

Delta Regional Monitoring Program Nutrients Synthesis

Modeling to Assist Identification of Temporal and Spatial Data Gaps for Nutrient Monitoring

March 2018

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Table of Contents

1	Executive Summary	5
2	Project Background	9
2.1	Objective	9
2.2	Approach.....	10
3	Results and Discussion	12
3.1	Volumetric “Fingerprints”	12
3.2	Particle Tracking Simulations.....	46
3.3	Synthesis and Recommendations for Monitoring.....	64
4	References.....	68
	Key to Data Files	69

Appendices

Appendix 1. Modeling Analyses

Appendix 2. Fate and Age Exposure Time Maps – September 2008

Appendix 3. Fate and Age Exposure Time Maps – September 2010

Appendix 4. Fate and Age Exposure Time Maps – June 2011

For a description of the contents of online Supplemental Materials, see Key to Data Files on page 69.

Tables

Table 1.	Summary table of the representative time periods that were selected for the analysis.	10
Table 2.	Average source water composition of Delta subregions in average flow conditions.	17
Table 3.	Median estimated residence time of water in each subregion in different flow scenarios	49
Table 4.	Residence time summary statistics.....	49
Table 5.	Source water characteristics summary: results for average flow simulation.	62

Figures

Figure 1. DSM2 volumetric fingerprints, comparison of regional averages.....	14
Figure 2. Subregions used in the modeling analyses.	16
Figure 3. DSM2 volumetric fingerprints at representative stations in the Sacramento River subregion.	18
Figure 4. Map of the Sacramento subregion showing the locations represented in Figure 3.	19
Figure 5. DSM2 volumetric fingerprints for locations in the North Delta subregion.	21
Figure 6. Map of the North Delta subregion showing the locations represented in Figure 5.	22
Figure 7. DSM2 volumetric fingerprints for locations in the Confluence subregion.	24
Figure 8. Map of the Confluence subregion showing the locations represented in Figure 7.....	25
Figure 9. DSM2 volumetric fingerprints for locations in the Suisun Bay subregion.	27
Figure 10. Map of the Suisun Bay subregion showing the locations represented in Figure 9.	28
Figure 11. DSM2 volumetric fingerprints at representative stations in the Eastside subregion.....	31
Figure 12. Map of the Eastside subregion showing the locations represented in Figure 11.	32
Figure 13. DSM2 volumetric fingerprints, comparison of Sycamore Slough with the regional average in the Eastside subregion.	33
Figure 14. DSM2 volumetric fingerprints for locations in the North Central Delta subregion.	35
Figure 15. Map of the North Central Delta subregion showing the locations represented in Figure 14.	36
Figure 16. Potential realignment of subregional delineations based on water source influence.....	38
Figure 17. DSM2 volumetric fingerprints for locations in the South Central Delta subregion.	41
Figure 18. Map of the South Central Delta subregion showing the locations represented in Figure 17.	42
Figure 19. DSM2 volumetric fingerprints at representative stations in the South Delta subregion.	44
Figure 20. Map of the South Central Delta subregion showing the locations represented in Figure 19.	45
Figure 21. Median estimated residence time of water in each subregion in different flow scenarios (see also Table 3).....	51
Figure 22. Sacramento River water fate simulation, low flow period.	52
Figure 23. North Delta water fate simulation, low flow and high-flow simulations.	53
Figure 24. Confluence water fate simulation, low flow simulation.	54
Figure 25. Suisun Bay water fate simulation.....	55
Figure 26. Eastside water fate simulation, low flow period.....	56
Figure 27. North (Upper) Central Delta water fate simulation, low flow period.....	58

Figure 28. South (Lower) Central Delta water fate simulation. Average inflow scenario (September 2010) and combined water exports of 10,403 cfs.59

Figure 29. South Delta water fate simulation, low flow and average flow period.60

Figure 30. Water age simulation for Sacramento River source water, average flow scenario.63

Figure 31. Recommended water quality monitoring stations to be added for nutrients.....66

Figure 32. Areas in the North Delta, Northeast Delta, and South Delta, where high-frequency water quality monitoring is recommended to investigate transformation hotspots.67

Executive Summary

Nutrient loads are an important water quality management issue in the Sacramento-San Joaquin Delta (Delta) and there is consensus that the current monitoring activities do not collect all the information needed to answer important management questions.

The purpose of this report is to use hydrodynamic model outputs to refine recommendations for monitoring nutrients and related conditions in the Delta. The basic premise was that variability in water source and hydraulic residence time can serve to estimate variability in water quality. Therefore, using existing hydrodynamic models that are highly resolved in space and time could be a cost-effective way to get information about likely spatial and temporal variability in nutrients and nutrient-associated parameters. We assume that the Delta can be divided into relatively homogeneous subregions (e.g., such as those proposed in a previous report by Jabusch et al. 2016) and that a representative monitoring location can be chosen in each subregion to track status and trends. We also assume that, within any subregion, areas with long hydraulic residence time and source water mixing may represent potential nutrient transformation hotspots.

Two types of modeling approaches were applied: 1) volumetric water source analysis to evaluate the mix of source waters within each subregion; and 2) particle tracking simulations. Results from the source water analysis were evaluated to assess heterogeneity of water sources within each of the subregions. Results from the particle tracking analysis were evaluated to identify high-residence-time areas. Finally, we compared analysis results to current monitoring locations to inform potential monitoring gaps or redundancies within each of the subregions.

Volumetric Source Water Analysis

“Volumetric fingerprints” for the 8 subregions and 49 individual locations were estimated using output from the DSM2 (Delta Simulation Model 2), a hydrodynamic model of the Delta and Suisun Bay. The volumetric water source analysis addressed two key questions for each subregion:

1. How variable is source water composition within each of the subregions?
2. Where are monitoring stations missing or redundant for monitoring the status and trends of nutrients in each of the Delta subregions?

The analysis revealed that each subregion has a unique “fingerprint” in terms of how much of its water comes from different sources (see Figure 1). Further, certain parts of the Delta show much more variability in source water composition, where the relative composition of source water shows substantial spatial, seasonal, and interannual variation

Relatively homogeneous subregions where source water composition is similar between locations include the Sacramento River, North Delta, Confluence, Suisun Bay, Eastside (Mokelumne and Cosumnes Rivers), and the South Central Delta. Heterogeneous subregions

with more variability in source water composition between stations include the South Delta and the North Central Delta.

Particle Tracking Simulations

Particle tracking is a modeling tool that can be used to simulate the sources and dispersal of water parcels at specified locations in aquatic environments. Model outputs were used to estimate residence time, age, and exposure (how much time spent) of water in each subregion. The results also highlighted smaller areas within each subregion where the residence time was high and thus might be locations of enhanced biogeochemical processes. Statistics on the age and exposure of particles in a subregion were qualitatively compared with “Volumetric Water Source” composition to better define source waters in each of the subregions.

The particle tracking simulations were used to address four key questions.

1. What is the residence time of water within the subregions under different flow regimes?
2. What are potential high-residence-time areas within each subregion?
3. How long does water from different sources typically spend in each of the subregions?
4. How “old” is the water?

The particle tracking simulation results indicate that residence time varies considerably among subregions. The regions with the longest median residence times are the peripheral subregions of North Delta (>28 days in low and average flow conditions) and Eastside (>28 d in low flow conditions). The regions with the shortest median residence times are the subregions along the flowpath of the Sacramento River towards San Francisco Bay: the Sacramento River, Confluence, and Suisun Bay subregions (0-5 days in all flow scenarios).

Subregions with a high degree of variability in residence time include the Eastside, the North Delta, and the North Central Delta. This indicates that there are more high-residence-time pockets in these areas.

Results from the age and exposure time analysis suggest that water from most sources typically spends less than 5 days in most subregions. The age and exposure time analysis also reveals that “old” Sacramento River occurs in downstream subregions. The oldest Sacramento River water occurs in the Central Delta (aged 25–28 days), where it mingles with younger water from other sources.

Recommendations for Nutrient Monitoring Design

Three major recommendations for a future monitoring design were derived from this analysis.

Recommendation #1: The subregions proposed for status and trends monitoring in a previous report should be redrawn to better reflect the mixtures of source waters.

The volumetric results indicate that splitting the North Central subregion apart and merging the parts with other subregions would improve the alignment of subregional boundaries with different water source influences. The split portions could be merged with the South Central Delta, South Delta, and Eastside subregions and result in expanded Central Delta, San Joaquin River, and Northeast Delta subregions.

Recommendation #2: Long-term water quality stations are needed in the North Delta, Eastside, and South Delta subregions.

Results from the analyses suggest that some subregions are adequately covered by the existing monitoring to capture spatial variability and that others have data gaps. The analysis also identified several redundancies, for example, in the South Central Delta and Suisun Bay. Subregions with adequate coverage include the Sacramento River, the Confluence, the South Central Delta, and Suisun Bay. The North Delta and the Eastside include important habitat areas, but long-term monitoring stations have not been established in these subregions. At least one long-term monitoring station is recommended in the North Delta to compare trends of nutrients with other subregions, and ideally two stations to capture the range of hydrologic conditions in this subregion. Two stations are recommended in the Eastside subregion, because there are distinctly different relative contributions of source waters upstream and downstream of the Delta Cross Channel. One additional station is recommended in the South Delta subregion to capture spatial variability. Some of these recommended long-term stations already have nitrate or chlorophyll sensors installed and/or have been sampled in recent years as part of special studies. Long-term stations in these places could be established by ensuring continued funding for existing sensor stations and either continuing or adding co-located discrete water quality sampling.

Recommendation #3: Areas with a long-residence time and where mixing of different water sources occurs are potential for nutrient transformation hotspots¹. High-frequency water quality mapping of these areas has the potential to increase our understanding of sources and sinks of nutrients in the Delta.

Subregions with a high degree of variability in residence time and where mixing of different water sources occurs are the most likely to contain potential transformation zones. Such areas include the Eastside, the North Delta, and the North Central Delta. There are also some

¹ Nutrient transformation or biogeochemical hotspots can be defined as areas or patches of disproportionately high reaction rates relative to the surrounding locations (McClain et al. 2003).

potential long retention time areas where mixing of different water sources occurs in the South Delta. These areas could be targeted with high-frequency water quality mapping to evaluate potential transformation zones.

Project Background

The Sacramento-San Joaquin Delta (Delta) is a hydrologically complex ecosystem, composed of a diverse array of aquatic environments, and influenced by gradients in flow, salinity, and other physical-chemical properties. Loads of anthropogenic nitrogen (N) and phosphorous (P) enter the Delta from a number of sources, including treated wastewater effluent, agricultural runoff, and stormwater runoff. Subregions of and individual habitats within the Delta respond differently to these N and P inputs, and also influence nutrient concentrations differently, as evidenced by the large degree of spatial variability in ambient water quality (e.g., Novick et al. 2015).

The Delta Regional Monitoring Program (Delta RMP) is in the process of developing a nutrient monitoring design that will answer the management questions of the program participants. Assessing the utility of a design with empirical data would require intensive field sampling - and actually oversampling - to thoroughly characterize variability and identify the network needed to capture necessary information in the complex Delta ecosystem. Hydrodynamic models can be used to simulate the system's dynamics, and the model outputs can be analyzed to identify the sampling design needed to answer management questions.

Objective

The objective of this project was to generate and evaluate model outputs that inform the Delta RMP Assessment Question:

- Are there important nutrient data gaps associated with particular water bodies within the Delta subregions?

This assessment question falls under the Delta RMP Management Question:

- Is there a problem or are there signs of a problem?

Two types of modeling approaches were applied: (1) volumetric water source analysis to evaluate the mix of source waters within each subregion; and (2) particle tracking simulations to further define the distribution of source waters within each subregion and characterize the hydrology in the different subregions. Results from the source water analysis were evaluated to assess heterogeneity of water sources within each of the subregions. Results from the particle tracking analysis were evaluated to identify potential high-residence-time areas. The results from the analyses were then compared against the current locations of monitoring stations, to inform potential monitoring gaps or redundancies within each of the subregions. The underlying assumption for the comparisons is that a Delta nutrient monitoring network of representative sites should be capable of adequately characterizing status and trends within

each of the proposed subregions and that targeted monitoring should adequately characterize potential “hotspots” of biogeochemical transformation.

Approach

The Delta RMP contracted with the consulting firm RMA to use modeling tools to better understand nutrient transport in the Delta. RMA used models investigate the temporal and spatial variations in transport and “residence time” (defined below). We also analyzed the source of water in Delta subregions. Finally, we explored whether the existing nutrient monitoring network is sufficient to capture the spatial variations in Delta water, and make recommendations where additional monitoring may be useful or current monitoring is redundant.

Two hydrodynamic/hydrologic models were used: (1) DSM2 (Delta Simulation Model 2), and (2) the RMA Bay-Delta model in particle tracking mode. The modeling approaches are briefly summarized below. **Appendix 1** provides additional detail.

Time Frames Selected for Analysis

Most of the modeling analyses were done using three time frames that are representative of Delta flow conditions. Table 1 shows the three time frames selected, as well as the monthly average values of the inflows and exports considered. The three time frames are roughly described as Average flow conditions, Low flow conditions, and High flow conditions, and were chosen as a single month and year for each condition.

Table 1. Summary table of the representative time periods that were selected for the analysis.

Time period	Flow Condition	Estimated average inflows and outflows in cubic feet per second (cfs)						
		San Joaquin River inflow	Sacramento River Inflow	Combined CVP and SWP outflow ¹	Calaveras River inflow	Cosumnes River Inflow	Mokelumne River inflow	Yolo Bypass/Lisbon Toe Drain
September 2008	Low	801	10,461	4,930	32	3	33	110
September 2010	Average	1,713	16,451	10,403	21	13	163	158
June 2011	High	10,529	41,397	9,676	103	947	1,786	655

¹The two large transfers out of the Delta are the federal Central Valley Project (CVP and the State Water Project (SWP).

Average inflows were calculated from daily average flow data estimated with the Dayflow computer program (<http://www.water.ca.gov/dayflow/>).

The recommended time frames were selected using a statistical analysis of monthly average flows into and out of the Delta for the period May to October during the period from 2000 to

2013. Outside of this time period, little information can be gained, as flows are high and residence times are short, and source water is contributed from two dominant sources.

