SRWTP does not appear to be the cause as the chlorophyll decline consistently began above the POTW. **Response #45.** Text changed.

Comment [d1]: Above and below RM44 are two different river ecosystems. Chlorophyll declines that seem to be mono-tonic actually result from two different forcings. Upper River decline is probably due to nutrient limitation. Below the decline is due to several forcings, 1) shutdown on NO3 uptake,*trannsects see our execsummary* the suppression of NH4 uptake, so the N production declines, and finally the suppression of C uptake (PP) by effluent.*Effex*. So this statement is not correct or supportable.*Source: Growouts/our report.*

Executive Summary 4th paragraph page 3. **Comment #47** A second hypothesis at the beginning of the study was that ammonia from the SRWTP inhibited nitrate uptake and reduced primary production rates in the river below the POTW. Other research has now demonstrated that ammonia concentrations greater than 0.056-mg/l prevent development of algal blooms in Suisun Bay but not in the Sacramento River below the SRWTP. No information presently exists on the effect of this concentration of ammonia on algal production in the Delta **Response #44**. Text changed but please also see **response #33.**

Comment [d2]: This statement applies only to the region where the water for growouts was obtained, e.g. at RM44, and not exactly correct here either since NO3 uptake is shutdown until NH4 is reduced to below .056. The delay in bloom development would preclude the development of a bloom within the river due to short residence time. Evidence from enclosure experiments done at Rio Vista (manuscript in prep) found no phytoplankton response whatever over 7 days. Water is clearly severely impaired at this point.Source: growouts, transects,

Introduction 4th paragraph page 4. **Comment #48** A draft final report has been prepared for the phytoplankton work (Parker *et al*., 2010). The report determined that ammonia did not inhibit primary production in the River below the SRWTP but did identify an ammonia concentration that caused a shift in nitrogen utilization from nitrate to ammonia. **Response #45** Text changed

Comment [d3]: What was actually said was that we couldn't directly relate the decrease in PP to NH4 as the results of the addition experiments didn't show a clear NH4 effect. However, PP declined downstream of RM44 to Isleton by 18-62%, and ammonium uptake declined by 0-57% in the 3 transects in which rates were measured. *See tables 9,12,15*.A relation to effluent was, however, shown in the addition experiments with suppression of carbon uptake (PP) at 32 micromoles/L or greater *See tables 26 and 28* and a suppression of NH4 uptake also occurred with effluent additions. *See Fig. 8.*

Results and Discussion 1st paragraph page 10. **Comment #49** Parker *et al*. (2010) observed an increase in algal biomass in five-day cubitaner grow out experiments filled with water from above and below the SRWTP and incubated at the Romberg Tiburon Center. The authors also consistently measured positive primary production rates in 24-hour C^{13} incubations of water collected at seven locations between Tower Bridge and Rio Vista. The authors concluded that the river phytoplankton community was healthy and capable of normal growth. **Response #46.** text changed

Comment [d4]: This sentence is meaningless and should be removed. There are no circumstances under which there would not be positive primary production rates measured with the 14C method, even as the rates approached almost 0.

Comment [d5]: This conclusion applied only to water collected at GRC and RM44 not to any downstream location, due to lack of data

Results and Discussion 2nd paragraph page 10. **Comment #50** An inverse relationship was observed between the loss of chlorophyll and the instantaneous minimum velocity (P<0.001, Figure 5). Pigment loss declined with increasing velocity. The break even point where no loss occurred was about 3 ft/sec. The relationship is still significant with the removal of the single high flow data point in Figure 5. Instantaneous velocity values at Freeport were assumed to be a surrogate for river turbulence. If so, the loss of chlorophyll may be related to settling and the subsequent inability of settled algae to become resuspended when water velocity increases again **Response #47** I agree that there is very little algal production in the River and the phytoplankton community cannot keep up with whatever is causing the loss. This brings up an important point. There are two processes at work here that act in concert to explain standing chlorophyll levels. The first is what controls primary production (gains) and the second is what explains the loss in chlorophyll. These are likely different processes. Your hypothesis is that reduced N uptake explains the low primary production rate. A second hypothesis explaining the low production rate is light limitation. Regardless, it does not seem that either hypothesis can explain the disappearance of 60% of the chlorophyll in 2 to 3 days down the river. No change in text.

Comment [d6]: Interesting point, what we would suggest is that there is very little productivity downstream due to the reduced N uptake, so the population is unable to keep up with the losses.

