I. Name of the Principal Investigator(s) with affiliation.

David Senn, San Francisco Estuary Institute (SFEI)
Carol Kendall, USGS
Marianne Guerin, Resource Management Associates (RMA)

II. Name of Co-Investigator(s), with affiliation(s) and role in proposed project.

Emily Novick, SFEI – data analysis/synthesis, report and manuscript preparation
Megan Young, USGS - data analysis/synthesis, report and manuscript preparation

III. Project title.

Characterizing and quantifying nutrient sources, sinks and transformations in the Delta: synthesis, modeling, and recommendations for monitoring

IV. Total budget.

$181,000

V. Study duration:

1 year

VI. Priority research topic and questions addressed and overall relevance

This study will address Priority Research Topic 2 and specific questions 2C, 2D and 2E.We propose to quantitatively explore the role the Delta plays in transforming, assimilating, and removing nutrients (ammonium, nitrate, phosphate), an investigation which is critically needed to inform important and potentially costly management decisions aimed at reducing nutrient loads to the Delta and Suisun Bay.

VII. Overall project purpose.

The IEP's conceptual model for the Pelagic Organism Decline (POD) recognizes that multiple factors may be acting in concert to degrade habitat and contribute to the sudden decline in native and non-native pelagic fish species (Baxter et al., 2010). Anthropogenic nutrient loads are considered one potential factor, with elevated ammonium (NH4) concentrations potentially inhibiting primary productivity (Dugdale et al., 2007; Parker et al., 2012) and contributing to the increased frequency of *Microcystis* blooms in the Delta (Lehman et al., 2008).Changes in nutrient ratios and forms of N have been hypothesized to be exerting additional bottom-up pressures on Delta and Suisun food webs (e.g., Glibert et al., 2011).

Although the Delta receives high nutrient loads from treated wastewater discharges (e.g., Jassby 2008) and from agriculture in the Central Valley (Kratzer et al., 2011), there has been limited systematic study of nutrient processing within the Delta to quantify the relative importance of transformations (nitrification, uptake), removal (denitrification), and internal loads or new sources of nutrients within the Delta. Quantifying the importance of these processes is critical for understanding observed concentrations throughout the Delta, which in turn influence phytoplankton response (primary production, biomass, and community composition including harmful algal blooms), and ultimately affect nutrient loads from the Delta to Suisun Bay.

We propose to synthesize long-term nutrient-related monitoring data from DWR-EMP sites within the Delta (1975-2011 or 2012, depending on data release dates) and existing stable isotope data from 2005-2012, and apply hydrodynamic and water quality models, to characterize the role the Delta plays in transforming, assimilating, and removing various nutrients. Specifically, this project will:

- Identify long-term and seasonal trends in nutrient form (e.g., NH4 vs. NO3), concentrations, and ratios, and explore the factors contributing to spatial, seasonal and temporal variability;
- Enhance the calibration of a reactive transport model (DSM2-QUAL) using existing stable isotope data collected at numerous sites in the Delta and its tributaries;

- Apply the DSM2-QUAL nutrient model to characterize and quantify nutrient transformations and losses during transit through the Delta under a range of flow conditions;
- Quantify nutrient loads to the Delta and loads from the Delta to Suisun Bay; and
- Identify additional monitoring and special studies needed to address critical data gaps.

While the primary focus of this proposed work is on nutrients, phytoplankton production and nutrients are tightly coupled in nature, and both sets of variables and their interdependence are parameterized in DSM2-QUAL. A more sophisticated phytoplankton-nutrient model may be needed in the future, and the proposed work will be a key building block that will inform subsequent efforts.

VIII. Project background and conceptual model.

The Sacramento-San Joaquin Delta and Suisun Bay are highly altered ecosystems with complex hydrology and biogeochemistry. The Sacramento and San Joaquin Rivers carry substantial loads of nutrients derived from agriculture in the Central Valley (Kratzer et al., 2011) and from treated wastewater effluent (Jassby 2008) to the Delta. Quantifying these loads to the Delta is relatively straightforward. However, flows from these rivers subsequently traverse a complex network of Delta channels during which time additional nutrient loads (agriculture return flows, wetland drainage, stormwater flows), substantial transformations (nitrification, uptake; e.g., Parker et al., 2012), and losses (e.g., denitrification, settling of particle-complexed P) occur. We hypothesize that these internal processes, which are currently poorly characterized, are quantitatively important and have a large impact on both observed concentrations within the Delta and loads to Suisun Bay.

Despite the hurdles to understanding nutrient dynamics in the Delta, there exists an excellent network of long-term nutrient monitoring data (e.g. Bay-Delta EMP; Jassby and Cloern 2000; Figure 1, Table 1), which could be used to explore changes in space and time in the Delta and develop mechanistic understanding of nutrient processing within the Delta. Abundant stable isotope data also exist from several transect-scale source and transformation studies (e.g., Kendall-Guerin collaborations), and these data and the knowledge gained from the studies can be applied to investigate sources and transformations at larger spatial scales. Finally, while there are existing hydrodynamic and reactive-transport models for the Delta (DSM2-HYDRO and DSM2-QUAL), these modeling tools have not yet been applied to quantify the extent to which the Delta transforms and removes nutrients on a regional scale.

IX. Estimated number of all FESA and ESA-listed fishes. *None*

X. Project description:

This project consists of three interlinked tasks, with timing and linkages indicated in Figure 2.

X.1.1 Task 1: *Nutrient dynamics in the Delta: Spatial and temporal trends, and assessing the Delta's role in transforming, assimilating, and modulating nutrient loads*

X.1.2. Investigators:

Lead: Senn and Novick, SFEI;
Collaborators: Kendall (USGS), Young (USGS), Guerin (RMA)

X.1.3. Specific Questions:

1.1 How have nutrient concentrations varied spatially, seasonally, and over time throughout the Delta over the past 4 decades (1975-2011; 22 DWR-EMP stations)? What are the major drivers of those changes?

1.2 What is the Delta's ability to transform, remove, and assimilate nutrients and modulate nutrient loads to downstream systems? How do those processes vary spatially and seasonally, and what regulates their magnitudes?
1.3 What additional monitoring or special studies are needed to address critical data gaps?

X.1.4. Approach and Methods: Task 1 is divided into four subtasks as described below.

Task 1a: Data compilation

Nutrient and flow data relevant to Tasks 1-3 will be gathered from several monitoring and research programs and compiled into a single database. In addition to serving as the data resources for this project, this database will be made publicly available to managers and researchers, within the constraints of relevant data dissemination agreements. Data will include water quality and physical data from DWR Environmental Monitoring Program sites (DWR-EMP; Table 1), and daily average flow at multiple locations in the Delta from DAYFLOW[1]. Stable isotope data and concentration data (Task 2) collected along transects (2005-2012) throughout the Delta will be geo-coded and included. In addition, time-series of volumetric fingerprints produced by the Delta Simulation Model (DSM2) at relevant stations will be included (Task 3), along with loads from wastewater treatment plants discharging to the Delta.

Task 1b: Seasonal, spatial, and long-term trends in nutrient concentrations and proportions

In this task we will analyze monthly nutrient concentration data and related parameters throughout the Delta using 22 DWR-EMP stations over the period 1975-2011 (or through 2012, depending on data release dates; Figure 1, Table 1). While changes in phytoplankton biomass and primary production over time in the Delta have received considerable investigation (e.g. Jassby and Cloern, 2000; Jassby 2008), this rich archive of inorganic nutrient data has not been thoroughly investigated. Therefore, there is a great opportunity to use these data to evaluate changes in space and time in the Delta, to develop mechanistic understanding of nutrient processing within and efflux from the Delta, and to inform on-going and future monitoring efforts.

We will explore seasonal, spatial, and interannual variability and long-term trends in nutrient concentrations (NH4, NO3, PO4), relative abundance of different nitrogen forms (NH4, NO3, dissolved organic nitrogen), and N:P. Since there have been considerable changes in hydrology, nutrient loading, and other factors in the Delta over the period of interest, we hypothesize that concentration and composition changes will be evident at stations throughout the Delta, and that the magnitude of those changes will vary and/or be attenuated differently among stations. As an initial proof of concept and test of this hypothesis, we evaluated seasonal and temporal patterns of NH4 and NO3 at C3 and D19 (with most recent DWR data, through 2011). Over the period 1975-2011, NH4 concentrations at C3 (Sacramento River, ~12km downstream of Sacramento Regional WWTP outfall) increased in all months and more than doubled at certain times of the year, and showed limited seasonal variation (Figure 3). NO3 at C3, however, showed only a relatively modest increase during this period, but strong seasonal variation, the latter possibly due to seasonally variations in agricultural loads (Kratzer et al., 2011). We compared these seasonal and long-term trends with those at D19, near Franks Tract, where 75-90% the water is from the Sacramento River (i.e., C3 composition based on DSM2 volumetric fingerprint calculations; pers. comm., M Guerin). Concentrations observed at D19 were quite different than C3 (Figure 4). There was little or no increase in NH4 from 1975-2011, and there is a 5x decrease from winter months to summer months, a seasonal trend that was absent at C3. Furthermore,

[1]http://www.water.ca.gov/dayflow/output/Output.cfm

NO3 at D19 was substantially greater than at C3 during winter months (internal sources or mixing with NO3-rich San Joaquin water), and NO3+NH4 at D19 was substantially less than at C3 during late summer, indicating N losses. These initial comparisons suggest there are large and seasonally varying nutrient transformation processes occurring in this area.

Similar analyses will be performed across all Delta DWR-EMP stations. Daily and monthly flow data (DWR DAYFLOW and DSM2, Task 3) and volumetric fingerprint time series (Task 3) will be used as independent variables for interpreting nutrient observations. In addition to evaluating seasonal and temporal trends (following approaches similar to Jassby 2008), we will apply multivariate tools, such as principal component analysis (PCA) and multivariate linear models to identify spatial and temporal patterns and potential drivers of those patterns (e.g., flow and residence time, seasonal variability or long-term changes in volumetric fingerprints and loads). While the focus will be on inorganic nutrients, a range of other physical and chemical parameters will also be analyzed, in particular chl-a, both to examine the relationship between phytoplankton response and nutrients. This task will identify zones and time periods of potentially large transformations or removal for more detailed analysis in Tasks 1c, 2, and 3.

Task 1c: Quantifying the Delta's role in transforming and assimilating nutrients, and modulating nutrient loads to downstream regions of the Estuary

This task combines input from Tasks 1b, 2, and 3 to quantify nutrient loads to the Delta (internal and external, and seasonal/spatial variation), characterize and quantify nutrient transformations and losses during transit through the Delta, and quantify nutrient loads to Suisun Bay (including how seasonal/spatial variation and factors influence this variability).

We hypothesize that processes within the Delta (nitrification, denitrification, uptake, and assimilation of N and P, and settling of particle-complexed PO4) play an important role in determining ambient concentrations, and consequently loads, to Suisun Bay. As an initial test of this hypothesis, we performed a Delta-wide scale mass balance on NH4, considering external inputs and efflux by water exports and flow into Suisun Bay. Our approach was modeled after the approach developed by Jassby and Cloern (2000) for organic matter, using monthly DWR-EMP data from 1975-1995 and DAYFLOW estimates of flow. The NH4 mass balance results (Figure 5) are consistent with the Delta playing a major role in N cycling, with an annual average NH4 loss of ~60%, presumably due to nitrification and uptake by phytoplankton or plants. The fraction of NH4 lost shows strong seasonal and interannual variation, with as much as 90% of NH4 lost during certain time periods.