Subregions Used for the Analysis

Figure 1 shows the subregions that were chosen for the modeling analyses: Sacramento River, North Delta (Yolo region and Liberty Island), Eastside (Mokelumne and Cosumnes River inflows), Central Delta, South Delta (San Joaquin River inflow), Confluence, and Suisun Bay. These subregions were proposed in a report titled Summary and Evaluation of Delta Subregions for Nutrient Monitoring and Assessment (Jabusch et al. 2016) that was funded by the Delta Science Program. The proposed subregions are derived from operational landscape units (OLUs), which are a newly developed planning tool for landscape-scale ecosystem restoration in the Delta (Grenier and Grossinger 2013). The OLU delineations are based on ecosystem functions and physical drivers such as water source and hydrology; therefore, there is a mechanistic linkage and scientific foundation for their use in the context of nutrient conditions and cycling. The proposed subregions are compatible with the DSM2 hydrologic model and are in general agreement with water quality regions used by major monitoring programs.

Volumetric Source Water Analysis with DSM2

The DSM2 model was used to calculate volumetric source water information for 49 individual locations to represent the variation within each subregion. The output provided monthly values for 12 years at each location. In addition, this output was used to calculate regional averages for each of the Delta subregions for each time period. Results from individual locations within subregions were compared to evaluate similarities and differences in the mix of source waters. Since the modeled locations include monitoring stations, the result of this evaluation informed recommendations about where stations are missing or redundant.

Particle Tracking Analysis

Residence Time

Spatial variability in residence time within a subregion indicates whether it is homogeneous or not. Residence time is defined as the time required for a water parcel at a certain location to migrate out of a subregion. An estimate of residence time was made using the RMA Bay-Delta Model (RMA 2005) by how long it took individual particles (initially uniformly distributed in a subregion) to exit the subregion. The model was run for 28 days for the low, average, and high flow conditions for each of the seven subregions. Statistics from the model output were used to estimate the residence time for particles in the subregions under different flow regimes.

Age and Exposure Time Analysis

The purpose of this analysis is to understand how long water from different sources typically spends in each of the subregions. Age is the complement of residence time. Age represents the amount of time an individual parcel of water has spent inside of the model domain since it

entered the model. So, age applies to parcels of water that enter through an inflow boundary in the Delta model domain (for example, at the San Joaquin River at Vernalis).

Exposure time is the amount of time a parcel spends within a specified region during a predetermined time period such as the length of a computer simulation, allowing for multiple entries and exits to the region. In comparison, the residence time calculation only considers the time to the first exit. Age/exposure time maps were generated with the RMA model by simulating the near continuous release of particles from a source water for 28 days under low, average, and high flow conditions.

The model tracked the movement of these particles through the Delta for 28 days. Statistics on the age of particles in a subregion on day 28 were calculated and qualitatively compared with “Volumetric Water Source” statistics to better define source waters in each of the subregions. For each example, if a region is 80% Sacramento River water, how “old” or “young” is that water?

Results and Discussion

This section describes and discusses the modeling results. Subsection 2.1 presents the results of the volumetric source water analysis, and subsection 2.2 presents the results of the particle tracking simulations. Subsection 2.3 synthesizes the results from both modeling approaches into monitoring recommendations.

Volumetric “Fingerprints”

This subsection outlines the results of the volumetric water source analysis. It addresses two key questions for each subregion:

1. How variable is source water within each of the subregions?
2. Where are monitoring stations missing or redundant?

Results are presented as volumetric “fingerprint” figures for each subregion and for representative locations within each of the subregions.

Comparison across subregions

Substantial spatial, seasonal, and interannual variability in water sources is evident in a comparison of the averaged volumetric fingerprints of all subregions (Figure 1). Each subregion (Figure 2) has a unique volumetric fingerprint (Figure 1, Table 2). The Sacramento River is the dominant water source in all subregions except the South Delta and Suisun Bay, which are dominated by San Joaquin River water and tidal exchange, respectively. In the Sacramento River subregion, water sources other than the Sacramento River are trivial in terms of their volumetric contributions. In the North Delta, water from the Yolo Bypass and from irrigation return flows can also be significant.

In the Confluence, additional water sources that can be temporally significant include San Francisco Bay (the tidal source) and the Mokelumne and Cosumnes River (Eastside tributaries). The tidal source is important in Suisun Bay. In the Eastside subregion, water source composition is largely controlled by the operation of the Delta Cross Channel (DCC) gates and either the Sacramento River or the Eastside tributaries are the dominant water source.

The North Central Delta has the most heterogeneous source water composition. Sacramento River water is the most significant water source overall, but the San Joaquin River, the Eastside tributaries, and irrigation return flows are also important sources. (As discussed in a later section, volumetric results for different locations inside the North Central Delta suggest that splitting this subregion further apart could improve the alignment of subregional boundaries with different water source influences.)

The South Central Delta has a similar source water profile as the North Delta, but it has on average more Sacramento River source water and more interannual variability in source water composition. The South Delta is dominated by San Joaquin River source water.

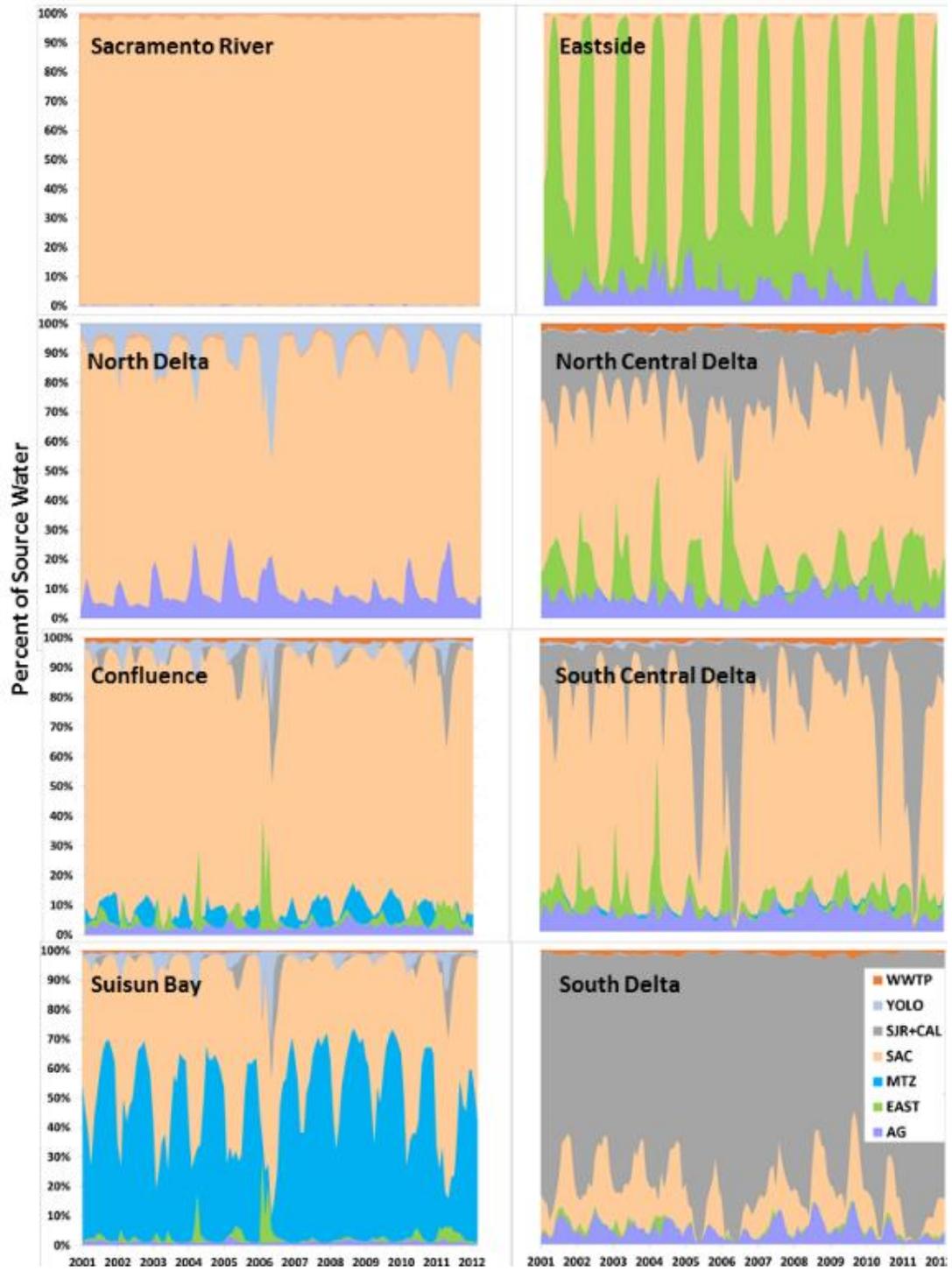


Figure 1. DSM2 volumetric fingerprints, comparison of regional averages.

Key to water sources: AG = irrigation return flows, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SJR+CAL =San Joaquin and Calaveras rivers, YOLO = Yolo Bypass, WWTP = combined wastewater effluent sources.

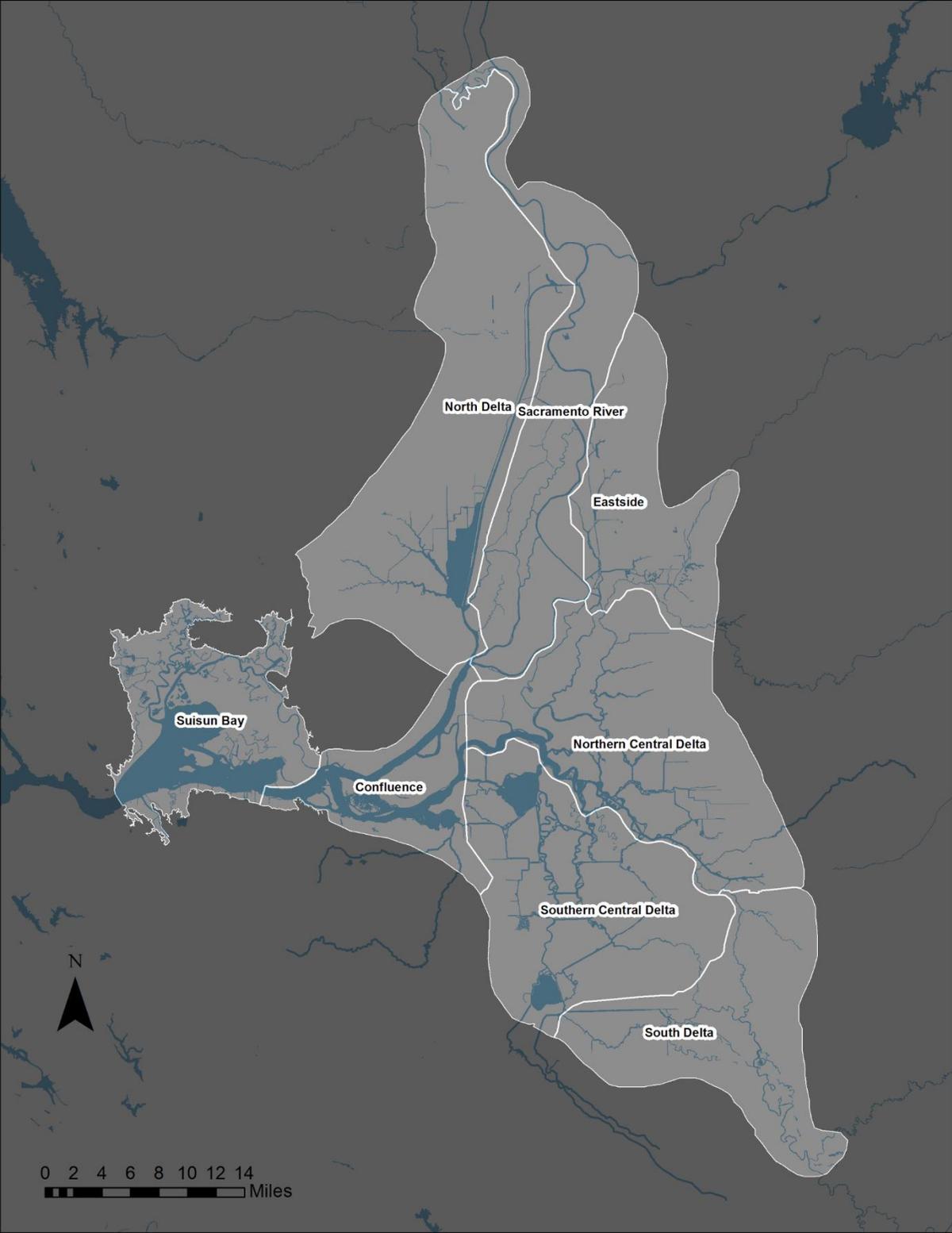


Figure 2. Subregions used in the modeling analyses.

Table 2. Average source water composition of Delta subregions in average flow conditions.

Subregion	Source Water (% of Total)						
	AG	EAST	MTZ	SAC	SJR+CAL	YOLO	WWTP
Sacramento River	<1	<1	<1	99	<1	<1	1
North Delta	6	<1	<1	91	<1	1	1
Confluence	3	<1	9	86	<1	1	1
Suisun Bay	1	<1	66	32	<1	<1	1
Eastside	2	26	<1	71	<1	<1	1
North Central Delta	6	2	1	70	19	<1	2
South Central Delta	5	1	2	86	5	<1	2
South Delta	5	<1	<1	23	76	<1	1

The results are calculated based on the average flow simulation for September 2010. Key to water sources: AG = irrigation return flows (calculated with Delta Island Consumptive Use Model [DICU]), EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SJR+CAL = San Joaquin and Calaveras rivers, YOLO = Yolo Bypass, WWTP = combined wastewater effluent sources.

Sacramento River

The Sacramento subregion is homogeneous with respect to source water (Figure 3). Water in the Sacramento River subregion is almost completely comprised of Sacramento River water (98-99%). The three volumetric fingerprints in Figure 3 represent the range of water source variability observed in this region. The locations represented in Figure 3 are shown in Figure 4. Freeport represents the boundary condition where upstream Sacramento River water is the exclusive water source. At Hood, downstream of the Sacramento Regional WWTP, in low flow conditions up to 2% of the total water volume can be comprised of wastewater effluent. The relative contribution of AG sources increases moving downstream and can amount to up to 1% of total volume in low flow conditions at Ida Island just above Cache Slough.