Results and Discussion 3rd paragraph page 15. **Comment #51** Twenty-four hour ^{13}C stable isotope incubations were made with water collected at seven locations (three above and four below the SRWTP) on four cruises to determine primary production rates. Chlorophyll-a normalized primary production showed no consistent trend above and below the SRWTP.

Comment [d7]: This assimilrtion number cannot be taken to mean that primary productivity showed no trend. It does mean that you can infer that PP follows chl concentration so clearly PP declines downriver. Primary production declined below RM44 from 18 to 50% to Islton. *See Table 9,12,15.*

Response #48. Text changed

Results and Discussion 5th paragraph, page 15. **Comment #52** Ammonium uptake was measured on three of the river cruises. No consistent pattern in ammonium uptake was observed above and below the SRWTP. However, there was a trend for the sum of nitrogen uptake (NO_3+NH_4) to decline downriver. Nitrogen uptake rates at Rio Vista were 30 to 60 percent less than at Hood. Paradoxically, the decline in both nitrate and total nitrogen uptake down the Sacramento River, unlike in Suisun Bay, was not accompanied by a decline in chlorophyll a normalized primary production rates.

Comment [d8]: Not a correct comparison, first is an absolute rate, the latter a rate normalized to biomass. Correct state ment is that the decline in both nitrate and total nitrogen uptake -----WAS accompanied by a decline in carbon uptake (primary production).

Response #49. Text changed

Central Valley Clean Water Association

Comment #53 CVCWA agrees with the findings of the report which indicate that neither acute nor chronic ammonia toxicity are occurring in sensitive aquatic organisms in the Delta, including Delta smelt. As stated in the report, this finding is based on an evaluation of ambient ammonia and pH data using USEPA aquatic life criteria and recent toxicity research results. CVCWA encourages the consideration of all available ambient data for the Delta in this evaluation, which will enhance the significance of this finding. See **Response #37** to the SRCSD

Comment #54 CVCWA also agrees with the finding that more research is needed to properly evaluate the effects of elevated nutrients levels on phytoplankton abundance and species composition in the Delta. CVCWA also believes that other environmental factors, in addition to nutrient concentrations, should be considered in the comprehensive evaluation of factors impacting the Delta food web, including temperature, hydraulic residence times, and the impacts of grazing by invasive clams and other benthic bivalves. This comprehensive analysis, which should be independently peer reviewed, is essential if any meaningful conclusions regarding the role of nutrients in the Pelagic Organism Decline are to be developed. See **response #27** above

Comment #55 CVCWA finds the statement in the report that "…research has now demonstrated that ammonia concentrations…prevent development of algal blooms in Suisun Bay…" to be somewhat misleading. Other factors, including the grazing effect of the invasive asian clams, have had a pronounced and consistent impact on phytoplankton levels in Suisun Bay since 1987. See **response #31** above

In addition to the above comments, CVCWA requests that Regional Water Board staff give serious consideration to making changes to the report to address the detailed comments that have been submitted by Sacramento Regional County Sanitation District. CVCWA is supportive of the technical and policy points embodied in those comments.

San Diego County Water Authority

The report concludes that the ammonia does not appear have a direct acute toxicity on the delta smelt. It further found that the nitrogen makeup downstream of the plant is significantly shifted from a nitrate to an ammonia dominated system. The report recommends further study on the impact of elevated ammonia concentrations on algal species in the Delta. A premise is that a shift from a nitrate dominated river to an ammonia dominated river will result in shift from the ecologically important diatoms to less desirable flagellates and blue green algae. This can significantly alter the food web and change the species of fish that are likely to survive.

Comment #56 We agree with this recommendation and strongly urge that the Regional Board further investigate this premise. There is an abundance of historical data on the water quality and biology of the delta. In addition to doing further study on the delta as it stands today, the Regional Board should evaluate this historical data and other recent scientific articles related to this issue to determine how the ammonia levels might impact the food web and reduce the population of delta smelt. We also encourage ongoing comprehensive evaluation of all water quality impacts on the delta food chain. See **response #27** above.

Kathleen Harder, Central Valley Regional Water Quality Control Board.

Comment #57. Please include an analysis of dissolved oxygen concentrations in the Sacramento River between Tower Bridge and Chipps Island as has been done for nutrient and pH values. **Response #50** Text added.