We will follow two approaches for quantifying transformations, removals, and loads. The first approach will be a Delta-wide mass balance of NH4, NO3, DIN, and PO4 (along with organic forms), using monthly DWR-EMP monitoring data and DAYFLOW flow data for 1975-2011. Using this approach (similar to Figure 5), we will quantify net transformations or losses, characterize seasonal variations and long-term trends, and explore the underlying causes of those variations and trends (e.g., flow and residence time, changes in external loads). During times when isotope data are available (Task 2), these will be used semi-quantitatively to confirm or clarify hypothesized transformations and to identify sources.

The second approach will involve the application of the DSM2-QUAL model, after the calibration has been enhanced with additional data (Task 3), to in essence divide the Delta into multiple smaller control volumes, and the use of this well-parameterized model to quantify the relative importance of major processes influencing observed nutrient concentrations in space and time. We hypothesize that nitrification and denitrification will be quantitatively important processes, but that internal sources of inorganic N (mostly as NO3) could offset a substantial portion of the denitrification loss. Where possible, we will use isotope data (Task 2) to further explore the extent of transformations as well as potential internal sources. In addition to quantifying the loss/transformation terms, we will explore the factors that influence seasonal, spatial, and temporal variability in those terms. DSM2-QUAL will be run for the time period 1990-2011, as described in Task 3. While this does not include the entire record of DWR data, we feel that this 20+ year simulation window using DSM2-QUAL covers a sufficiently long time period and a range of flow conditions to allow us to develop a thorough and quantitative understanding of nutrient processes. Although the primary focus of this proposed work is on nutrients, the interdependence of phytoplankton production and nutrients is well-parameterized in DSM2-QUAL. Thus, phytoplankton biomass (i.e., chl-a) will be used in the refinement of the nutrient model calibration and in data interpretation. An important output of this effort will include developing a conceptual model of the factors controlling primary production in the Delta. This conceptual model will be based on statistical analysis in Task 1b, interpretation of DSM2-QUAL results, and isotopic data from Task 2. A more sophisticated phytoplankton-nutrient model may be needed in the future, and the proposed work will be a key building block that will inform subsequent efforts.

Task 1d: Recommendations for on-going monitoring and special studies

Observations in Task 1b and 1c (as well as sensitivity analyses in Task 1b, 2 and 3) will identify high-priority data or conceptual gaps that currently limit our understanding of nutrient dynamics in the Delta. A section in the technical report will describe recommended monitoring activities (stations, analytes) and special studies to address these gaps. These recommendations will provide timely input for several major initiatives, including the development of the Delta Regional Monitoring Program, which will have a substantial focus on nutrients, and the joint SFRWQCB and the CVRWQCB nutrient science plan development for the Delta and Suisun required by the recent Delta Plan v6.

X.1.5. Interaction with existing monitoring surveys or other studies:

This proposal will interact with and provide data input for multiple ongoing studies and programs: San Francisco Bay Nutrient Strategy Studies[2]; Delta Regional Monitoring Program Development; SFRWQCB and CVRWQCB nutrient science plans for the Delta and Suisun; on-going Delta and Suisun POD and habitat-oriented studies funded by multiple organizations with complementary goals; a proposed study by Romberg Tiburon Center for this IEP RFP on wastewater effluent effects on nutrient assimilation; and recent IEP FLaSH studies.

X.1.6. Feasibility: Highly feasible. There is an extensive network of available data (Table 1) over a long period of record. The preliminary analysis presented in Figures 3, 4 and 5 demonstrate the feasibility and potential of methods proposed in Task 1b and Task 1c.

X.1.7. Deliverables:

- Database made publicly available to managers and other researchers
- Overall project Technical Report (Sections from Tasks 1b, 1c, and 1d, Task 2 and 3)
- A journal manuscript describing key findings from Tasks 1b, 1c, 2 and 3.

X.1.8. Detailed budget:

The total cost for Task 1 is $82,000 for SFEI data synthesis; report and manuscript preparation; in-house statistical support; publication costs; and for subcontract and invoice preparation.

[2] http://bayareanutrients.aquaticscience.org/

X.1.9. Task schedule: 1 year project; see Figure 2 for schedule (stated once here for all tasks)

X.1.10. FESA and ESA-listed species: None (stated once here for all tasks)

X.2.1. Task 2: Enhanced interpretation of stable isotope data to test hypotheses about nutrient sources and transformations as part of regional mass balance estimates

X.2.2. Investigators:
Lead: Kendall (USGS), Young (USGS);
Collaborators: Guerin (RMA), Senn (SFEI), Novick (SFEI)

X.2.3. Specific Questions:
2.1 Are there regional, river reach-dependent, and temporal variations in nitrification rate or other rates of nutrient degradation? If so, what are the likely causes?
2.2 What are the dominant processes affecting NH4 concentrations, in particular with respect to thresholds hypothesized to inhibit NO3 uptake?
2.3 Are measured changes in isotope values between Delta sites consistent with nutrient loss or gain estimates produced by modeling and mass balance calculations?

X.2.4. Approach and Methods:
Since the early 2000s, our USGS Isotope Tracers Project has been involved in about a dozen state-funded studies involving nutrient and organic matter isotopes, with many published papers and reports (e.g., Kratzer et al., 2003; Wankel et al., 2006; Kendall et al., 2008a,b; Kendall et al., 2010) and a number in various stages of preparation and review, as part of our recent POD and habitat-oriented projects in the Delta. We propose to take advantage of the large chemical and isotopic database from multiple locations throughout the Delta and Lower Sacramento River, and apply these data and interpretations at the regional scale to:

- Provide independent and quantitative evidence of major processes or important sources to confirm or clarify mass balance and model estimates, and identify transformation "hotspots" and "hot moments" (Task 1c).
- Quantify the extent of nutrient transformations in well-characterized areas of the Delta or river reaches, and use these data to update and refine the calibration of the DSM2-QUAL nutrient model through December of 2011, or possibly 2012 (Task 3)

The dates, spatial coverage, and analytes for samples collected between 2005 and 2012 are described in Figure 6 and Tables 2-3. Most samples collected in 2009-2012 were intended for analysis of δ^{15}N of NH4; δ^{15}N and δ^{18}O of NO3; δ^{15}N, δ^{13}C, δ^{34}S, and C:N of POM; δ^{13}C of DOC; and δ^{18}O and δ^{2}H of water. Most of the pre-2011 samples have already been analyzed for this suite of isotopes, and the rest of the fall 2011 samples will be analyzed this winter. Earlier samples generally lack POM-δ^{34}S and NH4-δ^{15}N data, except for USGS *Polaris* samples.

<u>Evidence of spatial and temporal variability in the importance of key processes or sources</u>

The reason isotopes have become such a popular tool for environmental quality studies is because different sources of nutrients (e.g., NO3 vs NH4) and organic matter (e.g., algae vs terrestrial) and different biogeochemical processes (e.g., nitrification, uptake, denitrification) often have distinctive isotopic signatures that allow different sources and sinks to be identified, traced, and quantified (Kendall et al., 2010). For example, the different N sources and processes in Figure 7a can often be resolved and quantified using isotope analysis. Figure 7b is a conceptual model showing how uptake and nitrification result in significant changes in the δ^{15}N of the NO3, NH4, and algae. Figure 8 shows that nitrification of NH4 downstream of SRWTP in 2009 results in distinctive changes in δ^{15}N, providing a useful tracer of this process. The combination of mixing of different nitrate sources and N cycling processes causes huge temporal and spatial variability in $\delta^{15}N$ and $\delta^{18}O$ of nitrate across the SFE, as shown in Figure 9.

Table 4 shows the kind of process and source information available by the multi-isotope approach used in our various Delta studies. These isotope data will be used to (1) confirm and clarify mass balance interpretations, and (2) identify hotspots of transformation activity or evidence of internal sources. For example, when mass balance suggests a substantial NO3 loss, the isotope data can be used to confirm whether uptake or denitrification is the more likely explanation. Alternatively, if the isotopic changes suggest inputs from a distinct new source while the mass balance shows little or no loss of NO3, there may actually have been losses masked by an internal source, thus providing new insights into ecosystem functioning.

We are currently using these approaches in our in-progress paper on ~20 Sacramento River isotope transects (conducted in collaboration with the Parker/Dugdale group and Foe). Since we have isotope data going back to 2005 in some parts of the Delta, and a limited isotope data set from even earlier pilot studies (e.g., Kratzer et al., 2003; Wankel et al., 2006), we will be able to compare changes in isotope compositions of nutrients over time with the estimated changes in nutrient concentrations and loadings compiled in Task 1. Longer-term patterns in isotope compositions can provide insight into whether changes in concentrations are driven by changes in types of source inputs, changing amounts of a stable source, or removal processes. These rate and process estimates will now be applied to larger-scale mass balance calculations as part of this new region-wide, longer term study.

Application of isotope data to refine and update the nutrient model calibration

This task will use the isotope data and insights developed through past and on-going projects to refine and ground-truth the calibration of the DSM2-QUAL nutrient model. A unique aspect of our ongoing collaborations with Marianne Guerin is that we have estimates from DSM2-QUAL of the relative volumetric proportions of water from different important water sources – and flow and net flow data – for most sites and dates that we have chemistry and isotope data. In these collaborations, we have used stable isotope data, combined with concentration data and DSM2 output (volumetric fingerprints and travel times) to construct complex isotope mixing models and calculate transformation rates at a select number of locations. In those past projects, however, we did not have the opportunity to compare these transformation rates to those used in the current calibration of the nutrient module (DSM2-QUAL) to update the calibration where indicated to more accurately predict transformations in the Delta. In the current project, we propose to iteratively perform these assessments and calibration refinements, and expect that such coupled hydrodynamic-isotope-mass-balance calibration approaches will dramatically improve our ability to accurately predict and quantify transformations in the Delta.

We will also use DSM2 output at additional stations throughout the Delta where we have isotope data from other studies to compute transformation rates, and use these rates to further refine the QUAL nutrient model calibration. Due to the complexity of the Delta, it is likely that different areas of the Delta may experience different dominant nutrient cycling and/or loading processes. By extending our combined isotope analysis and modeling work into a large portion of the Delta, we will be able to better understand how these critical processes change across spatial and temporal scales, which will then allow us to perform a variety of informative mass balance calculations. For example, we can use the volumetric estimates and chemistry for Rio Vista to estimate contributions from less-well-characterized sources (e.g., the Cache Complex tributaries), assuming that the concentrations of other main sources (the Sacramento River), and the marine source (at Martinez) are better known. Alternatively, we can use the chemistry to independently calculate relative proportions of sources. Discrepancies between the results of these forward and backward modeling approaches provide useful information about model assumptions and the extent of non-conservative behavior (e.g., residual analysis).

X.2.5. Interaction with existing monitoring surveys or other studies:

The USGS Isotope Tracers group (Kendall, Young, etc.) has collaborated with several Delta monitoring surveys and other studies that were collecting samples for chemical analysis (Figure 6, Tables 2-3) 2005-2012, and piggybacked the collection of isotope samples on their cruises. For all these Delta studies, Guerin also received funding via the SWC and the Kendall IEP/BOR projects to provide DSM2 support for collaborative activities. See the notes at the bottom of Tables 2-3 for more specifics.

X.2.6. Feasibility:

Highly feasible: Most of the isotope data are already available and other relevant isotope data will be available in early 2013. Furthermore, this project continues and extends ongoing collaborative research 2009-present between the Kendall group and Guerin to use DSM2/RMA modeling tools to provide supporting hydrological information to help interpret and apply the isotope and chemical data from specific sites to address a series of POD and habitat-oriented questions. The enhanced collaboration described in this proposal, alongside data analysis of long-term monitoring data and mass balances and DSM2-QUAL nutrient modeling, will be extremely valuable in both directions.