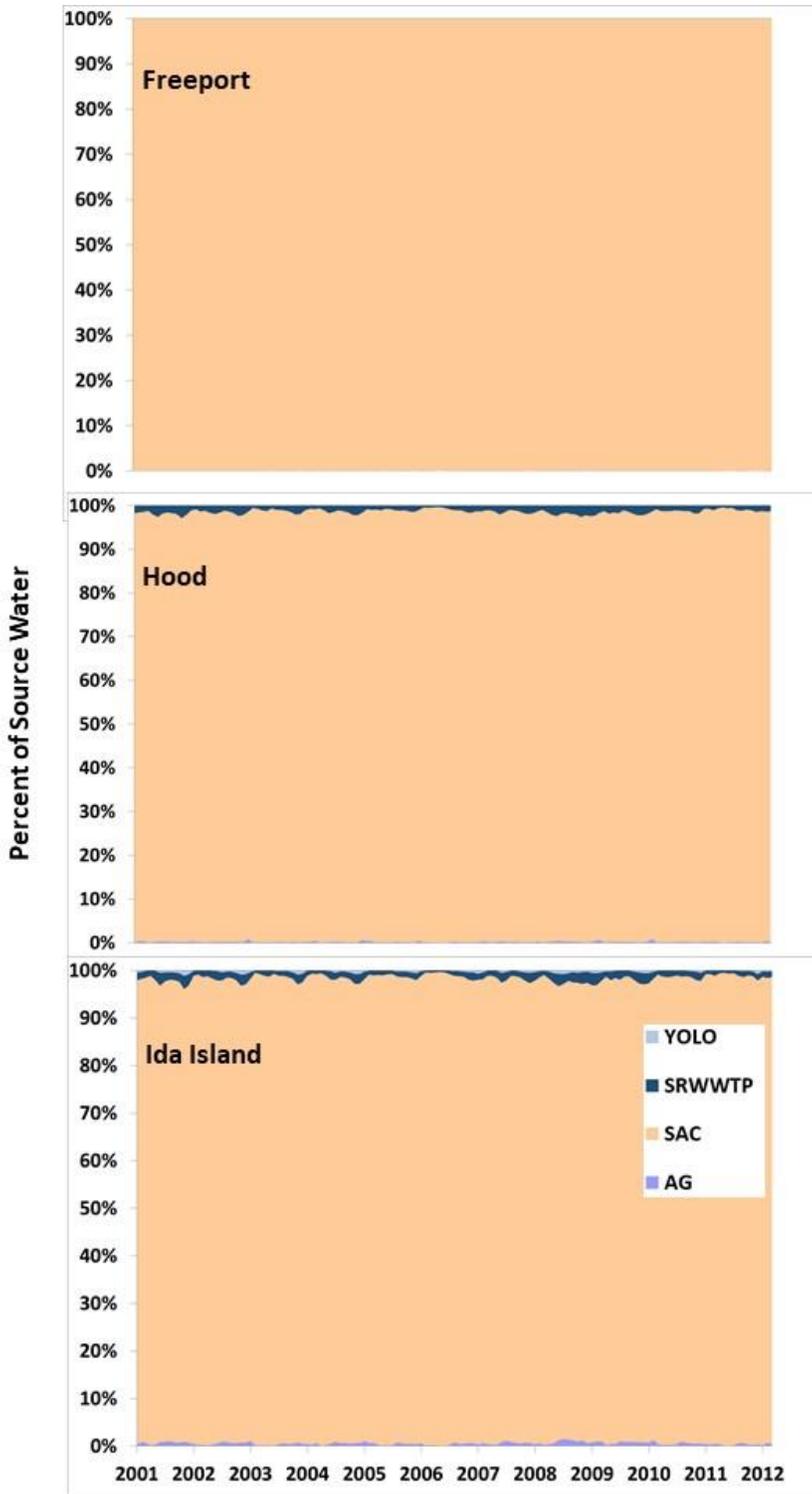


Figure 3. DSM2 volumetric fingerprints at representative stations in the Sacramento River subregion.

Key to water sources: AG = irrigation return flows, SAC = Sacramento River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, YOLO = Yolo Bypass. All other water sources were negligible.

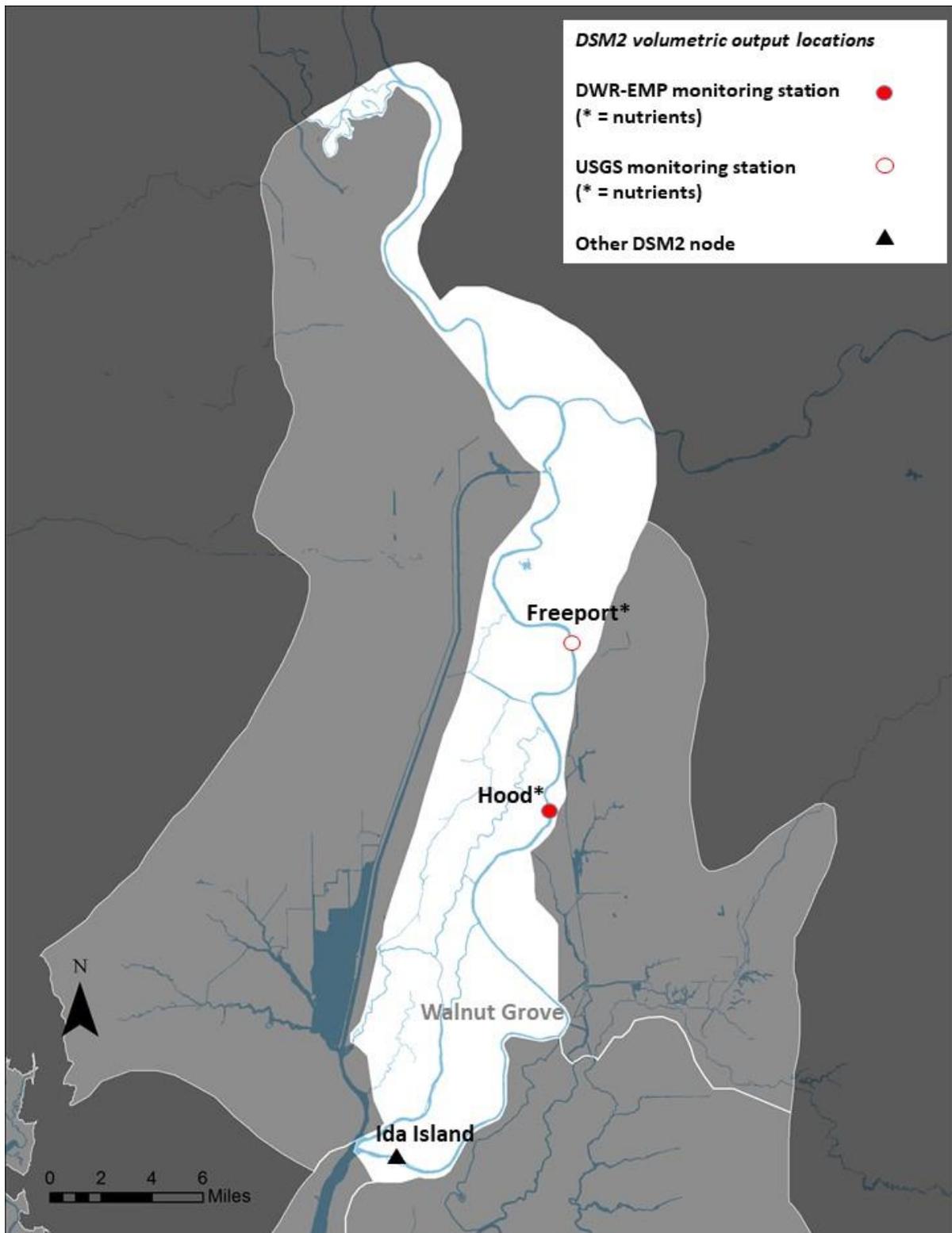


Figure 4. Map of the Sacramento River subregion showing the locations represented in Figure 3.

Implications for Monitoring

Based on the source water analysis, the current stations Freeport (USGS) and Hood (DWR) adequately represent the boundary condition and the impact of the Sacramento Regional Wastewater Treatment Plant (SRWWTP) source on the river (Figure 3).

North Delta

The volumetric data suggest that water source composition is similar across all analyzed locations in the North Delta, but the relative contributions of these main water sources varies between locations (Figure 5). Sacramento water is the dominant water source in the North Delta and contributes in average between 89-95% of the total water volume in the three reference time frames selected for the analyses. The balance of the water in the subregion is: agricultural return flow between 7-8% on average, the Yolo Bypass/Toe Drain source from 1% to more than 7%, and the SRWWTP from less than 1% up to 2% (Figure 5). Note that the contribution of the Yolo Bypass source can be much higher in wet season conditions, and may contribute more than 40% in wet years. The relative contribution of agricultural return flows can be as large as 70% in wet seasons in Cache Slough near Hastings Tract, and as small as 0.7% in the same conditions in the Cache Slough at Ryer Island. Note that model estimates do not include the contribution from smaller and lower-order upstream tributaries to Barker Slough and Cache Slough. The SRWWTP source is relatively consistent across stations. The locations represented in Figure 5 are shown in Figure 6.

Implications for Monitoring

There is currently no long-term monitoring station in the North Delta, even though it contains large biologically significant areas (e.g., the Cache Slough complex and the Deep Water Ship Channel). At least one and ideally two permanent monitoring station in this subregion are recommended for comparing nutrient trends in the North Delta to those in other subregions with different source water composition. Sacramento water is the dominant water source in the North Delta, but source water composition is considerably different and more variable here than in the mainstem Sacramento River. Depending on hydrologic conditions, the Yolo Bypass/Toe Drain can be an important source in this subregion, and this source water contribution is not captured by monitoring in other subregions. As discussed in the particle tracking simulation results later in this report, residence times can vary considerably in this region both spatially and temporally, and two monitoring stations would capture some of the variability.

Based on the volumetric analysis, continued monitoring at the existing USGS high-frequency sensor stations in the Deep Water Ship Channel and at Liberty Island would capture the range of conditions (Figure 5). DWR Municipal Water Quality Investigations has conducted bi-monthly sampling near these locations since 2013, as part of a DSM2 Nutrient Special Study (Delta RMP 2016). The recommended approach would be to ensure continued funding for the

existing USGS sensor stations, co-located with continued discrete water quality sampling to capture a wider range of parameters.

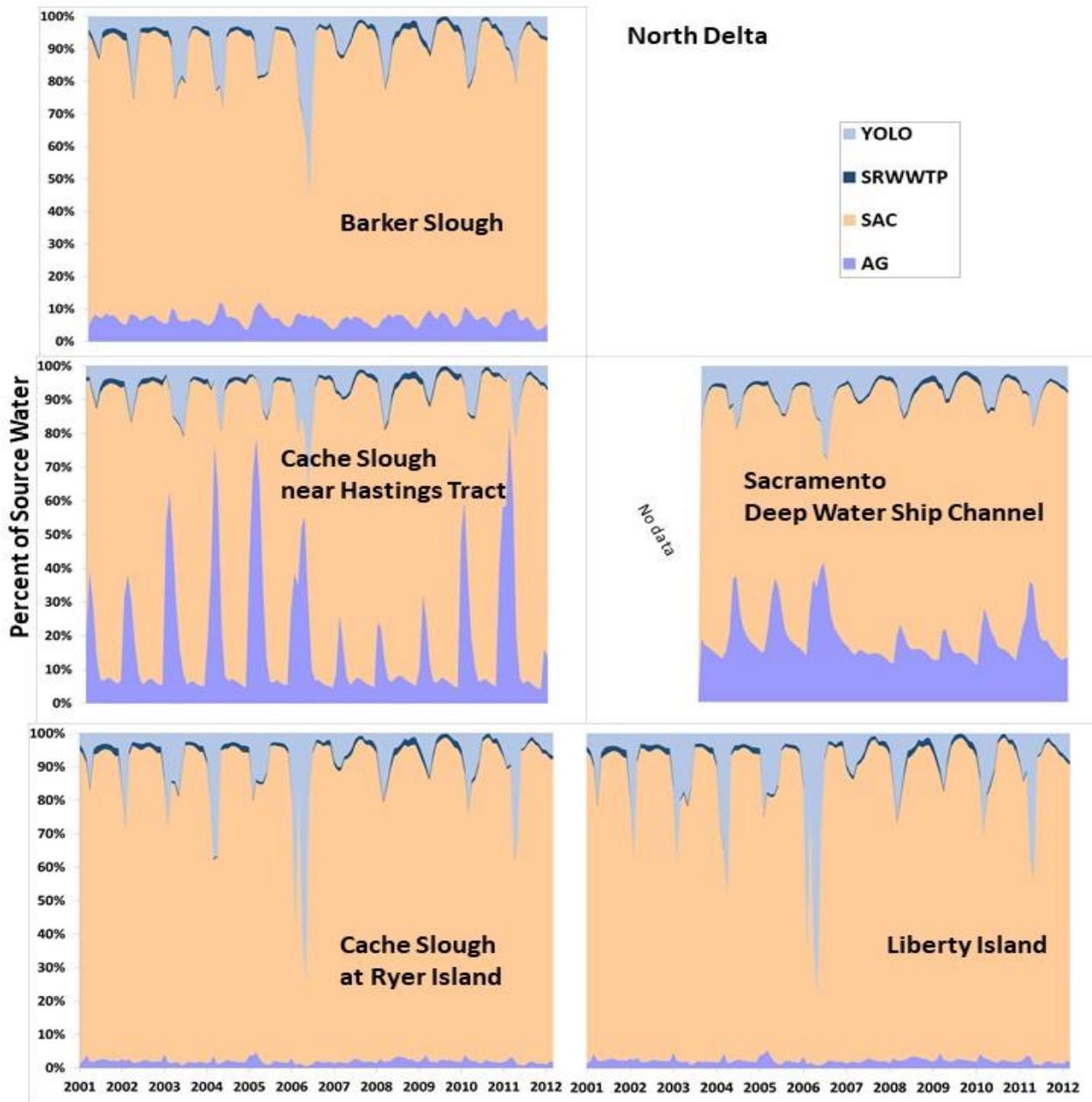


Figure 5. DSM2 volumetric fingerprints for locations in the North Delta subregion.