X.2.7. Deliverables:

- Sections on isotope data analysis for the overall project technical report and journal article (Task 1), and for modeling documentation, written by Kendall and Young
- New isotope-oriented insights will also be incorporated into other planned Kendall-Young papers as part of the existing IEP/BOR funded projects - especially the small Kendall "X2" study, funded as part of an IEP-2010 study that is evaluating 20+ years of chemistry data.
- Progress reports with invoices

X.2.8. Detailed budget:

USGS - $34K, which includes 57.92% USGS overhead. This funding provides 9 weeks of salary for Young; no salary requested for Kendall (in kind contribution).

X.3.1. Task 3: Refine and update the calibration and validation of the DSM2 nutrient model, and application of DSM2 for quantifying nutrient fate in the Delta

X.3.2. Investigators:

Lead: Guerin (USGS)
Collaborators: Senn (SFEI), Kendall (USGS), Young (USGS), Novick (SFEI)

X.3.3. Specific Questions:

3.1 What processes have the greatest influence over nutrient concentrations, speciation, fate, and movement within and efflux from the Delta?
3.2 How do these processes vary seasonally and spatially in their magnitude and relative importance?
3.3 What are the predictions of concentrations and loads most sensitive to?
3.4 How important are nutrient concentrations and loads and turbidity in controlling pelagic primary production in the Delta? What are the major data gaps?

X.3.4. Approach and Methods:

The initial work in Task 3 (Task 3a) focuses on the refinement of the existing DSM2 nutrient model calibration and the extension of the current simulation time frame to include recent data. Model output (Tasks 3b and 3c) will then assist in the interpretation of existing data, in support of Tasks 1 and 2, to refine our understanding of nutrient dynamics in the Delta and to calculate regional estimates of nutrient loads at specific time frames. QUAL has distinct implementations used in this project: for volumetric load calculations; for calculating turbidity in the Delta[3]; and, for calculating nutrient dynamics and water temperature. Figure 10A depicts QUAL's conceptual model for nutrients (Rajbhandari 2003). The QUAL nutrient model has been extensively calibrated (Guerin, 2011) - the current calibration is robust for analysis applications at daily to monthly time steps, as most tributary boundary conditions with the exception of water temperature and dissolved oxygen are monthly time series. DSM2-HYDRO model output is reliable at 15-minute time steps in most locations.

Task 3a: Extension of DSM2 nutrient model simulation; refinement of calibration using a finer temporal and spatial scale of measurements, including isotopes

Task 3a uses a recent set of nutrient and isotope data (Tables 2-3, Figure 6) for refining the nutrient model calibration. Nutrient model boundary conditions, including HYDRO effluent inflows, will be extended from the current simulation end of December 2008 to December 2011 or 2012, with the extension date depending on the availability of operational data from DWR. Table 4 identifies the interpretive value of water quality measurements and isotopes for this Task. Incorporating isotopic analyses into the calibration process for QUAL offers a unique opportunity to more accurately capture the dominant mechanisms involved in nutrient transformation in the Delta, and also to identify major data gaps.

Specifically, the extensive set of data of nutrients and isotopes can inform and constrain the nutrient model parameterization and improve the calibration by:

- identifying the dominant processes involved in the transformation of nutrients via distinctive shifts in isotopic composition from standard ratios;
- providing fine spatial and temporal scale measurement data for model calibration and validation;
- providing an independent means of calculating rate parameters for individual nutrient transformations (e.g., nitrification, algal growth); and
- identifying nutrient sources (e.g. waste water vs. agricultural), which provides a test of the model assumptions on source load and inflow from different sources.

For example, agricultural inflow and concentration boundary conditions are specified by the Delta Island Consumptive Use[3] (DICU) model, which has over 250 locations in the model domain. The magnitude of DICU influence can be poorly constrained, so identifying whether nutrient loads are from waste water treatment facilities or from agricultural sources can be problematic. The isotopic fingerprints can help constrain these model variables (Table 4) since these sources usually have distinctive compositional ranges (Kendall et al., 2010). Isotopic analyses are also an independent source of information for constraining or corroborating model rate coefficients, as illustrated in Figure 10 (B and C). In nutrient model applications, model rate coefficients are typically set using rates measured in laboratory experiments. However, as in

[3] Guerin has been modeling Delta turbidity for several years – including the development and calibration of a turbidity model using QUAL for the period 1975 - 2011 – this work is supported by Metropolitan Water District
[4]http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/DICU_Dec2000.pdf

most rate-dependent processes, field rates will vary significantly from laboratory rates (Lund et al., 1999; Wankel et al., 2007; Cifuentes et al., 2009; Sugimoto et al., 2009).

Task 3b: Apply DSM2 to quantify major drivers of nutrient concentrations; and to calculate downstream loads at regional spatial scales and at selected temporal scales

Working with PI's directing Tasks 1 and 2, this task uses the refined calibrated/validated model from Task 3a, parameterized with transformation rate constants from Task 2, to determine which specific uptake/loss processes can best explain observed nutrient concentrations and to supply model calculations at locations and times where data do not exist or at different spatial and temporal scales than data alone allows. In parallel, information will be extracted from nutrient model runs and turbidity model runs to identify factors (e.g., nutrient concentrations and forms, temperature, and turbidity) controlling primary production in the Delta. Note in Figure 11 that algal mass is a nutrient model variable- it is assumed linearly related to chlorophyll a concentration. In addition to Delta-wide estimates, DSM2 nutrient model output and information from isotopic analyses will be used to calculate regional load influx/efflux estimates on several temporal scales (e.g., seasonal, monthly). Several regions and time frames will be considered to categorize sub-Delta loads and transformations.

Task 3c: Apply the Historical DSM2 model to calculate volumetric percentages

The task is directed at supplying volumetric model output to PI's to inform or constrain data analyses in Tasks 1 and 2 using modeled volumetric percentages by source (Figure 11). This task cannot be accomplished without adding in effluent inflows to HYDRO, part of Task 3a.

X.3.5. Interaction with existing monitoring surveys or other studies:

Tables 1-3 specify existing data that will be used in this Task. The cost for model development is reduced since work from previous studies will be used to support the extension of the nutrient model to 03/2012 specified in Task 3a. Kendall's FLaSH project "Residence Time as an Aid to Interpreting Nutrient Dynamics in the Suisun, SJR Confluence and Cache Complex Regions" provides support for extending HYDRO with effluent inflow data through 2011, but does not support the extension or recalibration of the QUAL nutrient model, or the iterative process of refining the rates of nutrient transformation using isotope data and using DSM2 model output to support the interpretation of isotope analyses.

X.3.6. Feasibility:

Highly Feasible: The existing DSM2[4] models are well-calibrated and widely used. The QUAL nutrient model will benefit substantially from refinement using isotope data (Task 2, Task 3a) and detailed data analysis (Task 1a). General understanding of dominant processes and transformation rates will be confirmed using these complementary data analysis techniques.

X.3.7. Deliverables:

- An updated calibrated and validated DSM2 nutrient model, including boundary conditions and documentation of model extensions and revisions that will be made publicly available and given to DWR-DMS along with a technical report (Task 3a).
- Results from Tasks 3b and 3c will be included in the overall project technical report and will serve as critical input to the manuscript quantifying the importance of major processes.

X.3.8. Detailed budget:

RMA - $65K for RMA staff time

[4] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

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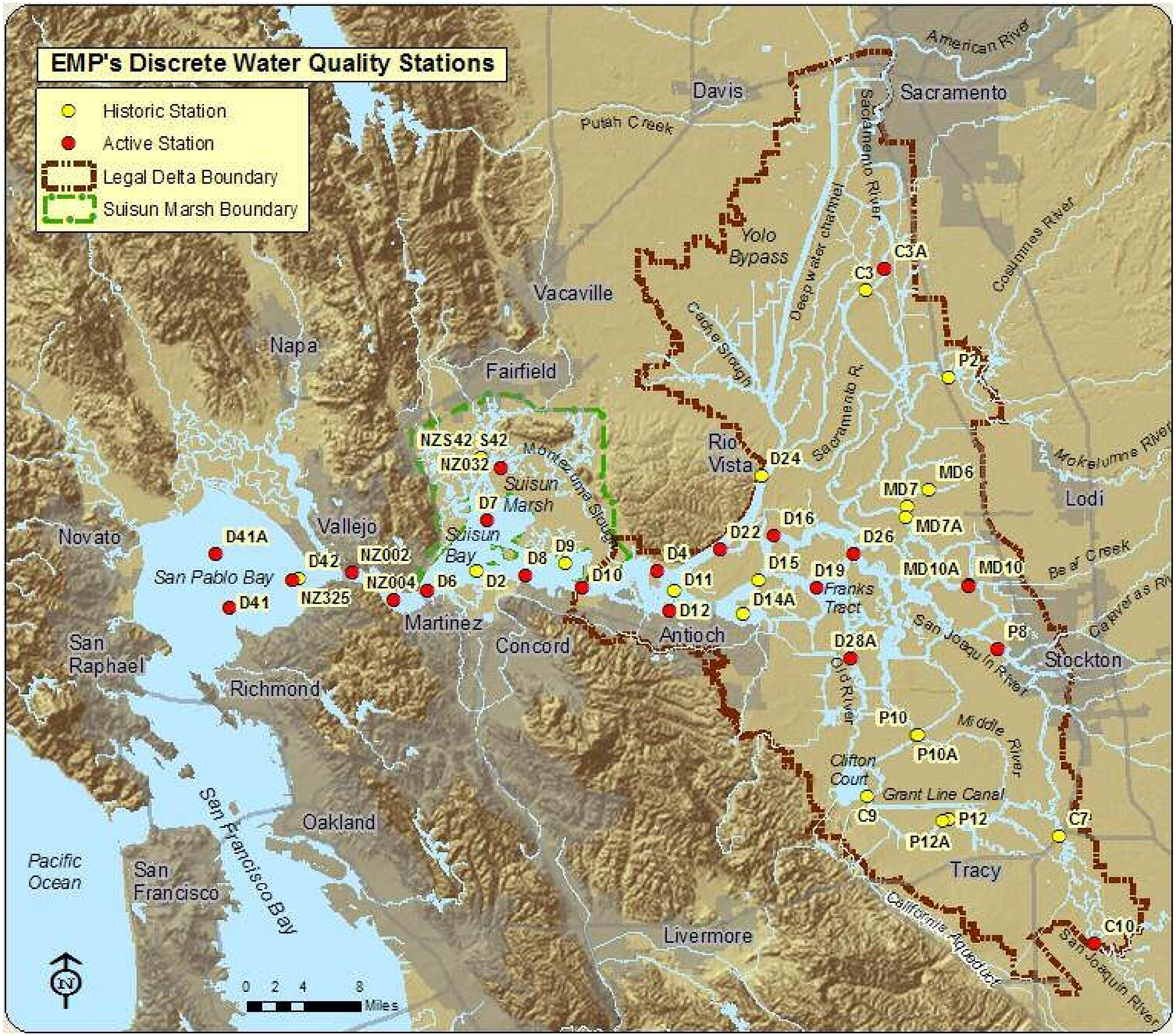

Figure 1. Location of DWR-EMP sites where monthly water quality samples are taken. Coincident stations were considered as one (i.e. MD10 and MD10A) for a total of 22 stations within the legal delta boundary. Source: http://www.water.ca.gov/bdma/meta/discrete.cfm

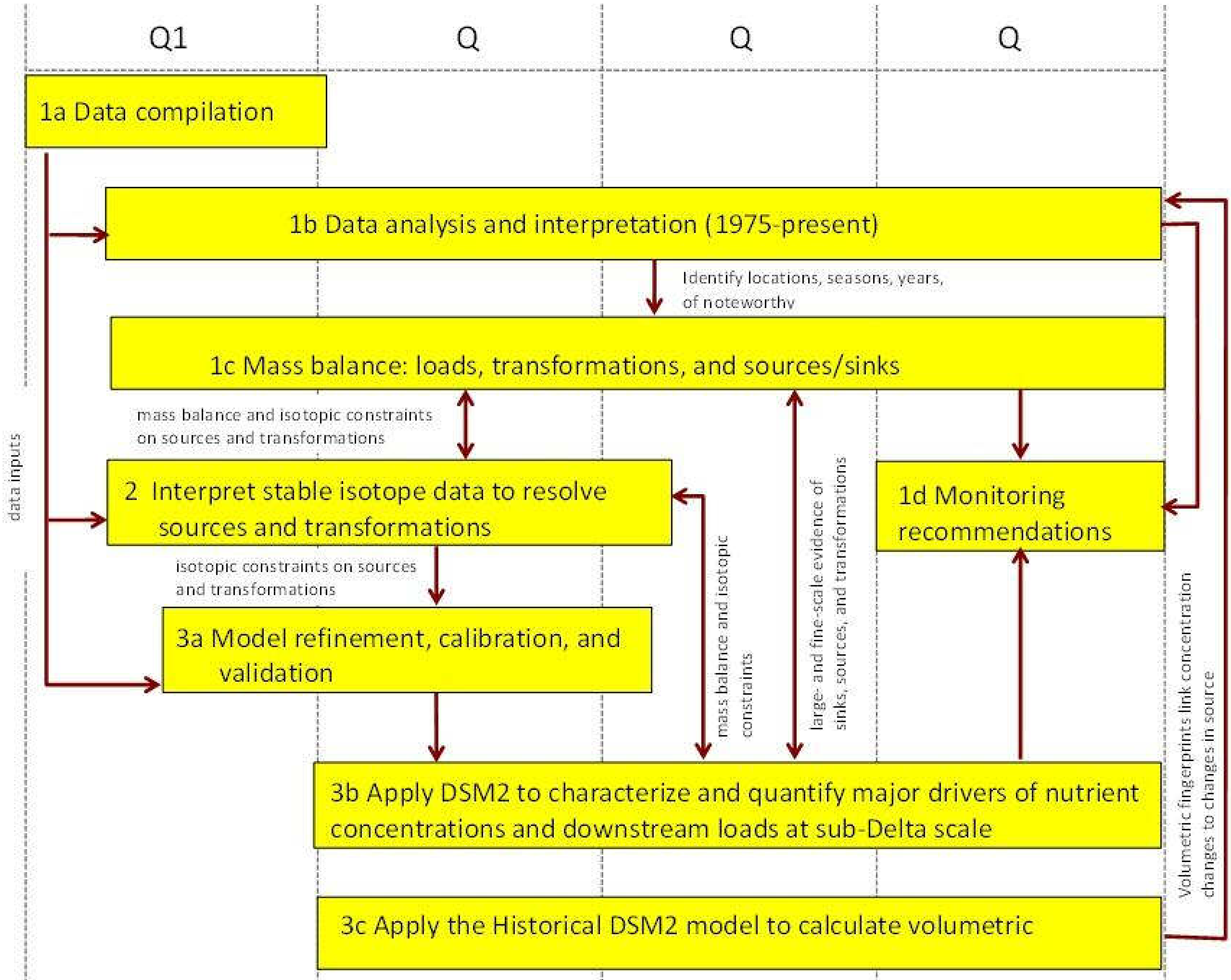

Figure 2. Approximate workflow and interaction between tasks. This project is scheduled to be one-year long.

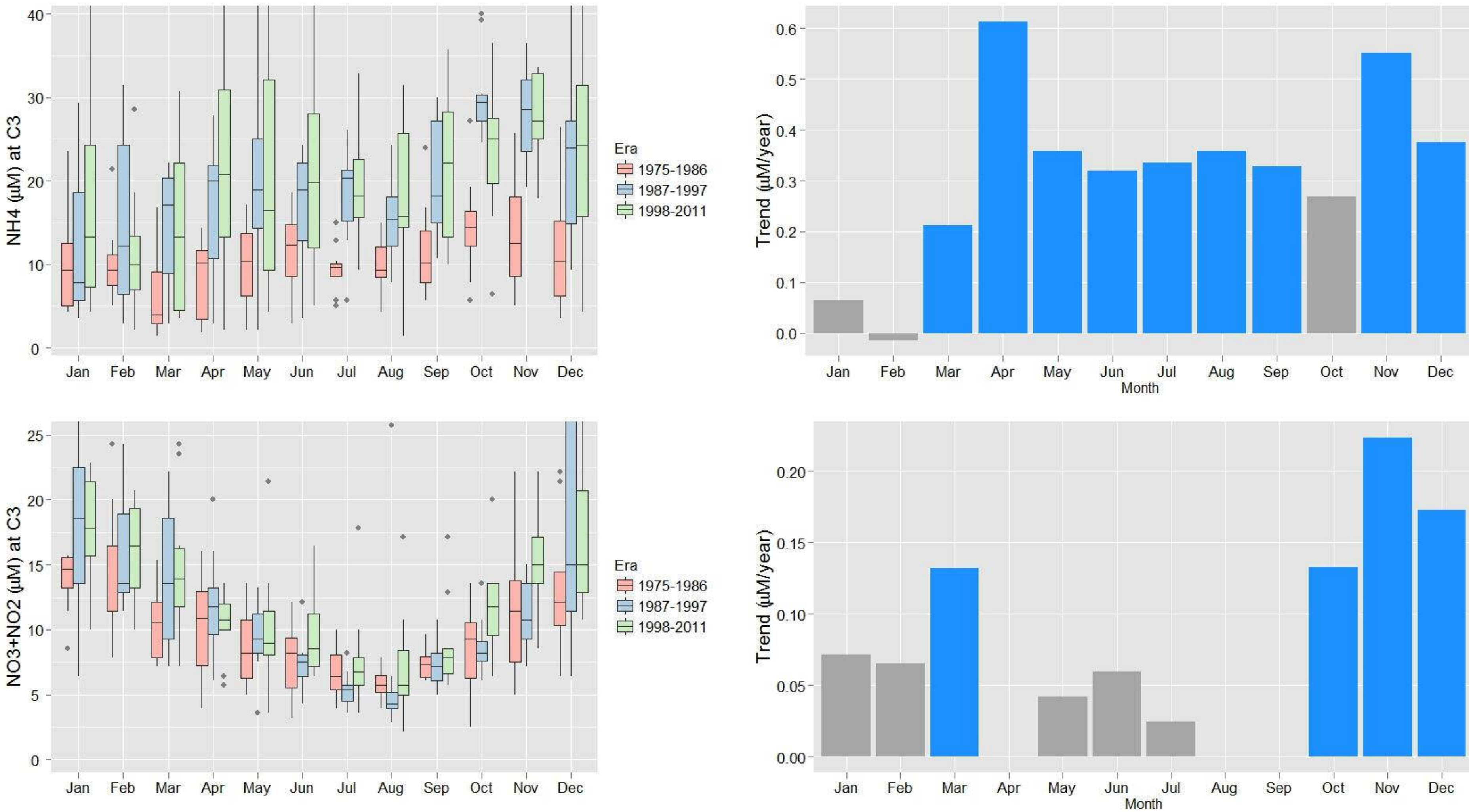

Figure 3: Nutrient trends at DWR-EMP Station C3, ~12 km downstream of Sac Regional. Strong (left panel) and statistically significant (right panel) increases in NH4 concentrations in waters entering the Delta along the Sacramento were observed. There was limited seasonal variability in NH4, except slightly higher concentrations during low flow (presumably less dilution due to lower Sacramento River flow). NO3 concentration did exhibit strong seasonal variation (due likely to decreased runoff from upstream agriculture in low-flow months, likely primary source of NO3) and moderate increase over the past 35 years. In the left panels, boxes extend from 25^{th}-75^{th} percentile, with the line in the middle denoting the mean, and whiskers extend to 1.5 times the interquartile range. Data outside of this range is represented by points. Trends in the right panel are given by the Theil-Sen slope, and blue shading indicates statistical significance ($p < 0.05$ as determined by Regional Kendall test; for further explanation see Jassby 2008).

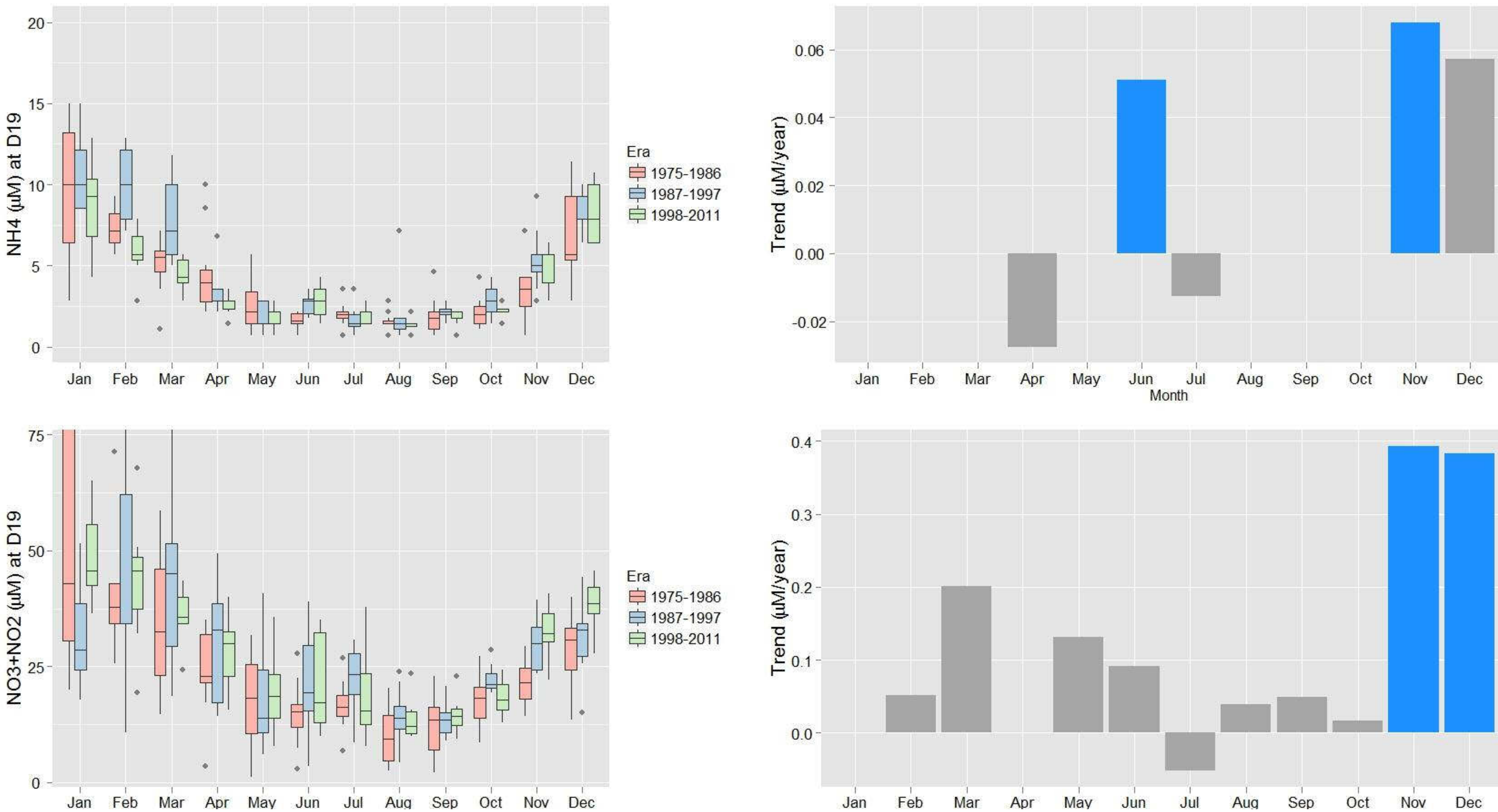

Figure 4: Calculations and figure properties in Figure 4 are the same as those in Figure 3..At D19, which receives most of its water from the Sacramento River, observations differ considerably from those at C3. There were strong seasonal patterns in NH4 concentrations (which were absent at C3). The large increases in NH4 concentration observed at C3 were not evident in increased NH4 concentration at D19. Statistically significant increases were observed during June and November, however these increases were 5-10x lower than those increases observed at C3. NO3 concentrations in January too large to be explained by NO3+NH4 at C3, suggesting there must be either internal sources of NO3 or mixing of water from Sacramento and San Joaquin, which has higher NO3, but its NH4 levels are lower (~5uM), and so can not explain the relatively high January NH4 at D19.