Key to water sources: AG = irrigation return flows, SAC = Sacramento River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, YOLO = Yolo Bypass.

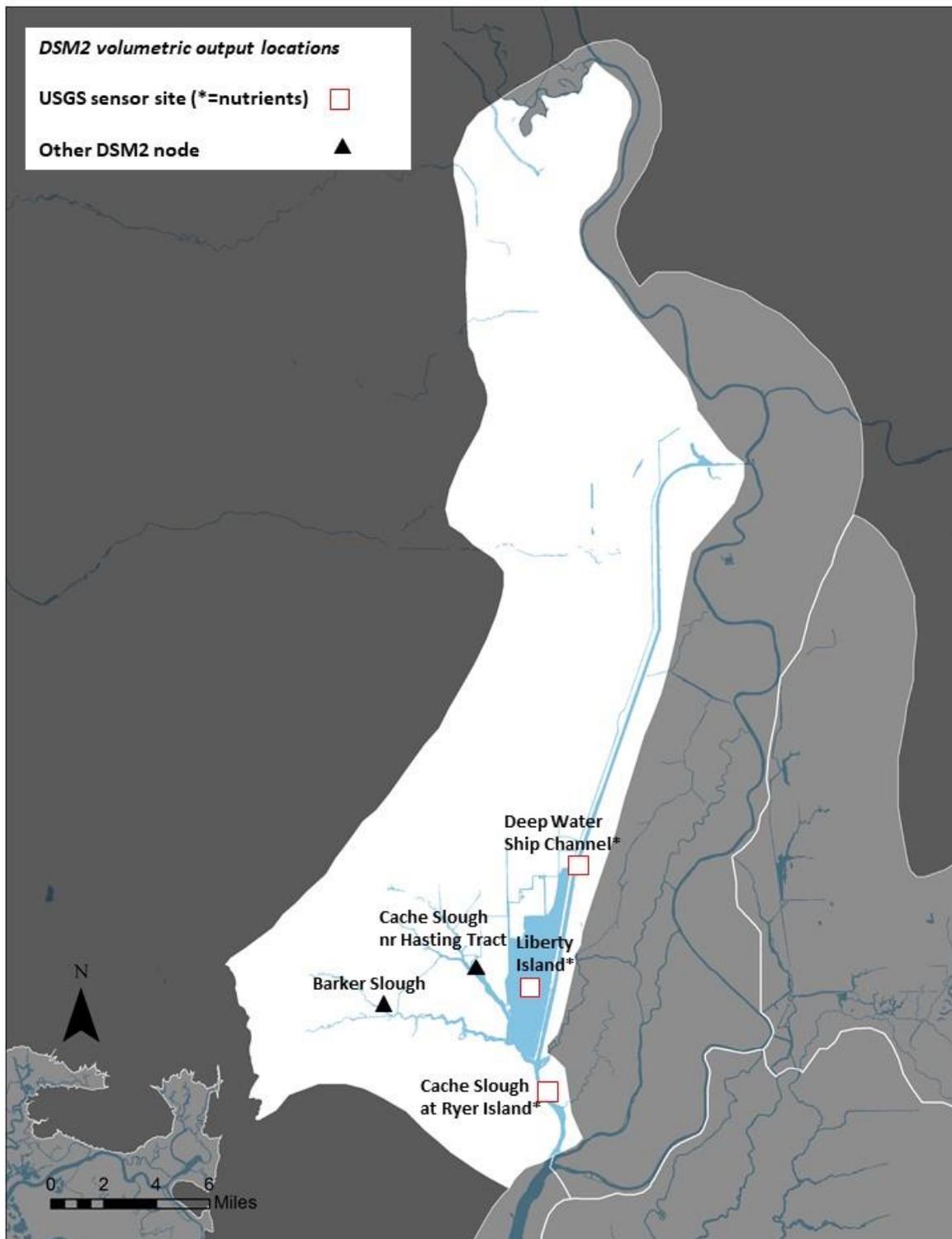


Figure 6. Map of the North Delta subregion showing the locations represented in Figure 5.

Confluence

The Confluence subregion has a more diverse mix of water sources than regions farther upstream; however, source water composition is similar across most locations in this region. Sacramento water is the dominant water source, the regional average ranges from 78% to 86%. Other temporally significant sources in the Confluence subregion include the San Joaquin River (regional average up to 11% in high flow scenario) and San Francisco Bay (up to 10% in low flow scenario). Agricultural return flows contribute between 1 and 5% on average, and the Yolo Bypass/Toe Drain source and SRWWTP each up to 2%. Figure 7 illustrates the range of volumetric fingerprints encountered in the Confluence subregion. The represented locations are shown in Figure 8.

Sacramento River at Rio Vista represents the boundary condition where the Sacramento River enters the Confluence subregion and looks different from the other stations. Here, the average contribution of the Sacramento River is larger than at the other stations (between 93 and 96%), and additional sources other than agricultural returns (up to 3%) and the Yolo Bypass (up to 3% in the analyzed periods and exceeding 40% in wet years winter flows) are negligible.

All stations further downstream have significant contributions from additional sources, including highly seasonal signals from the tidal source (MTZ) and the San Joaquin and Calaveras Rivers. WWTPs contribute up to 2%, mostly originating from the SRWWTP. The Stockton WWTP never contributes more than 0.2%.

Implications for Monitoring

This region is relatively homogeneous with respect to source waters and well monitored. No additional water quality monitoring stations are needed based on this analysis.

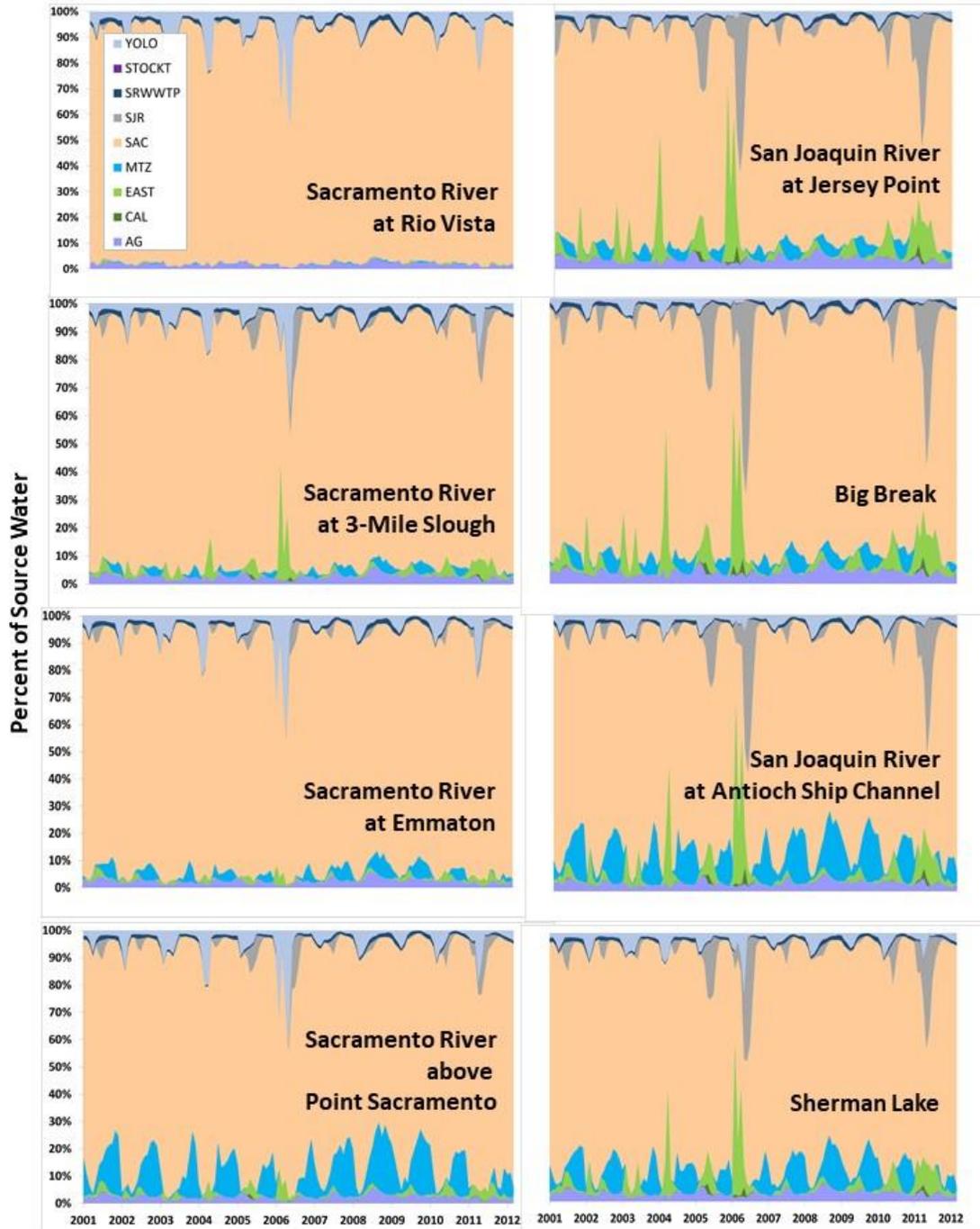


Figure 7. DSM2 volumetric fingerprints for locations in the Confluence subregion.

Key to water sources: AG = irrigation return flows, CAL = Calaveras River, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SJR = San Joaquin River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, STOCKT = Stockton WWTP, YOLO = Yolo Bypass.

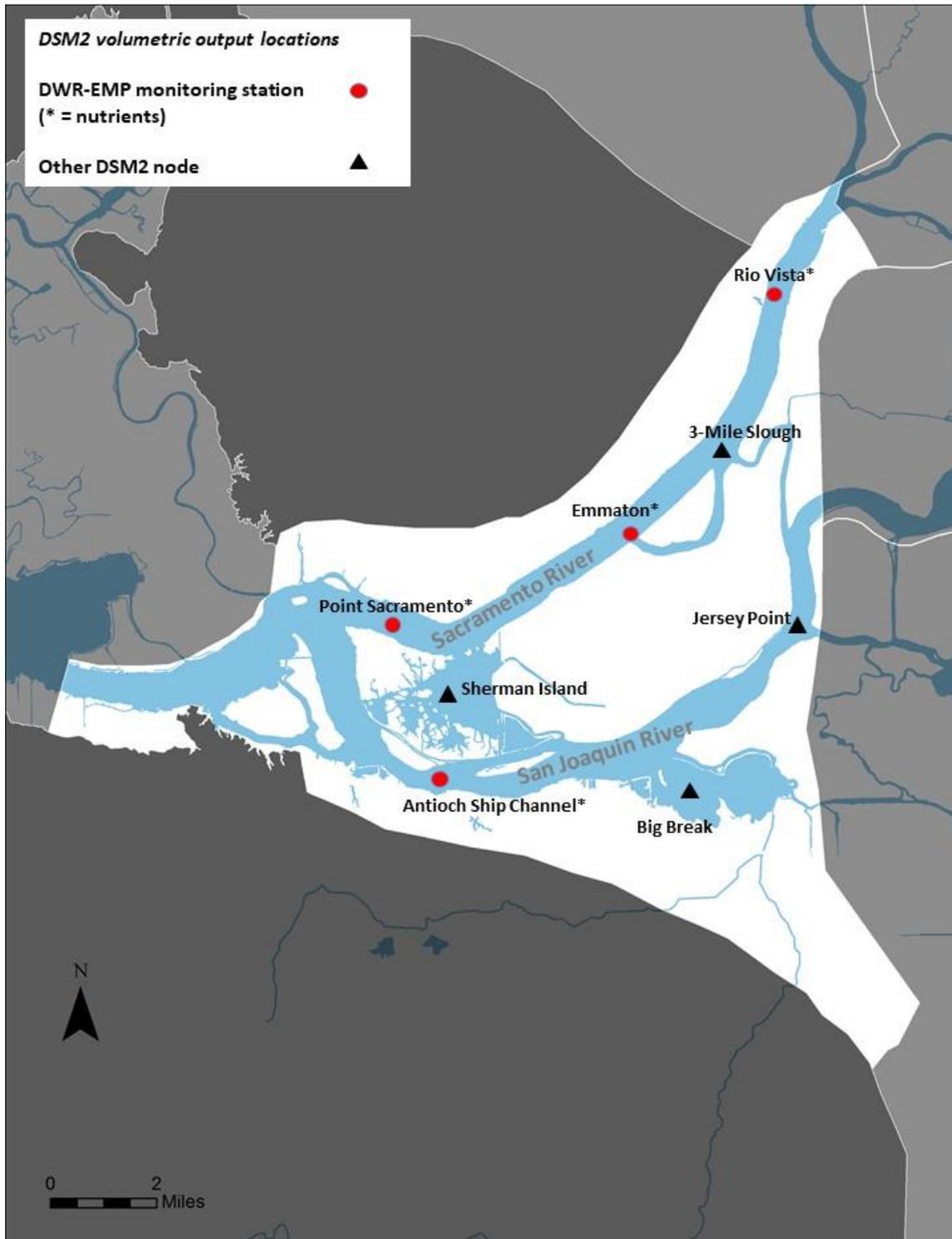


Figure 8. Map of the Confluence subregion showing the locations represented in Figure 7.

Suisun Bay

The relative water source composition of Suisun Bay is similar across most locations (Figure 9). However, it varies considerably at each individual location by season and flow condition. Figure 10 shows the locations of the volumetric profiles presented in Figure 9. Across the region, either the Sacramento River or the tidal source (input from San Francisco Bay) is the dominant source at any given place and time (Figure 9). As Figure 9 illustrates, the Sacramento River signal diminishes towards the ocean along the deep water channel (as shown in the left side panels top to bottom) and along Montezuma Slough (right side panels top to bottom). Other tributary sources can be significant in high flows. Averages for contributions in the high flow period analysis are 8% for the San Joaquin River (the contribution from the Calaveras River is negligible), 4% for Eastside tributaries, and 2% for the Yolo Bypass. During spring runoff following the very wet winter of 2006, the Eastside tributaries contribution peaked at 33% (January 2006), the Yolo Bypass contribution at 32% (April 2006) and the San Joaquin River contribution at 27% (May 2006). In low flow conditions, on the other hand, contributions from these tributaries are negligible. Relative contributions from agricultural return flows and WWTPs are largest in low flow conditions, with an average of 3% for AG and 1% for WWTPs.