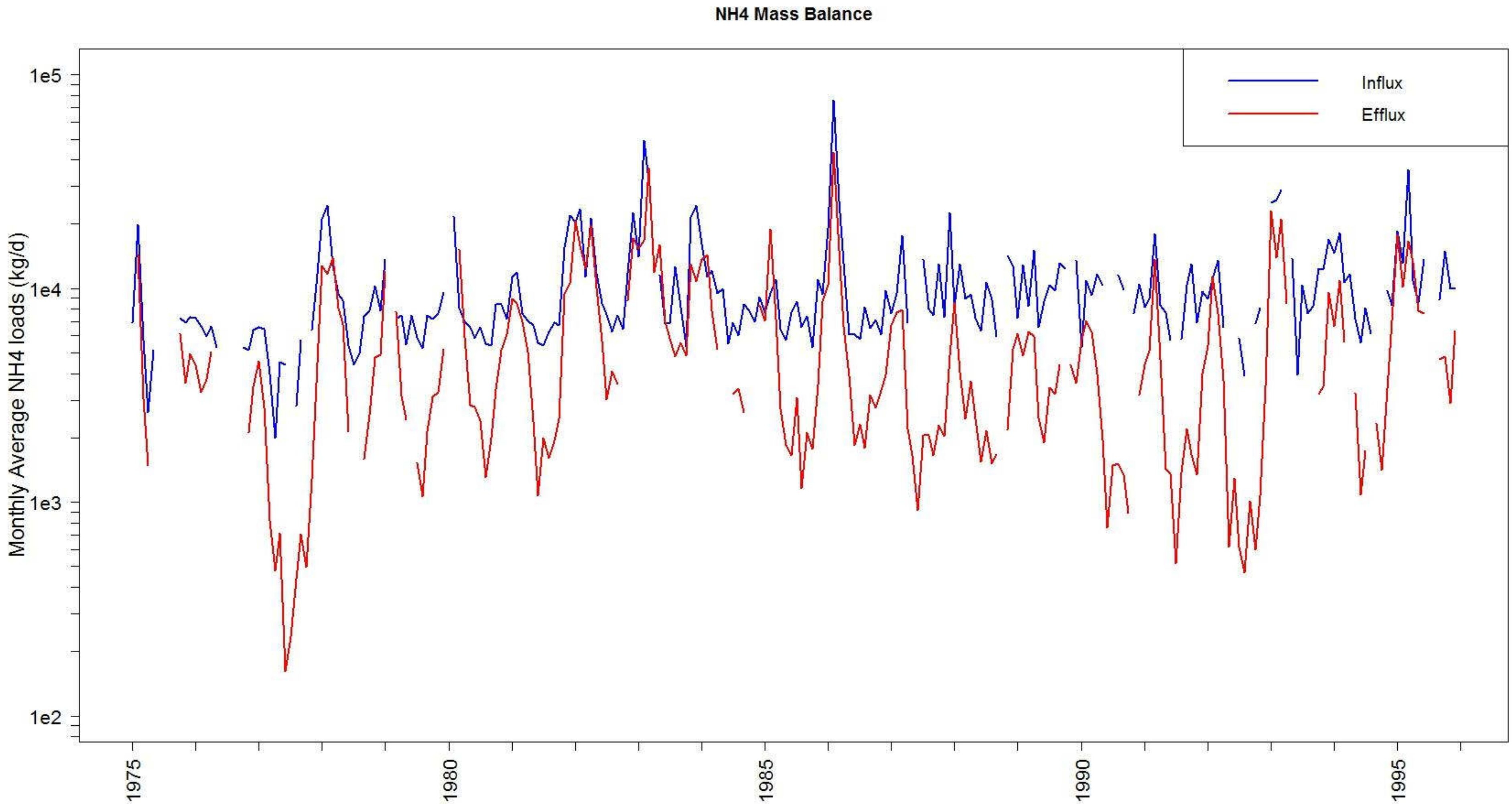

Figure 5: Monthly-averaged NH4 loads into (influx) and out (efflux) of the Delta (note: log scale on y-axis). Loads were calculated using concentration data from DWR-EMP stations and flow data from DWR DAYFLOW stations, following the approach of Jassby and Cloern (2000). Influx includes loads from Sacramento (including wastewater loads from the greater Sacramento area) and San Joaquin Rivers, as well as from streams east of the Delta; efflux includes both loads to Suisun Bay and loads to water exports. The vertical distance between the red and blue lines represents loss of NH4 by nitrification or assimilation. NH4 losses are greatest during high flow,,likely due to shorter residence time or lower temperature. On average, 75% of the efflux loads are to Suisun Bay and the remaining 25% are to water exports.

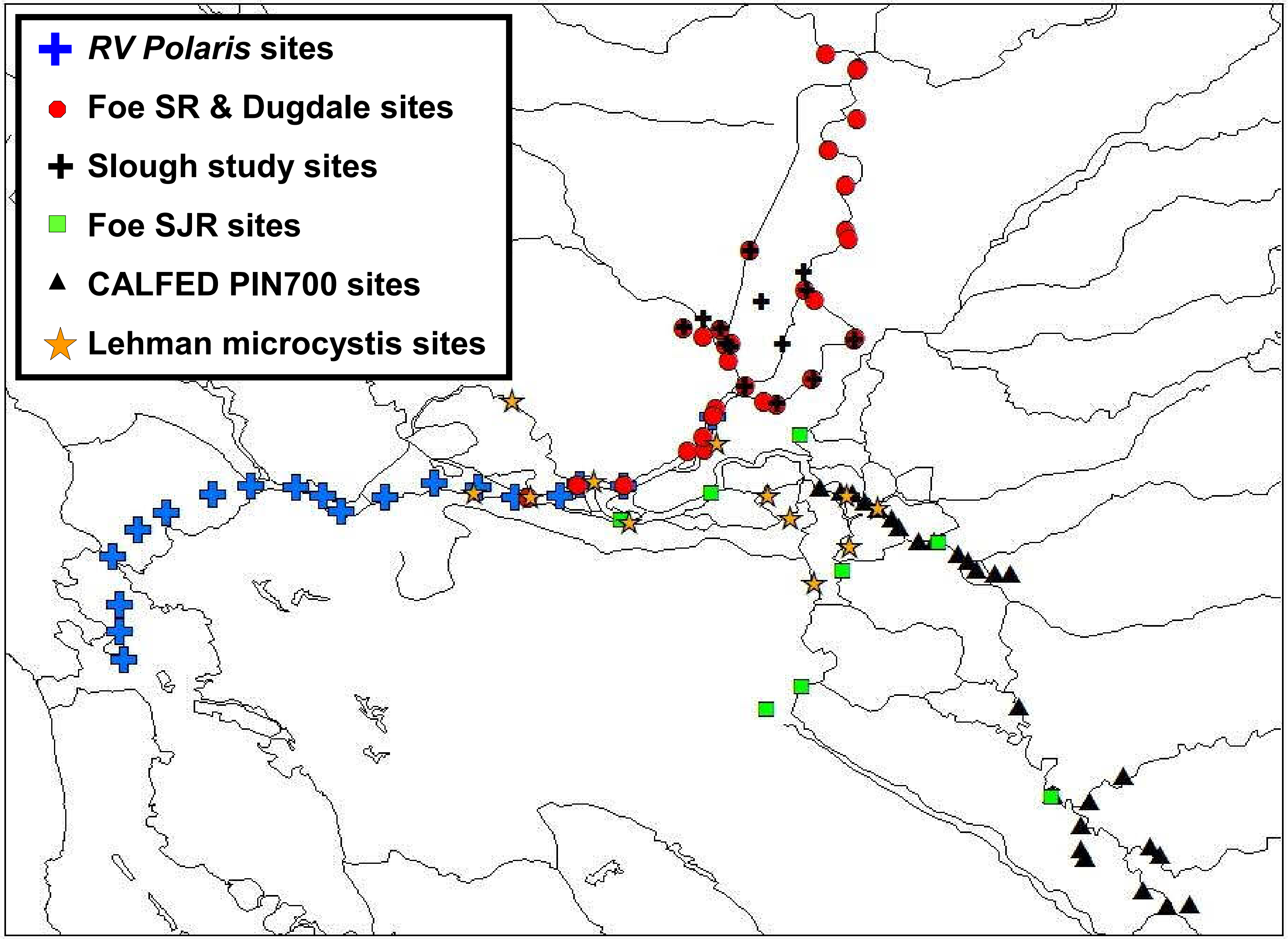

Figure 6. Map showing the sites sampled as part of the different transects listed in Tables 2 and 3. Some of these sites (mainly the USGS Polaris sites) have >30 years of chemistry data and > 2 years of isotope data, and others have different sets of chemistry and isotope data (see the list of analytes in Table 2).

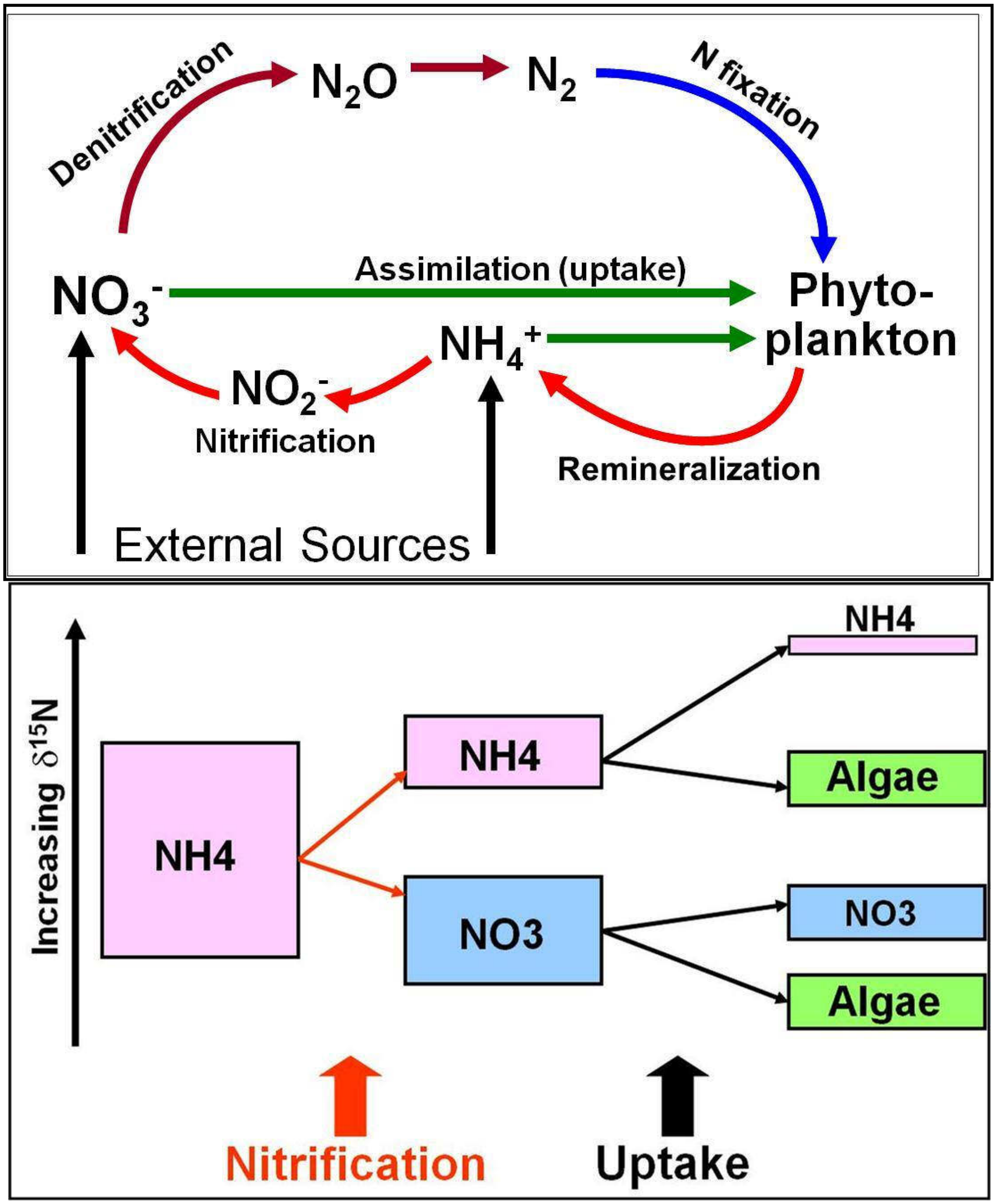

Figure 7A (upper)**.** Main sources of N and processes that cycle-N in aquatic systems. External sources include waste water treatment plants, agricultural loads, and wetlands.**B**(lower)**.**Conceptual model showing how biological processes can produce distinctive changes in isotope composition. Boxes are different pools of N, size is proportional to size of N-pool, and position reflects its average $\delta^{15}N$. Nitrification produced new NO3 with a lower $\delta^{15}N$ and residual NH4 with a higher $\delta^{15}N$ than the original NH4. Uptake of the NH4 or NO3 by algae (phytoplankton) results in algae with different $\delta^{15}N$ values depending on the source of the N. Therefore, the $\delta^{15}N$ of the algae can be used to determine whether NH4 or NO3 was the dominant source of N to uptake.

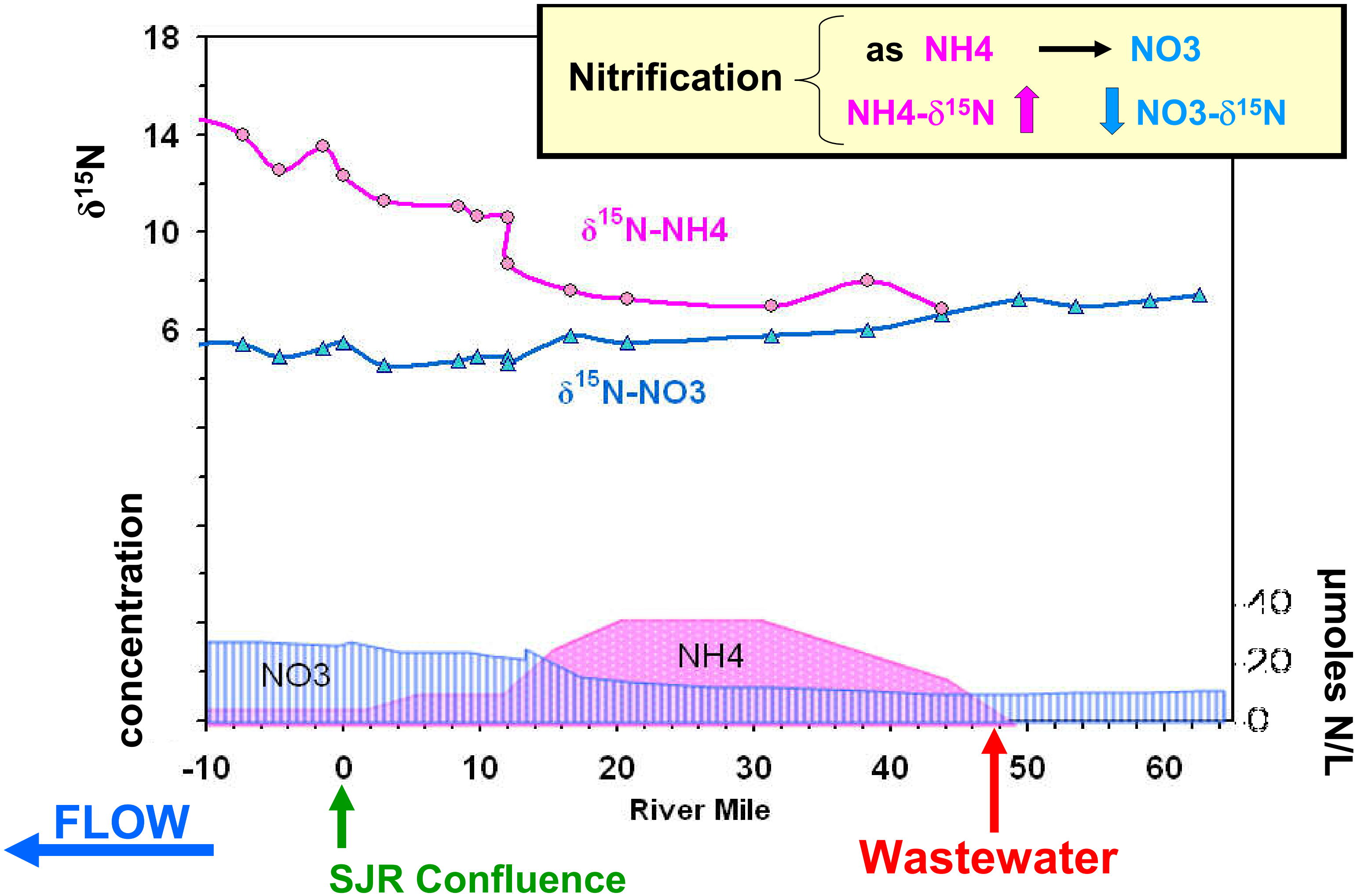

Figure 8. Downstream changes in nutrient concentration (data from Parker) and $\delta^{15}N$ (datafrom Kendall) for a March 2009 transect, plotted against river mile. The plot shows how nitrification of NH4 derived from wastewater causes the $\delta^{15}N$ of NH4 and NO3 to become more isotopically distinctive as the waters flow downstream.

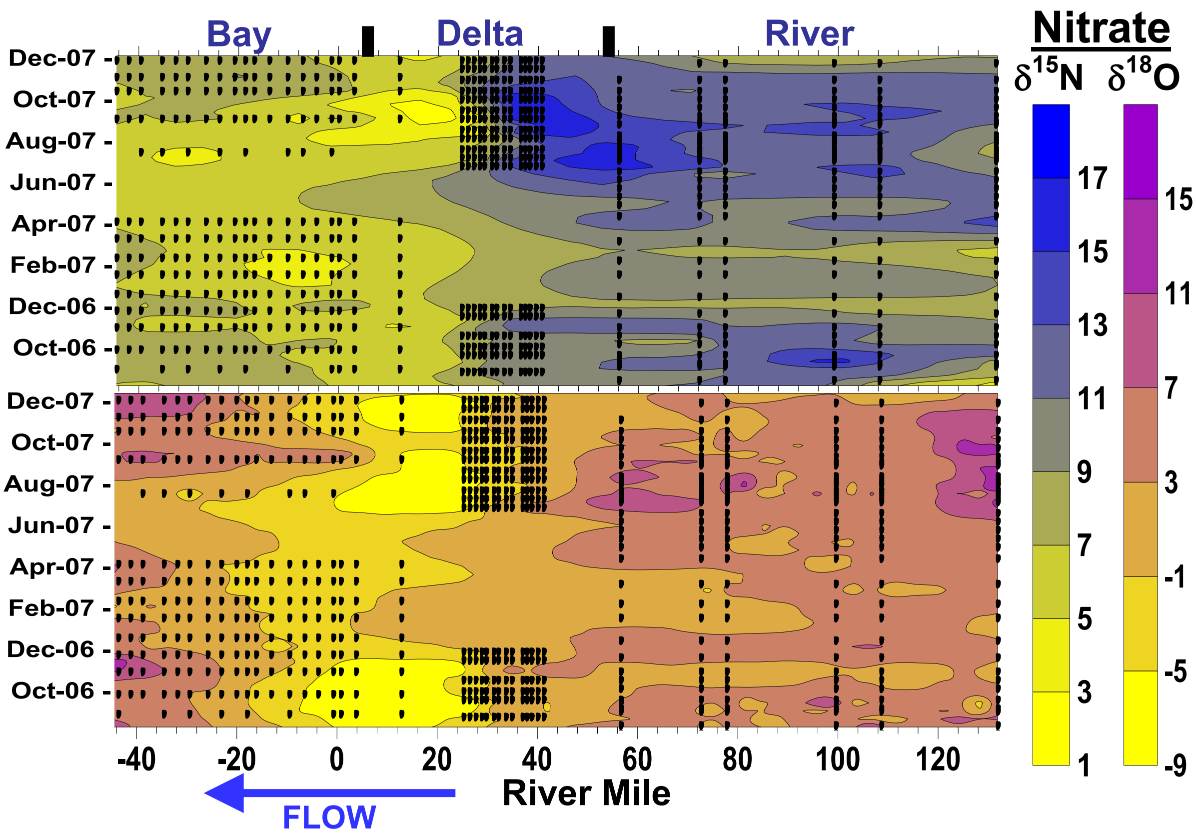

Figure 9. Temporal and spatial variation in the $\delta^{15}N$ and $\delta^{18}O$ (in permil) of nitrate for about 700 samples collected along the San Joaquin River, Delta, and Bay 2006-2007, plotted relative to river mile (RM), extending from Lander Avenue in the San Joaquin to the Golden Gate Bridge. The analytical precision is less than 1 permil. Hence, these changes in isotopic composition reflect huge changes in nitrate sources (low $\delta^{15}N$ values typically reflect marine and soil/fertilizer sources whereas higher values suggest manure/waste), and N cycling processes such as uptake and nitrification. The low $\delta^{15}N$ and $\delta^{18}O$ values upstream of the San Joaquin River confluence at RM=0 indicate extensive nitrification in the Sacramento River.Modified from Kendall et al. (2010).