Implications for Monitoring

Spatial variability in source water composition appears to be adequately captured by existing monitoring stations. Source water composition is similar across monitoring stations in Suisun Bay. An exception is the Martinez station at the outflow of Suisun Bay, where the Sacramento River influence is reduced compared to other locations (<20% compared to >40% at the other Suisun Bay locations). Eight of the ten locations in **Figures 9** and **10** are monitoring stations. Nutrient data are currently collected at three Suisun Bay monitoring stations (including Martinez).

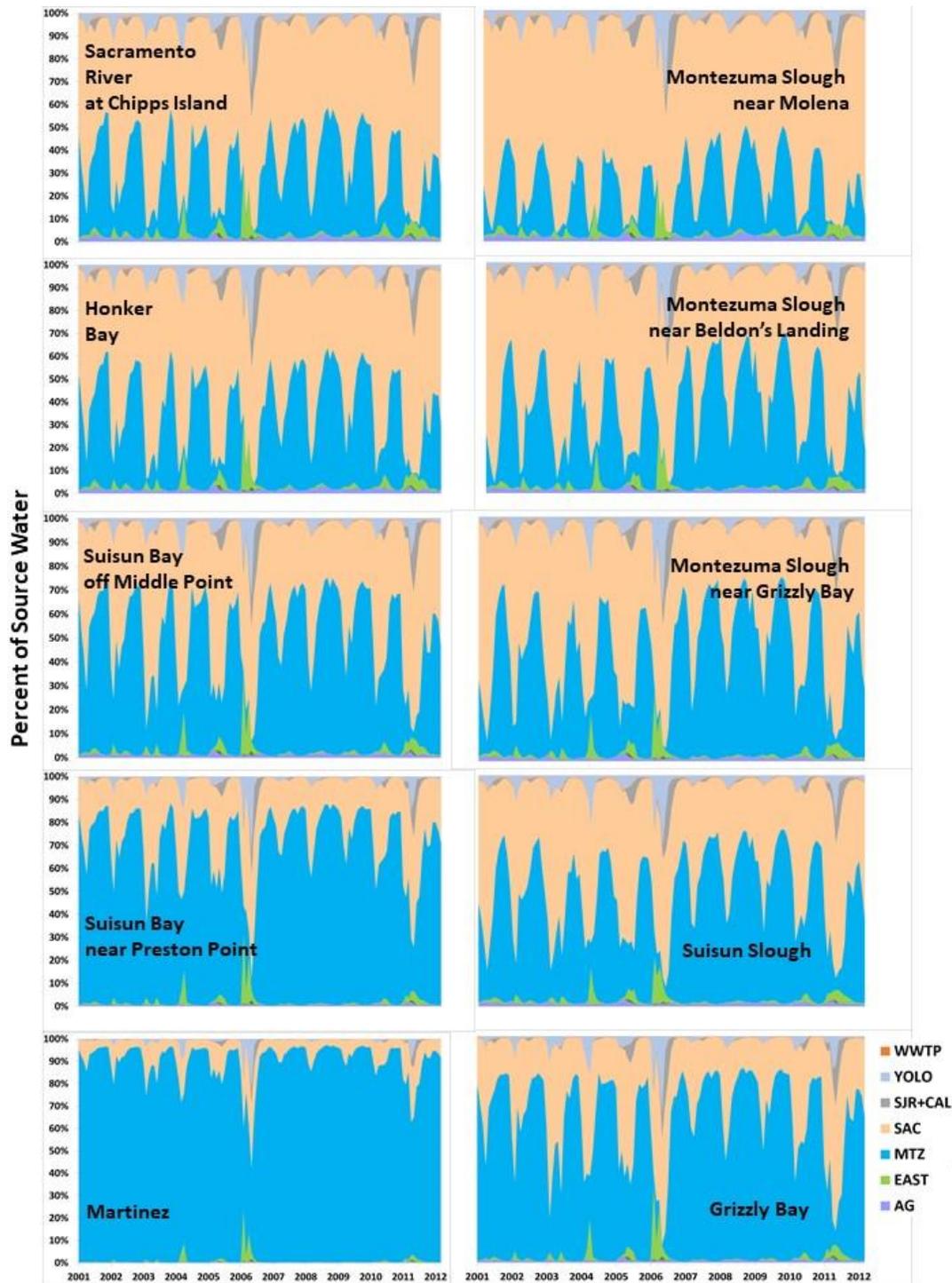


Figure 9. DSM2 volumetric fingerprints for locations in the Suisun Bay subregion.

Key to water sources: AG = irrigation return flows, SJR+CAL = San Joaquin and Calaveras rivers, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, YOLO = Yolo Bypass, WWTP = combined wastewater effluent sources.

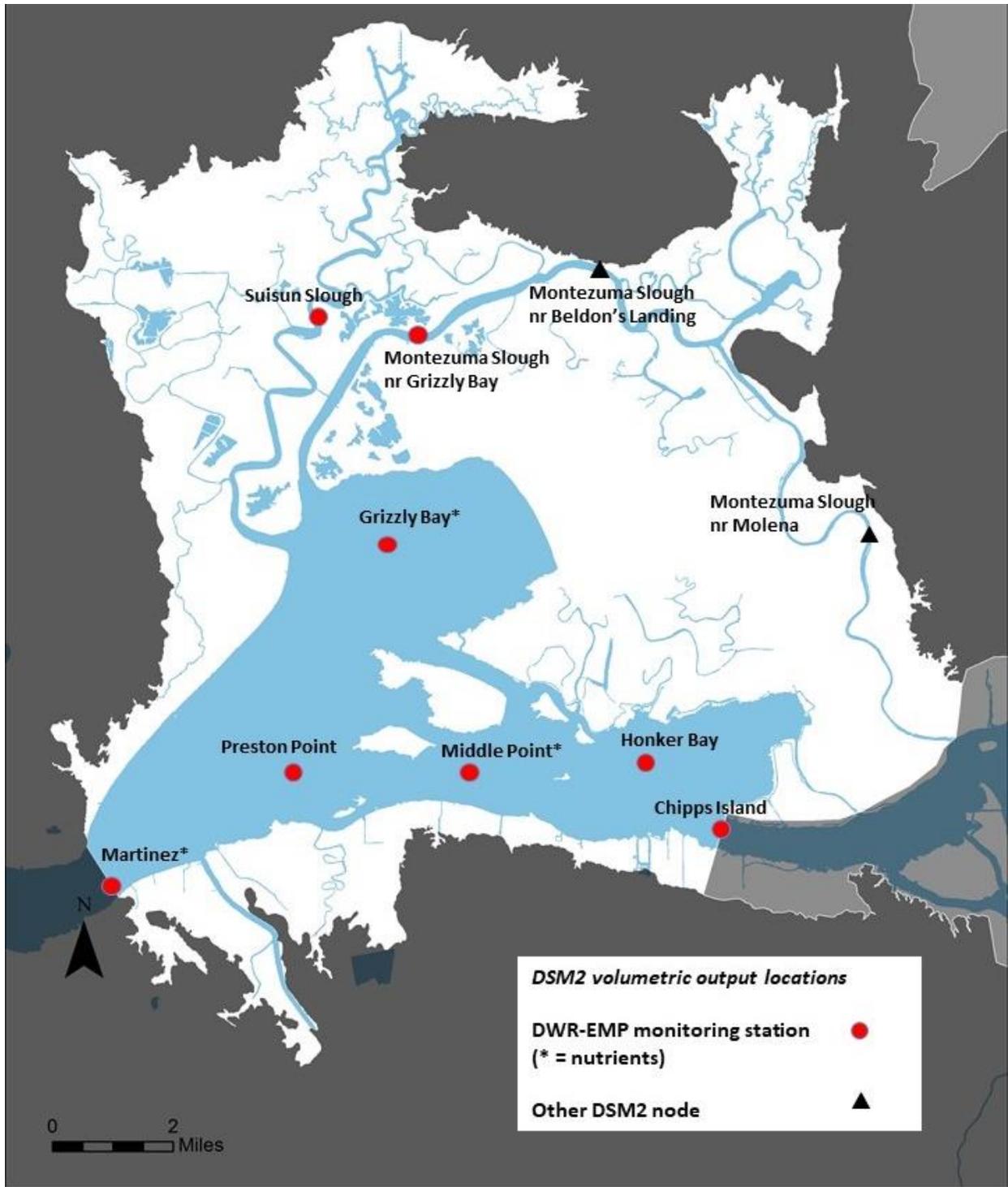


Figure 10. Map of the Suisun Bay subregion showing the locations represented in Figure 9.

Eastside

The Eastside subregion has a unique source water profile compared to other regions (Figures 1 and 11). The source water composition of the Eastside subregion is strongly influenced by the operation of the Delta Cross Channel (DCC) gates. Depending on whether the gates are open or closed either the Sacramento River or the Eastside tributaries are the dominant water source. The gates are generally open during the summer months and closed in winter and spring for flood control and to protect fisheries. During the high flow period of analysis (June 2011), the DCC was closed and Eastside tributaries contributed 99% of the flow volume. During the low flow period of analysis, the situation was completely reversed: the Sacramento River contributed 96% of the flow and the SRWWTP 2%, the Eastside tributaries contribution was close to 0%. The AG contribution was at around 1% in all three scenarios.

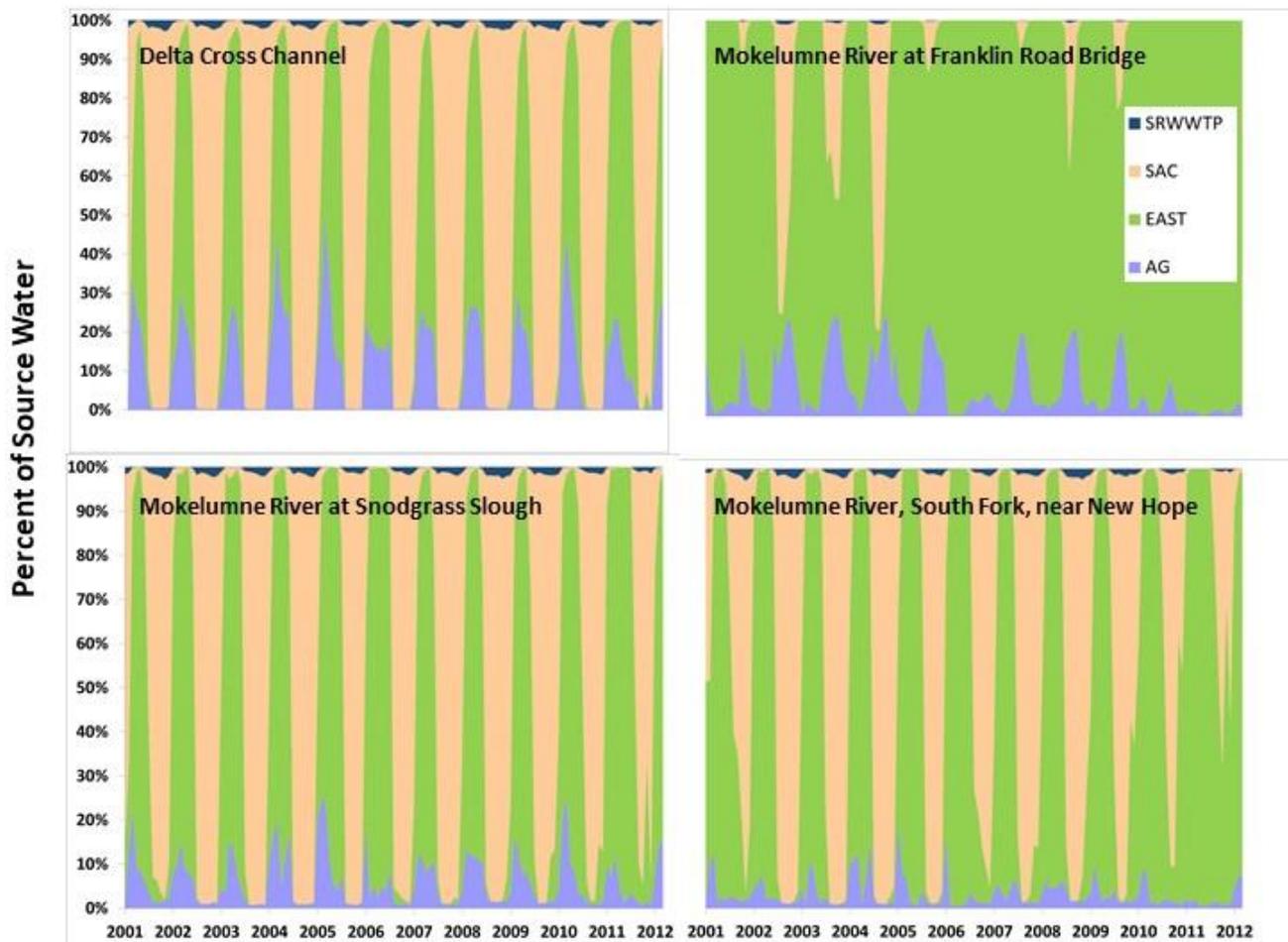


Figure 11 shows similar volumetric profiles for all locations downstream of the DCC (compare panels for Delta Cross Channel, Mokelumne River at Snodgrass Slough, and South Fork Mokelumne River). Figure 12 shows a subregion map with these locations. The DCC has a relatively high contribution from AG (9%) when the flood gates are closed. The results for the station upstream of the DCC (Mokelumne River at Franklin Road Bridge) are unique in that the contribution of the Sacramento River is much smaller here, even when the gates are open (3% in

low flow period of September 2008). However, closer examination of the detailed results reveals that the contribution of the Sacramento River upstream of the DCC has been quite high in the summer of some years and reached 78% in August 2004.

Several locations that are currently assigned to the North Central Delta should be merged with the Eastside (to form an expanded Northeast Delta subregion), because their volumetric fingerprints fit into the volumetric profile of this subregion (more on this in the next subsection for the North Central Delta, see **Figure 13**).