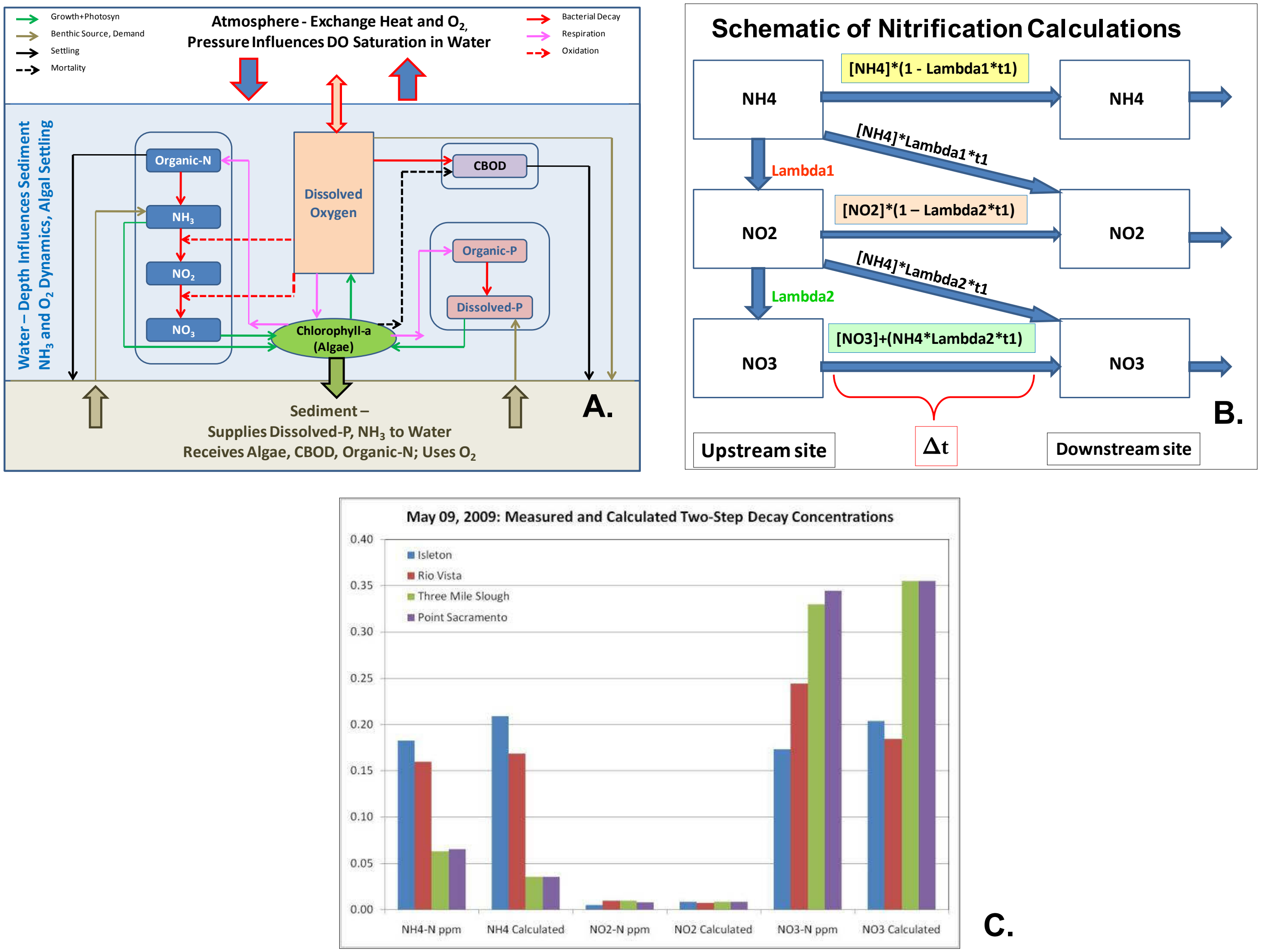

Figure 10A.QUAL's conceptual model of nutrient dynamics– boxes and oval in the water/blue section are model variables. Process rates (arrows) will be refined using water quality and isotope data. **B**. Schematic of plug flow model (no mixing) and constant concentration at Hood. Travel time, Δt, from Hood to downstream locations was estimated with DSM2 tracer models. Ammonia and NO2 decay linearly as traveling; Lambda2 < Lambda1. **C**. Comparison of constituent measurements and concentrations for the 05/09 transect calculated using DSM2-calculated travel times and the simplified conceptual model of nitrification illustrated in B.

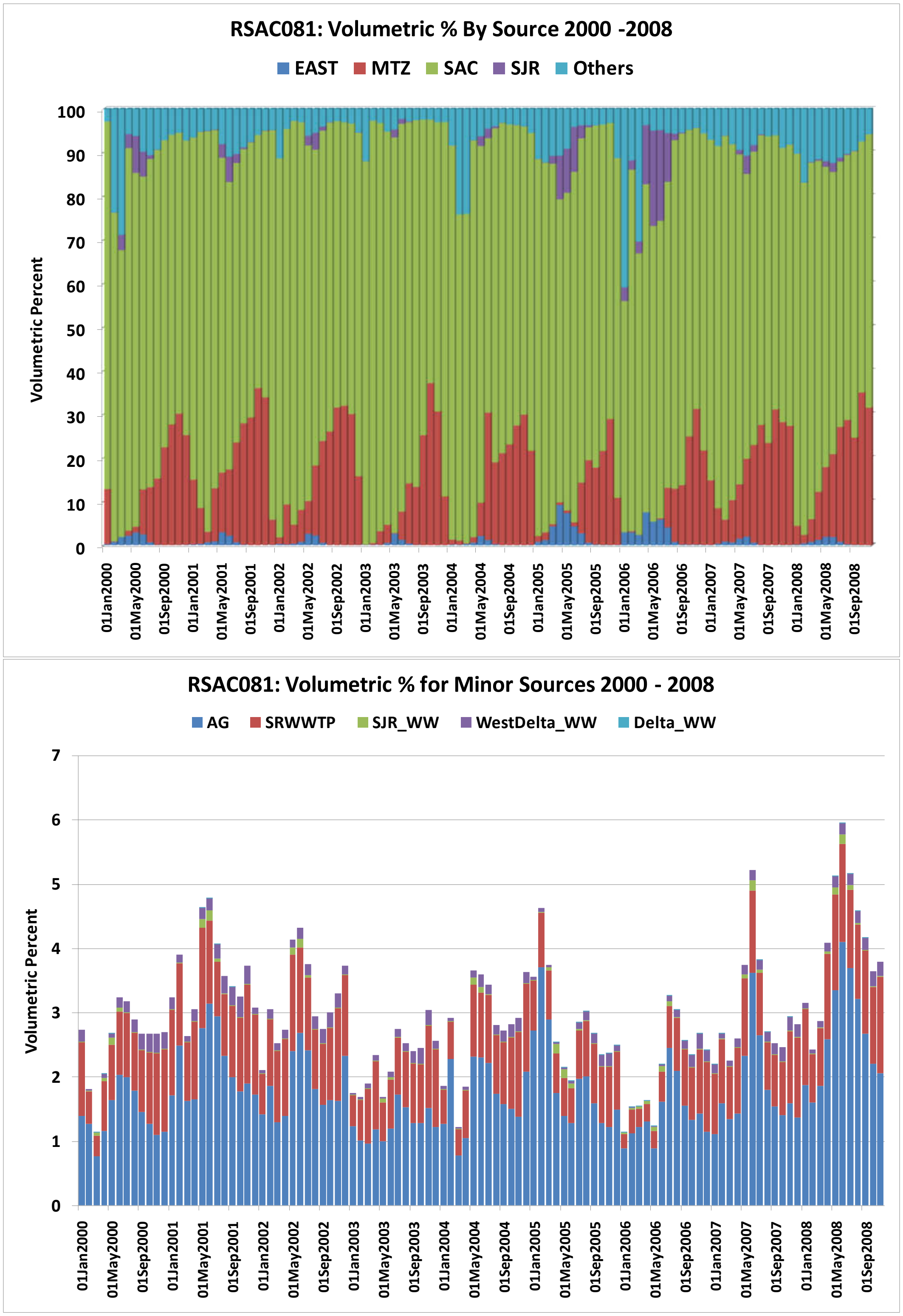

Figure 11. Volumetric percentages by source – top figure category "others" includes all sources in bottom figure. The Ag source is the sum of all DICU inflows; SJR_WW includes Stockton and other effluent sources on the SJR; Delta_WW includes all minor effluent sources in the south and central Delta; and, WestDelta_WW includes all sources in the lower SJR, Suisun and from the confluence to the model boundary at Martinez.

Table 1. Record of available nutrient data at 22 DWR-EMP stations with the Delta. Includes station name, approximate location, corresponding DAYFLOW station (if applicable), and dates and number of samples for 6 nutrient analytes.

Station Name	Location	Corresponding DAYFLOW station (Jassby/Cloern)	NH_4	$NO_3 + NO_2$	TKN	Organic N	PO_4	TP
IEP Stations								
C3/C3A	Influx from Sacramento River	Q_{sac}, Q_{yolo}	1975-2011 n=436	1975-2011 n=437	1975-2011 n=439	1975-2011 n=392	1975-2011 n=436	1975-2011 n=437
C10	Influx from San Joaquin River	Q_{sjr}	1975-2011 n=376	1975-2011 n=437	1975-2011 n=437	1975-2011 n=431	1975-2011 n=438	1975-2011 n=435
C7	Influx from San Joaquin River		1975-1995 n=234	1975-1995 n=247	1975-1995 n=250	1975-1995 n=245	1975-1995 n=248	1975-1995 n=248
MD10/MD10A	Influx from Eastern Streams	Q_{csmr} Q_{moke} Q_{misc}	1975-2011 n=400	1975-2011 n=436	1975-2011 n=439	1975-2011 n=433	1975-2011 n=433	1975-2011 n=436
P8	Influx from Eastern Streams		1975-2011 n=432	1975-2011 n=435	1975-2011 n=435	1975-2011 n=430	1975-2011 n=434	1975-2011 n=434
P2	Influx from Eastern Streams		1975-1977 n=23	1975-1977 n=30	1975-1977 n=36	1975-1977 n=35	1975-1977 n=32	1975-1977 n=36
MD7	Influx from Eastern Streams		1975-1983 n=89	1975-1983 n=96	1975-1983 n=101	1975-1983 n=98	1975-1983 n=97	1975-1983 n=97
MD6	Influx from Eastern Streams		1975-1995 n=228	1975-1995 n=231	1975-1995 n=232	1975-1995 n=221	1975-1995 n=227	1975-1995 n=227
D26	Within Delta		1975-2011 n=433	1975-2011 n=438	1975-2011 n=439	1975-2011 n=420	1975-2011 n=436	1975-2011 n=437
D19	Within Delta		1975-1995 2004-2011 n=319	1975-1995 2004-2011 n=338	1975-1995 2004-2011 n=339	1975-1995 2004-2011 n=330	1975-1995 2004-2011 n=337	1975-1995 2004-2011 n=337
D28A	Efflux to CCC	Q_{ccc}	1975-2011 n=413	1975-2011 n=433	1975-2011 n=433	1975-2011 n=420	1975-2011 n=433	1975-2011 n=433
C9	Efflux to SWP	Q_{swp}	1975-1995 n=241	1975-1995 n=246	1975-1995 n=248	1975-1995 n=244	1975-1995 n=243	1975-1995 n=241
P12/P12A	Efflux to CVP	Q_{cvp}	1975-1995 n=246	1975-1995 n=248	1975-1995 n=250	1975-1995 n=245	1975-1995 n=248	1975-1995 n=247
P10	Efflux to CVP		1975-1995 n=231	1975-1995 n=237	1975-1995 n=237	1975-1995 n=235	1975-1995 n=236	1975-1995 n=235

D24	Efflux to Suisun	Q_{rio}	1975-1995 n=247	1975-1995 n=248	1975-1995 n=250	1975-1995 n=234	1975-1995 n=247	1975-1995 n=247
D16	Efflux to Suisun	Q_{west}	1975-1995 n=243	1975-1995 n=247	1975-1995 n=251	1975-1995 n=242	1975-1995 n=247	1975-1995 n=247
D22	Efflux to Suisun		1975-1995 n=246	1975-1995 n=249	1975-1995 n=249	1975-1995 n=233	1975-1995 n=246	1975-1995 n=247
D15	Efflux to Suisun		1975-1995 n=228	1975-1995 n=247	1975-1995 n=249	1975-1995 n=236	1975-1995 n=243	1975-1995 n=243
D14A	Efflux to Suisun		1975-1995 n=215	1975-1995 n=241	1975-1995 n=243	1975-1995 n=234	1975-1995 n=236	1975-1995 n=237
D11	Efflux to Suisun		1975-1995 n=234	1975-1995 n=244	1975-1995 n=246	1975-1995 n=237	1975-1995 n=241	1975-1995 n=242
D12	Efflux to Suisun		1975-1995 n=233	1975-1995 n=248	1975-1995 n=250	1975-1995 n=243	1975-1995 n=247	1975-1995 n=248
D4	Efflux to Suisun		1975-2011 n=434	1975- 2011 n=437	1975- 2011 n=438	1975- 2011 n=421	1975- 2011 n=435	1975- 2011 n=436

Table 2. Dates, programs, locations, and measurement types of SR and Delta transects with isotope data 2009-2012.

Transect Dates	PI and program	Isotope samples *	SR-Cache-Delta-Bay samples +	Chemistry (includes measured values and ones calculated by difference)#
Monthly$	USGS Polaris	°	0-0-9-10	see http://sfbay.wr.usgs.gov/access/wqdata/ for details.
3/26-27/09	Dugdale SWC	Yes	10-2-11-2	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake (C,NO3,NH4), OBS, T, etc.
4/23-24/09	Dugdale SWC	Yes	10-3-10-1	
5/26-27/09	Foe WB	Yes	5-4-4-0	
6/8-9/09	Foe WB	Yes	5-4-4-0	
6/22-23/09	Foe WB	Yes	5-4-4-0	
7/14-15/09	Foe WB	Yes	5-4-4-0	
8/3-4/09	Foe WB	Yes	5-4-4-0	
9/28-29/09	Foe WB	Yes	5-4-4-0	
10/20-21/09	Foe WB	Yes	5-4-4-0	
11/9-10/09	Foe WB	Yes	5-4-4-0	
12/7-8/09	Foe WB	Yes	5-4-4-0	
1/25-26/10	Foe WB	Yes	5-7-4-0	
2/22-23/10	Foe WB	Yes	5-7-4-0	
4/26/10	Dugdale 2Rivers &	Yes	22-0-4-1	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake rates (C, NO3, NH4), OBS, T, etc.
8/25/10	Dugdale 2Rivers	Yes	16-0-4-1	
4/19/11	Dugdale 2Rivers	Yes	15-0-4-1	
4/15/10	Kendall Sloughs	Yes	4-3-0-0	NO3, NO2, NH4, TN, DON, TP, TDP, PO4, DOC, Chl-a, Pheo, EC, pH, DO, NTU, T, etc.
4/19/11	Kendall Sloughs	Yes	5-7-0-0	
5/10/11	Kendall Sloughs	Yes	5-7-0-0	
6/9/11	Kendall Sloughs	Yes	5-7-0-0	
7/20/11	Kendall Sloughs	Yes	5-7-0-0	
8/22/11	Kendall Sloughs	Yes	5-8-0-0	
9/14/11	Kendall Sloughs	Yes	5-9-0-0	
10/12/11	Kendall Sloughs	Yes	5-16-0-0	
11/16/11	Kendall Sloughs	Yes	5-9-0-0	
12/12/11	Kendall Sloughs	Yes	5-9-0-0	
3/22/12	Kendall Sloughs	Yes	5-9-0-0	
4/24/12	Kendall Sloughs	Yes	5-9-0-0	
5/10/12	Kendall Sloughs	Yes	5-9-0-0	

7/24/12	Kendall Sloughs	Yes	5-9-0-0	
8/16/12	Kendall Sloughs	Yes	5-9-0-0	

NOTES:

+ Sites are divided into the categories “SR” (I-80 to Isleton), “Cache” (tributaries and sloughs in the Cache/Yolo Complex, which for the “Slough” project includes Miner and Steamboat Slough sites), “Delta” (Rio Vista downstream to Martinez), and “Bay” (downstream of Martinez to near Angel Is.). Hence, 4-2-4-0 means 4 sites in the SR, 2 in the Cache Complex, 4 in the Delta, and 0 in the Bay. “Foe” sites and “Dugdale 2 Rivers” sites sampled on the San Joaquin River are not included in this table.

* Isotope analyses include NH4-δ^{15}N; NO3 δ^{15}N and δ^{18}O; DOC-δ^{13}C; POM δ^{13}C, δ^{15}N, δ^{34}S, C:N, C:S; and water δ^{18}O and δ^{2}H; also DIC-δ^{13}C on recent Slough project samples and 2006-2007 Polaris samples.

Thistable lists the chemistry data we have access to; other data may be available.

$ Data are site-dependent; for example, nutrient data are only available for a subset of sites. We have isotope samples from Polaris transects starting 8/06 (see other table for more info).

° We only have limited isotope data for Polaris cruises 2009-2011; however, we have almost monthly isotope data (all but for NH4-δ^{15}N) for 8/06-5/08, and in-progress archived samples for 7/08, 11/08, 5/09, 4/11, and 8/11. See next table for more specifics. Monthly Polaris isotope samples 9/11-12/11 are being analyzed for our current suite of isotopes.

& Thistable includes extra grab samples collected by the Kendall team that have a reduced suite of chemical and isotopic measurements.

Table 3. Dates of transects in the SJR and SF Bay and western Delta where we have piggybacked isotope samples onto various cruises. Dates from different cruises of different monitoring programs have been lined up so the months match. +

SF Bay/Delta *RV Polaris* cruises; all sites to #18 *	**Project of the Polaris sampling**	**Dates for non-*Polaris* cruises [ie, Foe, *San Carlos (SC)*, DFG, and other cruises]***	**Project of the non-Polaris sampling** Δ	**water year type of the preceding spring for the Sacramento valley**
08/15/06	PIN700	08/09/06	SC sites (PIN700 project)	wet
09/12/06	PIN700	09/07/06	SC sites (PIN700 project)	wet
	PIN700	09/19/06	SC sites (PIN700 project)	wet
10/17/06	PIN700	10/05/06	SC sites (PIN700 project)	wet
11/14/06	PIN700	11/06/06	SC sites (PIN700 project)	wet
12/12/06	PIN700	11/20/06	SC sites (PIN700 project)	wet
01/09/07	PIN700			
02/06/07	PIN700			
03/06/07	PIN700			dry
04/03/07	PIN700			dry
		06/28/07	SC sites (PIN700 project)	
07/19/07	PIN700	07/12/07	SC sites (PIN700 project)	dry
		07/26/07	SC sites (PIN700 project)	dry
		08/10/07	SC sites (PIN700 project)	dry
		08/23/07	SC sites (PIN700 project)	dry
09/11/07	PIN700	09/25/07	SC sites (PIN700 project)	dry
		10/11/07	SC sites (PIN700 project)	dry
10/23/07	PIN700	10/25/07	SC sites (PIN700 project)	dry
11/14/07	PIN700	11/09/07	SC sites (PIN700 project)	dry
		11/26/07	SC sites (PIN700 project)	dry
12/11/07	PIN700	12/12/07	SC sites (PIN700 project)	dry
02/12/08	PIN700			
03/11/08	PIN700			critically dry
05/06/08	PIN700			critically dry
07/17/08	Lang project			critically dry
11/18/08	Lang project	11/18/08	Kendall (SWC)	critically dry
		3/26-27/09	Dugdale (SWC)	dry
		4/23-24/09	Dugdale (SWC)	dry
05/19/09	Lang project	5/26-27/09	Foe WB	dry
		6/8-9/09	Foe WB	dry
		6/22-23/09	Foe WB	dry
		7/14-15/09	Foe WB	dry

		8/3-4/09	Foe WB	dry
		9/28-29/09	Foe WB	dry
		10/20-21/09	Foe WB	dry
		11/9-10/09	Foe WB	dry
		12/7-8/09	Foe WB	dry
		1/25-26/09	Foe WB	below normal
		2/22-23/10	Foe WB	below normal
		4/26/10	Dugdale 2 Rivers	below normal
		8/25/10	Dugdale 2 Rivers	below normal
04/19/11		4/19/11	Dugdale 2 Rivers	wet
08/16/11	FLaSH			wet
09/20/11	FLaSH			wet
10/18/11	FLaSH		Some DFG sites:FLaSH	wet
11/15/11	FLaSH	11/9-21/11	DFG sites: FLaSH	wet
12/13/11	FLaSH	12/7-12/11	DFG sites: FLaSH	wet
		1/18-20/12	DFG sites	
		2/14-16/12	DFG sites	
3/20/12		3/6/12, 3/8/12	DFG sites	
4/11/12		4/3/12, 4/5/12	DFG sites	
5/23/12				
7/17/12				
8/7/12		8/21-23/12	DFG sites	

Notes:

[+] Samples 8/06 to 5/08 were collected and analyzed for isotopes as part of Kendall's CALFED PIN700 project. This project also included weekly to biweekly samples for ~20 sites from the upper SJR 1/05 to 12/07 that are not shown on this table.

* Several of the Polaris sites were sampled on all the Dugdale SWC and Foe transects; isotope analyses of these samples will be completed this fall.

[Δ] Very few of the SJR sites sampled as part of these programs in 2009-2011 have been analyzed thus far for isotopes

Table 4. The value of isotopic measurements for the interpretation of water quality data and for setting rate parameters and identifying and testing dominant processes in the QUAL nutrient model.

Tracer type	Interpretive Value for Processes	Value for QUAL Nutrient Model
Particulate organic matter (POM) $\delta^{15}N$, $\delta^{13}C$, $\delta^{34}S$, C:N	Information about the source of C, N, and S and the biogeochemical reactions that cycle them; Quantify algal *vs* terrestrial contributions to biomass; Evaluate role of algal-based foodwebs, contributions of marine sources of POM & nutrients.	Evaluate and constrain the modeled contribution of DICU nutrients *vs.* riverine or marine sources (*i.e.,* from the Martinez boundary) , or mixing of waters from different boundary inflows
Nitrate $\delta^{18}O$ and $\delta^{15}N$	Quantify nitrate from different sources (fertilizer, wastewater, wetlands, etc); Role of algae and degree of recycling; Evidence for denitrification or assimilation.	Constrain sources of nitrate – distinguish between nitrate from boundary inflow (*e.g.,* wastewater or other sources) or as a product of reaction kinetics
Ammonium $\delta^{15}N$	Quantify NH_4 from different sources (fertilizer, wastewater, wetlands, etc); Role of algae and degree of recycling; Evidence for nitrification or assimilation.	Constrain sources of NH_4 – distinguish between NH_4 from boundary inflow, or sources of nitrate as a product of reaction kinetics
Water $\delta^{18}O$ and $\delta^{2}H$	Ideal conservative tracers of water sources and mixing; useful for quantifying flow contributions from different tributaries and groundwater.	Evaluate the modeled contribution of DICU inflow and mixing of waters from different boundary inflows
Dissolved organic carbon (DOC) δ13C	Information on sources of DOC; evidence for degradation of organic matter; quantify algal vs terrestrial contributions to DOC.	Evaluate the modeled contribution of DICU nutrients *vs.* riverine or marine sources. Evaluate the respective roles of algae and bacteria in the transformation of nutrients.