Implications for Monitoring

This subregion has a unique source water profile and is currently not monitored for nutrients. It also contains important habitat areas (for example, spawning areas in Eastside tributaries and sloughs). The relative contribution of different source waters is very different depending on whether one is above the DCC or below it. Based on this assessment, at least two long-term monitoring stations are needed to characterize this subregion, one above and one below the DCC. Despite the differences above and below the DCC, it still makes sense to treat this area as one subregion because the types of source waters are consistent across the subregion. Based on the volumetric analysis (**Figure 11**), Mokelumne River at Franklin Road Bridge (above DCC) and Sycamore Slough (below DCC) would be good candidate sites. Sycamore Slough is also of potential interest as a potential high-residence-time area and as an important habitat.

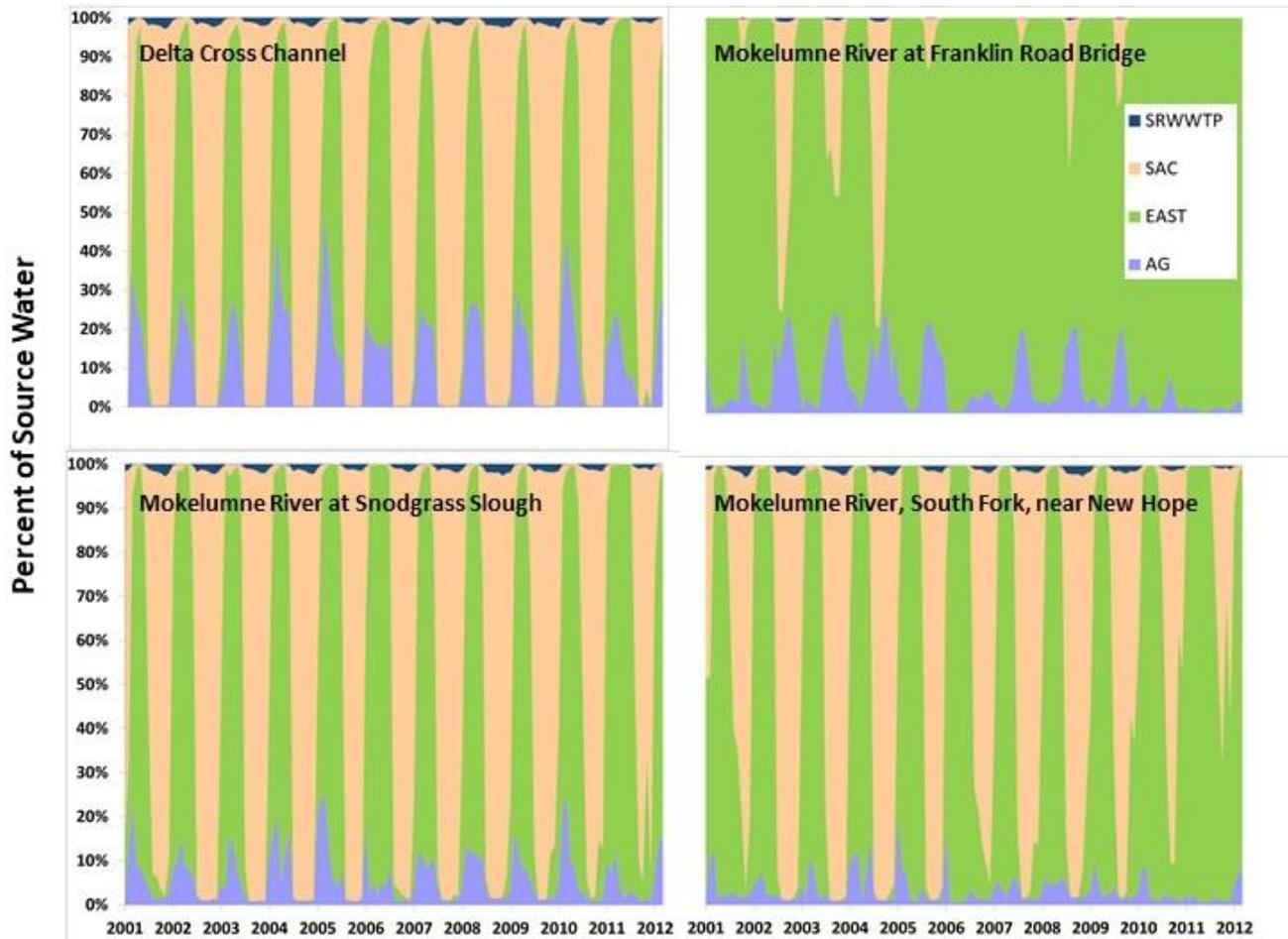


Figure 11. DSM2 volumetric fingerprints at representative stations in the Eastside subregion.

Key to water sources: AG = irrigation return flows, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), SAC = Sacramento River, SRWWTP = Sacramento Regional Wastewater Treatment Plant.

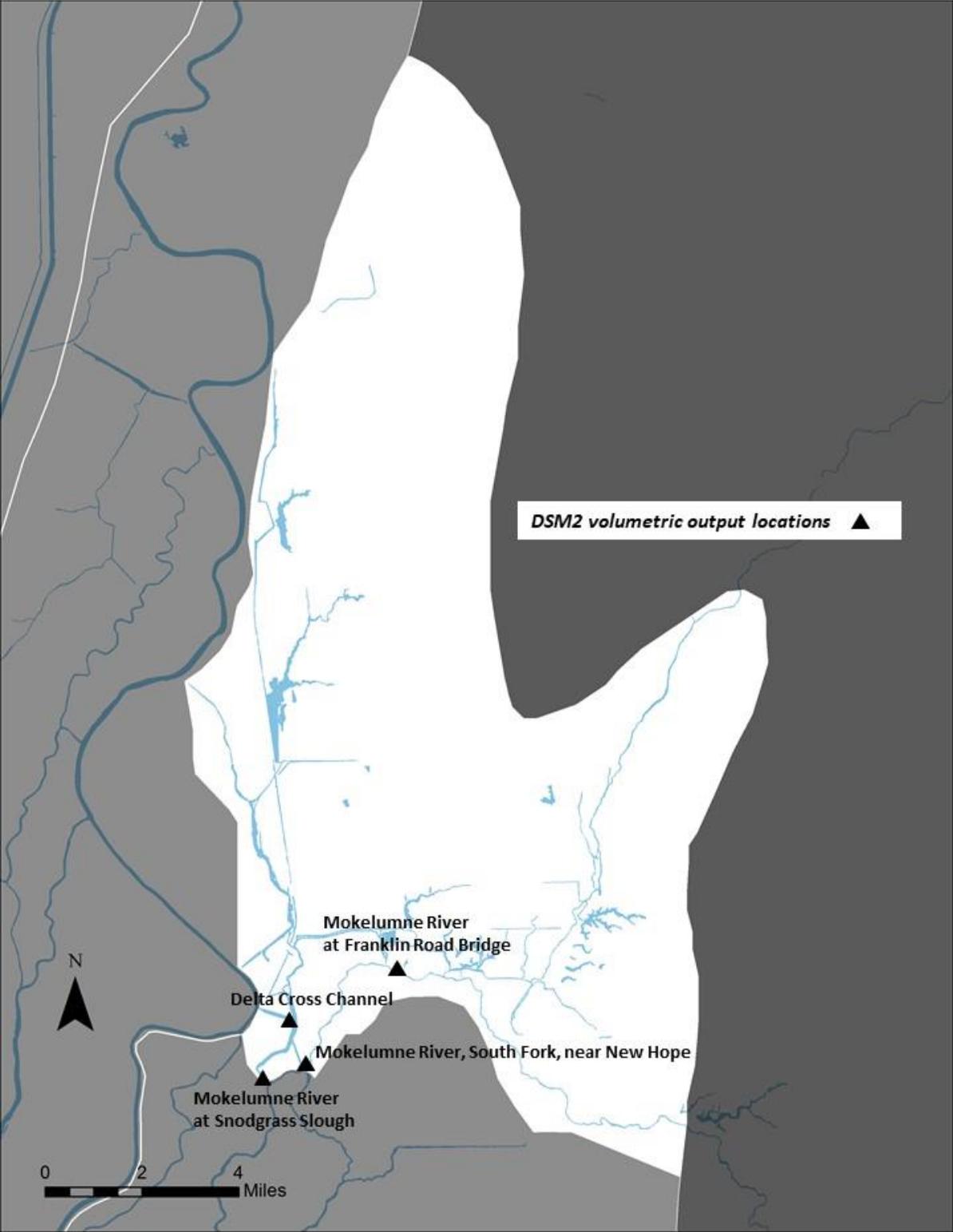


Figure 12. Map of the Eastside subregion showing the locations represented in Figure 11.

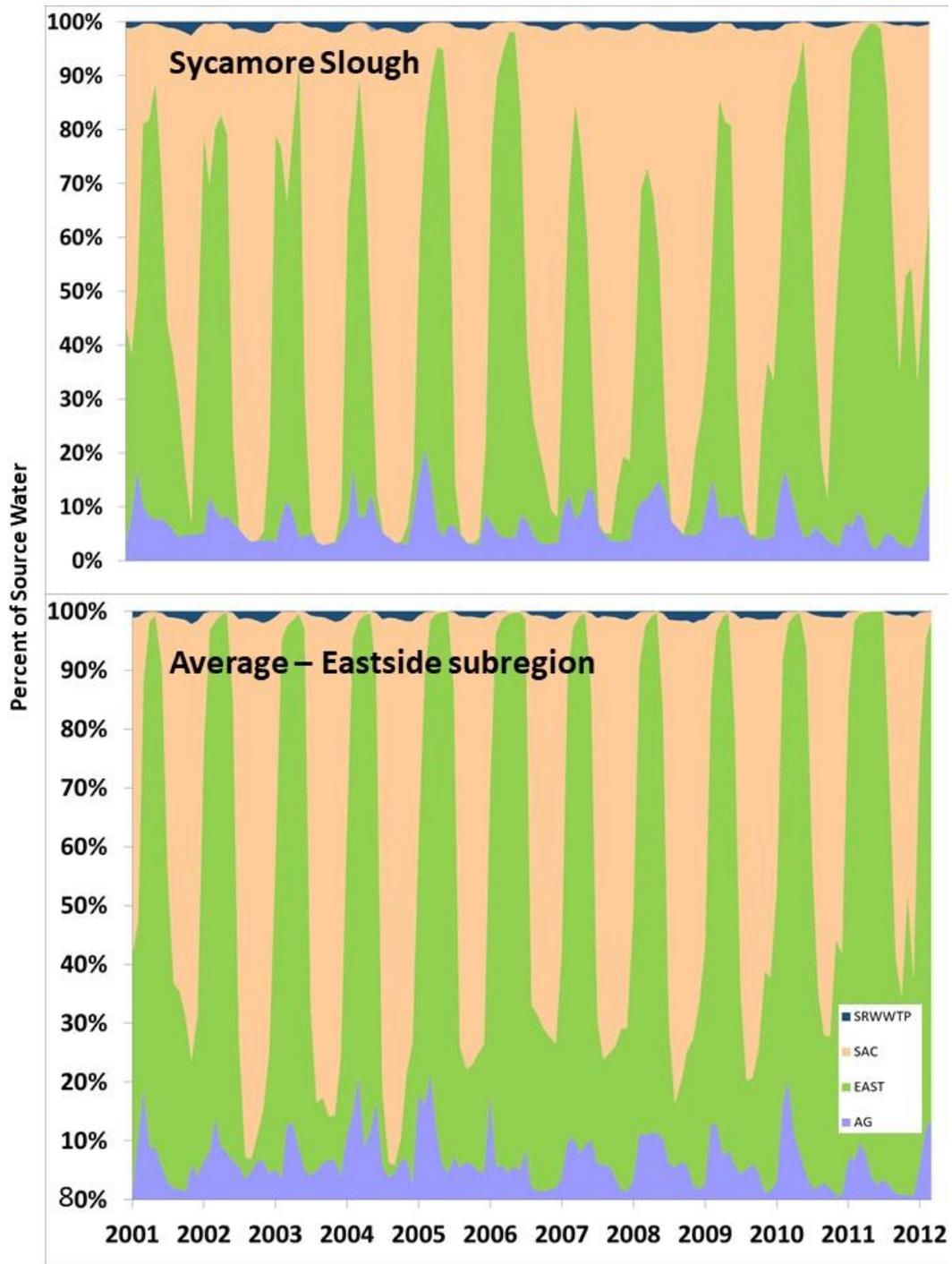


Figure 13. DSM2 volumetric fingerprints, comparison of Sycamore Slough with the regional average in the Eastside subregion.

The Sycamore Slough volumetric fingerprint is representative of those at other stations in the northeastern portion of the North Central Delta. Key to water sources: AG = irrigation return flows, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), SAC = Sacramento River, SRWWTP = Sacramento Regional Wastewater Treatment Plant.

North Central Delta

The volumetric fingerprints for locations in the North Central Delta (Figure 14) suggest a very heterogeneous region in regard to both the mix of water sources in different places and their relative contribution over time. The locations for the volumetric fingerprint analysis are shown in Figure 15. The Sacramento River dominates the volumetric fingerprint at the two San Joaquin River stations that are located downstream of the Middle River terminus, Twitchell Island and Potato Point, contributing over 90% of the total flow volume in the average and low flow period of analysis. It also dominates flow volume at locations in the lower reaches of the Mokelumne River (97% in low and average flow periods) and the South Fork Mokelumne River (94% in low and average flow periods)

Above the Old River confluence, the significance of the Sacramento River source in the San Joaquin River is diminished (see panel for Shima Bend in Figure 14). These observations are consistent with the flow routing of Sacramento River water via the Mokelumne River and Georgiana Slough, across the San Joaquin through the reversed Middle and Old Rivers towards the South Delta water pumps. Farther upstream on the San Joaquin River, Sacramento River water constitutes only 4% of the total source water volume during the low flow period and 0% during the high flow period. Here, the San Joaquin River is the dominant source and can contribute close to 100% of the flow in high flow conditions. The Calaveras River can also be a significant source here. The highest estimated contribution of the Calaveras River was 41% in November 2005.

The volumetric fingerprint of the Sycamore Slough location is similar to that of the Eastside subregion (Figure 15) and strongly influenced by the DCC gates operation. During the high flow period of analysis (June 2011), the DCC was closed and Eastside tributaries contributed 95% of the flow volume in Sycamore Slough. During the low flow and average flow period of analysis, the Sacramento River contributed 93% and 87% of the flow. The influence of Eastside tributaries is reduced farther downstream and smallest in the San Joaquin River upstream of Old River (Shima Bend, Buckley Cove).

Disappointment Slough represents the most fluid and heterogeneous mix of sources. For example the contribution from the San Joaquin River ranges from 0 (in August and September of 2007, a dry year) to close to 95% estimated for May 2006 (wet year spring runoff). It also has the largest contribution of AG among all the locations for which estimates were made. The AG contribution here is estimated to be close to 30% in the low flow period of analysis. Contributions from the SRWWTP and Stockton WWTP can both amount to several percent.

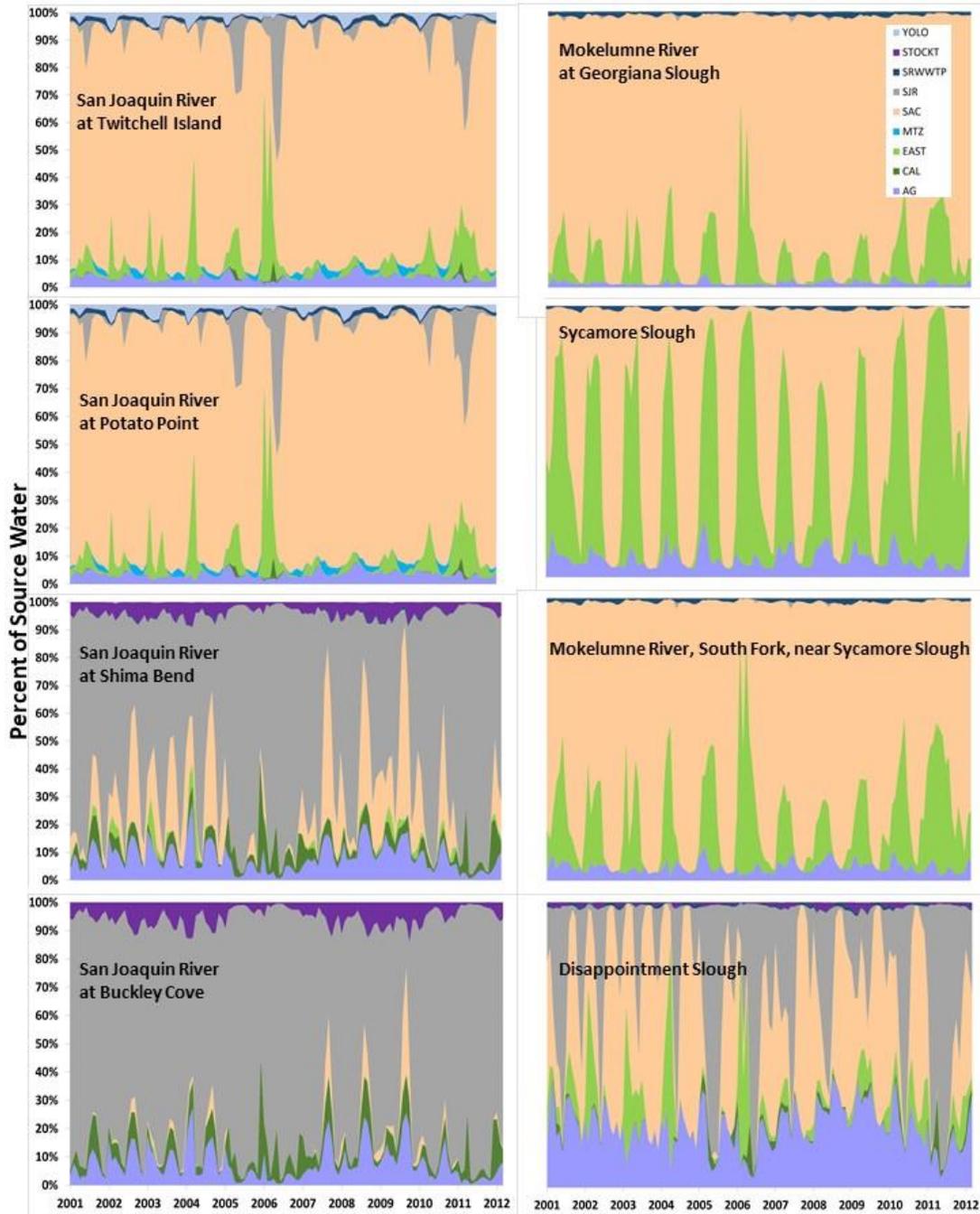


Figure 14. DSM2 volumetric fingerprints for locations in the North Central Delta subregion.

Key to water sources: AG = irrigation return flows, CAL = Calaveras River, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SJR = San Joaquin River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, STOCKT = Stockton WWTP, YOLO = Yolo Bypass.

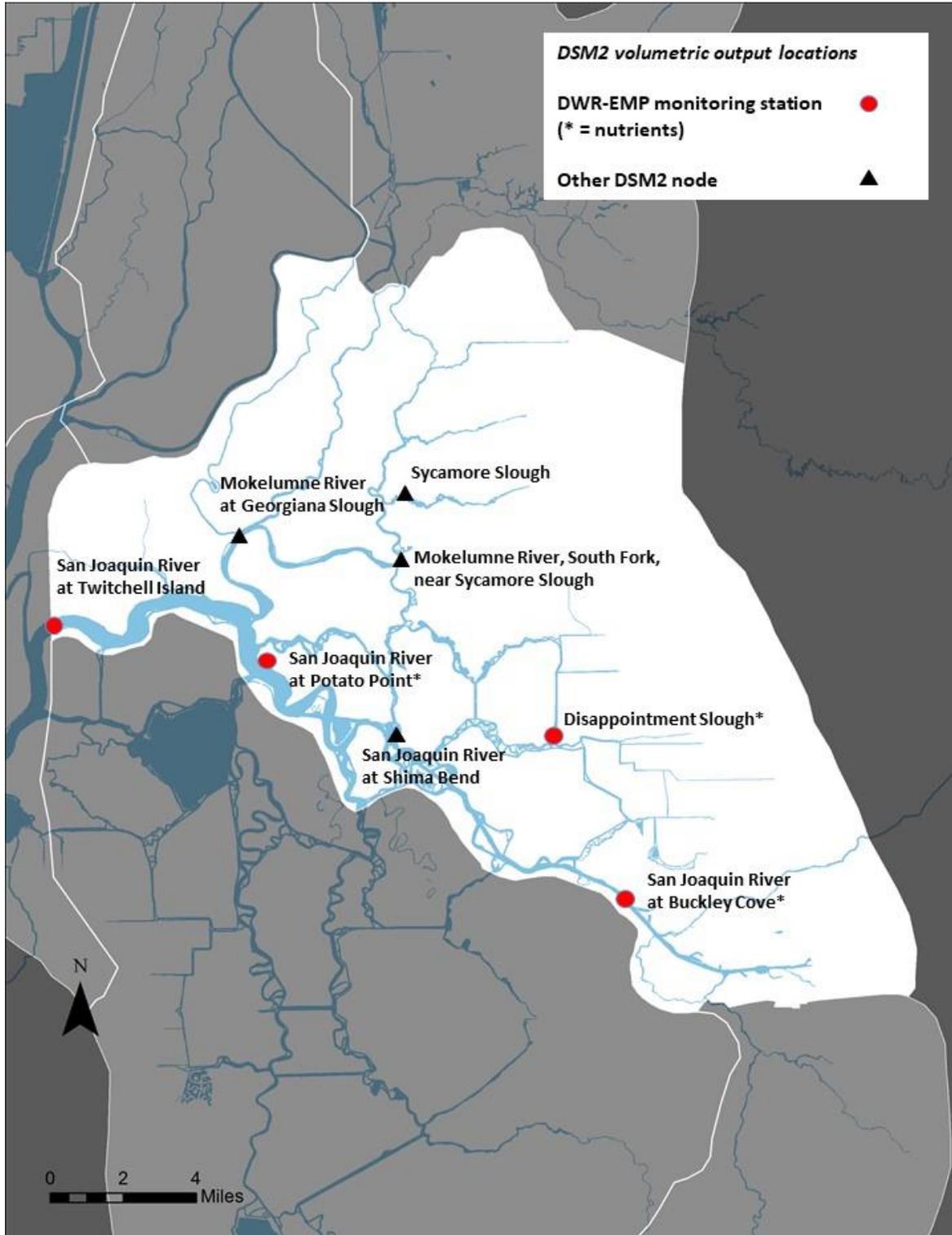


Figure 15. Map of the North Central Delta subregion showing the locations represented in Figure 14.

Contributions of several smaller sources may be locally and seasonally important, such as:

- The Stockton WWTP at Buckley Cove (up to 14% in low flow conditions). Generally, the relative contributions from both the Stockton WWTP and the SRWWTP co-vary somewhat with the relative contributions from the San Joaquin and Sacramento Rivers. The exception is Disappointment Slough. Here, the Stockton WWTP source can contribute up to 4%, but the contribution is not always proportionate to contributions from the San Joaquin River, which indicates a complex flow scenario (presumably tidal mixing combined with extensive source mixing and fluctuations in flow volume)
- Yolo Bypass source near the subregion boundary with the Confluence (Twitchell Island) in winter flow conditions (6% in January 2002)
- Tidal source near the near the subregion boundary with the Confluence (Twitchell Island) in low flow/reverse flow conditions (5% in August 2007)

Implications for Monitoring

The volumetric analysis suggests that current nutrient monitoring at D16 (SJR at Twitchell Island), D26 (SJR at Potato Point), P8 (SJR at Buckley Cove), and MD10 (Disappointment Slough) only partially captures the source water heterogeneity in this region (Figure 14). It also suggests some redundancy at Twitchell Island and Potato Point in terms of source waters. Resuming monitoring at Sycamore Slough is recommended to better capture spatial variability, trends, and rates in this region. Sycamore Slough is a dead-end back-slough with potentially high-residence-time (see particle tracking simulation result for the North Central Delta later in this report) that also represents important shallow water back slough habitat.

Implications for Subregional Delineations

The volumetric results indicate that splitting the North Central subregion apart would improve the alignment of subregional boundaries with different water source influences. Figure 16 shows a potential realignment, which would be threefold:

- 1) Areas upstream of Old River, where San Joaquin River water is the dominant source, could be merged with the South Delta subregion to form a larger San Joaquin River subregion. (Compare volumetric fingerprint for the South Delta in Figure 1 with the volumetric fingerprints for San Joaquin River at Buckley Cove, San Joaquin River at Shima Bend, and Disappointment Slough in Figure 14).
- 2) The San Joaquin River downstream of Old River, where Sacramento River water is the dominant source, could be merged with the South Central Delta for a slightly expanded Central Delta subregion. (Compare volumetric fingerprint for the South Central Delta in Figure 1 with the volumetric fingerprints for San Joaquin River at Twitchell Island in Figure 14).

3) The remaining northeastern portion with a strong influence from Eastside tributaries (Mokelumne and Cosumnes Rivers) could be merged with the Eastside subregion to form a Northeast Delta subregion (see Figure 13).

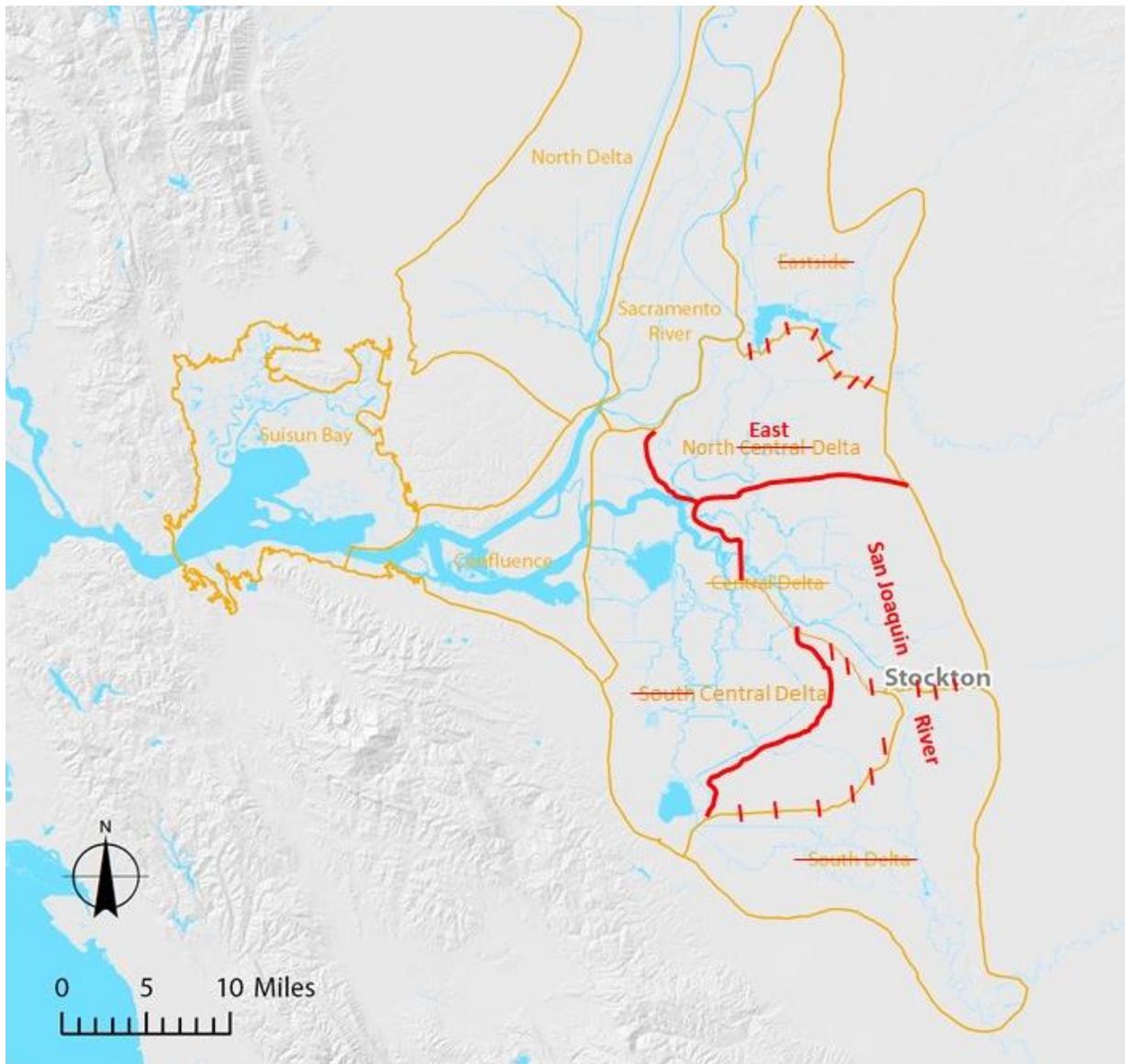


Figure 16. Potential realignment of subregional delineations based on water source influence.

Instead of a North Central Delta Region, there would be: 1) a larger San Joaquin River subregion where San Joaquin River water is the dominant source); 2) an expanded Central Delta subregion where Sacramento River water is the dominant source; and 3) a Northeast Delta subregion where the Mokelumne and Cosumnes Rivers have a strong influence.

South Central Delta

Volumetric fingerprints suggest that the South Central Delta is a relatively homogeneous subregion with regard to water source. Therefore, there are no recommended changes to the subregion delineations based on water source mixing.

The regionally averaged volumetric fingerprint for the South Central Delta (third panel from top on the right in Figure 1) is similar to that of the North Central Delta, with a few notable differences. Overall, the Sacramento River is the most important source in the South Central Delta region at most times (Figure 1) and contributes ~85% of total flow volume in the low and average flow periods. However, note that the contour of this source appears more “jagged” than for the North Central Delta, a result of a much stronger seasonal signal from the San Joaquin River contribution. In wet years (early 2005, 2006, and 2011), the San Joaquin River was the most important source for part of the year and particularly during the spring runoff period (97% in May 2006). Contributions from the Eastside, AG, and WWTP sources are generally smaller in the South Central Delta than in the North Central Delta, and the tidal source slightly larger (Eastside ~8% in South Central Delta vs 24% in North Central Delta in June 2011; AG ~8% vs 10% in September 2008, WWTP 2% vs 4% in September 2008; MTZ ~2% vs 1% in September 2010). The contribution from the Yolo Bypass source was negligibly small during the three periods of analysis but was up to 4% in winter months of wet years. There are gradients but no stark contrasts in the volumetric fingerprints at different locations in the subregion (Figure 17). As would be expected, the gradients are a function of geographical distance from source. For example, the contribution from the San Joaquin River increases with proximity to this source. In summary, this region is more homogeneous in terms of volumetric fingerprint than the North Central Delta.

Volumetric results for individual locations in the North Central Delta (see North Central Delta section above) suggest that merging the San Joaquin River segment downstream of Old River with the South Central Delta (for a slightly expanded Central Delta subregion) would improve the alignment of subregional boundaries with source water profiles. Sacramento River water is the dominant source at these stations and their volumetric profiles resemble those of stations in the South Central Delta subregion (compare volumetric fingerprint for the South Central Delta in Figure 1 with the volumetric fingerprints for San Joaquin River at Twitchell Island and San Joaquin River at Potato Point in **Figure 14**).

Implications for Monitoring

There are three DWR-EMP nutrient monitoring stations in this subregion: D19 (Frank’s Tract), D28 (Old River at Rancho del Rio), and C9 (West Canal at Clifton Court Intake). There are no stark contrasts in the volumetric fingerprints at different monitoring stations in this subregion, which indicates homogeneity within the subregion. Therefore, adding new fixed stations to this subregion should not be a priority.

The San Joaquin River downstream of Old River, where Sacramento River water is the dominant source, should be merged with the South Central Delta for a slightly expanded Central Delta subregion (Figure 16, compare volumetric fingerprint for the South Central Delta in Figure 1 with the volumetric fingerprints for San Joaquin River at Twitchell Island in Figure 14). The station San Joaquin River at Potato Point (D26, currently assigned to North Central Delta) should be continued, because it has a continuous 40-year data record, will increase the power for trend detection in the Central Delta, and help establish transformation rates along the flowpath of Sacramento River water through the Central Delta. Nutrient monitoring at the station at Twitchell Island could potentially be discontinued to redirect resources to fill priority gaps in other subregions. However, this decision should not be taken lightly. This station has a long-term time series for nutrients that would be impossible to replace.

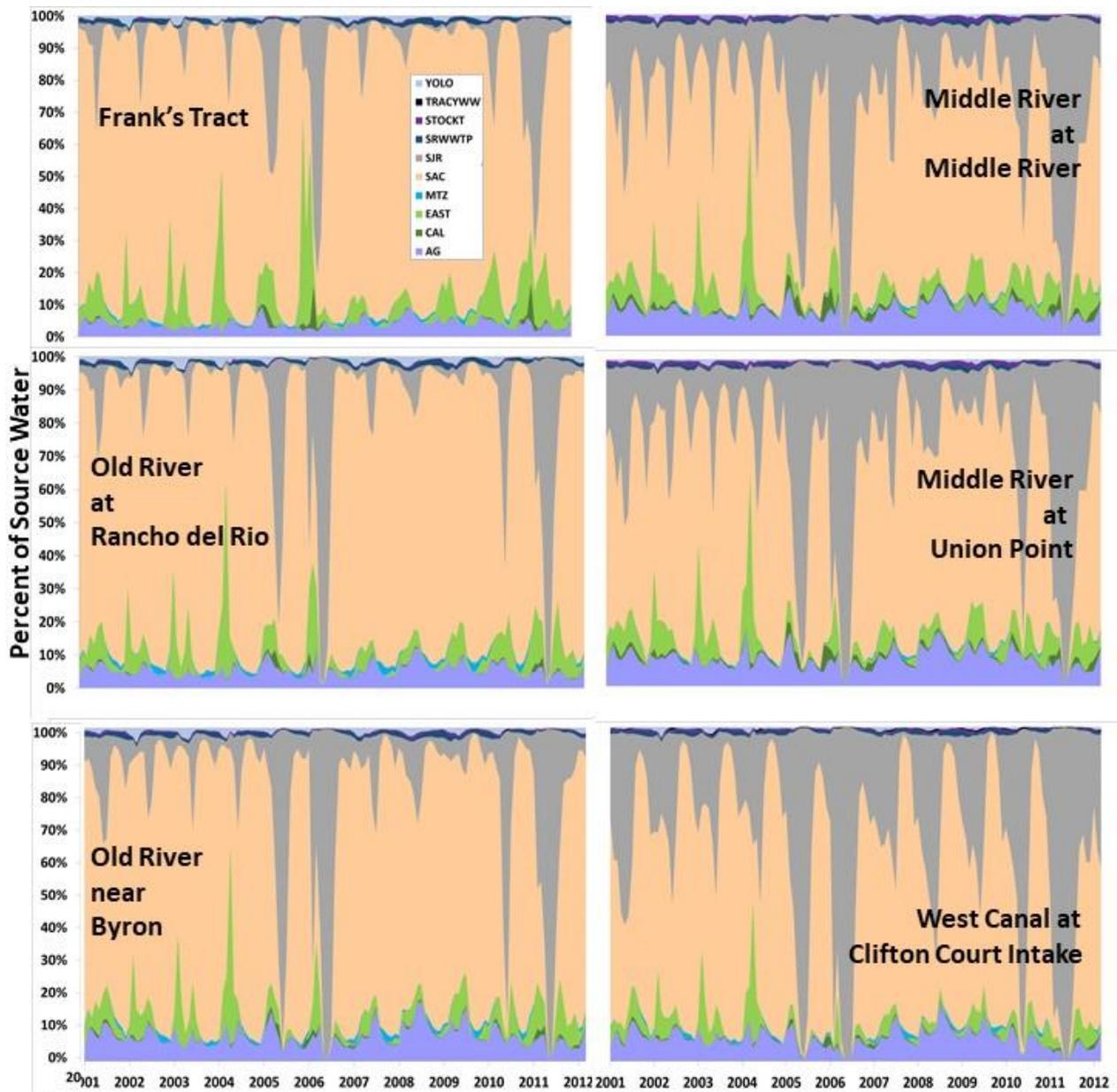


Figure 17. DSM2 volumetric fingerprints for locations in the South Central Delta subregion.

Key to water sources: AG = irrigation return flows, CAL = Calaveras River, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, STOCKT = Stockton WWTP, TRACYWW = Tracy WWTP, YOLO = Yolo Bypass.

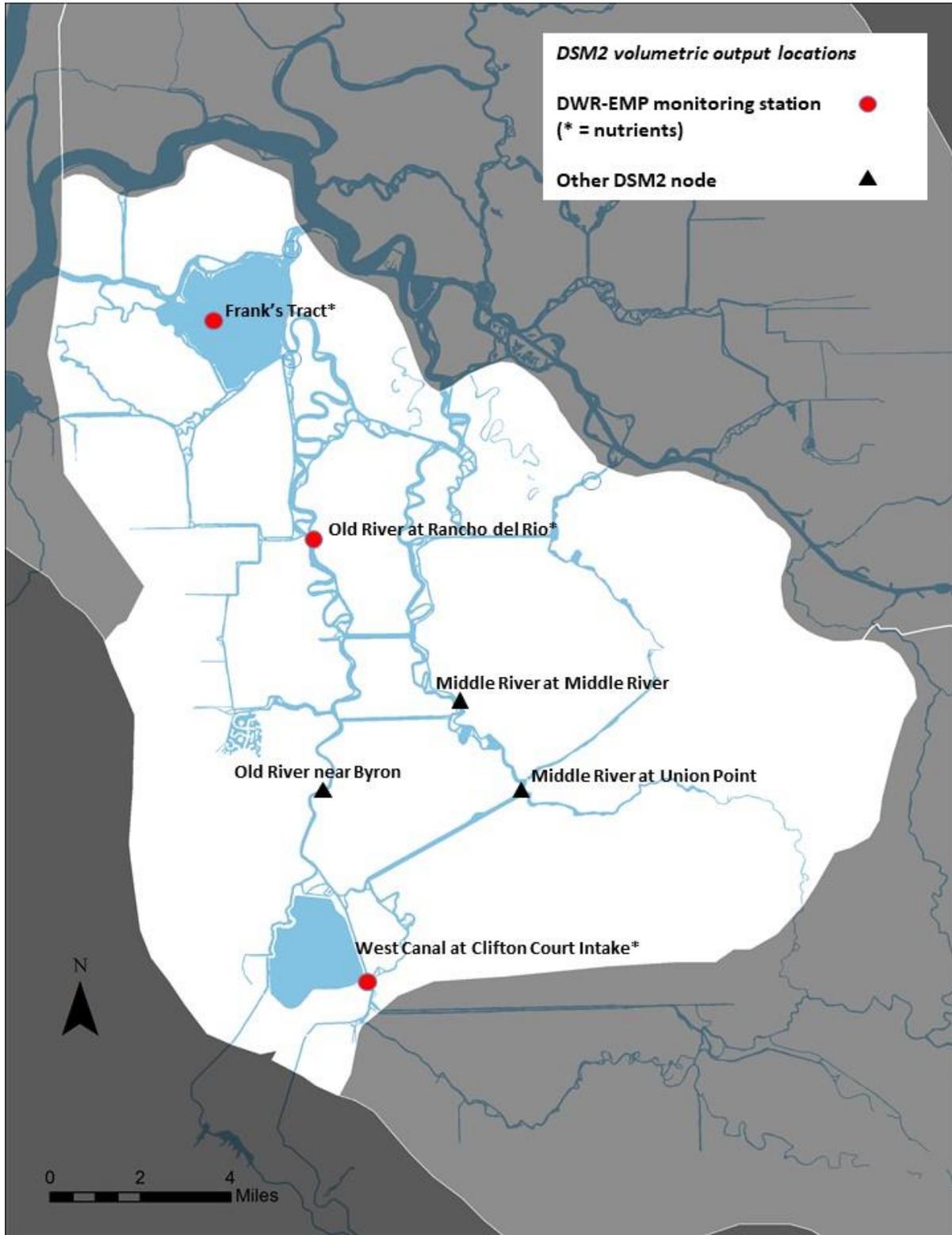


Figure 18. Map of the South Central Delta subregion showing the locations represented in Figure 17.

South Delta

The volumetric results indicate that the South Delta is a heterogeneous subregion. The San Joaquin River is the dominant water source (Figure 1, bottom right panel, and Figure 19), but volumetric fingerprints also suggest large seasonal and interannual variability in the relative contribution of various sources over time (Figure 17). The contributions from other sources varies seasonally and interannually and is largest in low flow conditions. The relative source water contribution of the San Joaquin River ranges from 57% in drought conditions (August 2009) to 100% in spring runoff conditions in a super-wet year (May 2006). Regionally averaged contributions during the low flow period of analysis were 26% from the Sacramento River (and up to 35% in September 2003), 9% from AG, and 3% from WWTPs. Other sources are negligible most of the time. In the wet season of drought years, the contribution from Eastside tributaries can be significant (8% in March 2004). The tidal and Yolo Bypass sources are always less than 1%.

As mentioned above, three stations that currently fall inside the North Central Delta delineation (Buckley Cove, Shima Bend, and Disappointment Slough, Figure 14) have volumetric fingerprints that are more similar to those of stations in the South Delta (Figure 19). These stations are upstream of the Old River, where San Joaquin River water is the dominant source.

Implications for Monitoring

The South Delta is a relatively heterogeneous region in terms of water source, nutrient monitoring is currently only conducted at Vernalis (by USGS and DWR-EMP). A single nutrient station seems insufficient to characterize spatial variability in this region. Resuming a station in the Old River (e.g. Old River at Tracy, Figure 19 and Figure 20) will help capture the spatial variability.

Information about status and trends in this portion of the Old River between Middle River and the Delta-Mendota Canal is potentially significant from a management perspective. This river segment constitutes a major portion of the back slough type habitat in the South Delta and at the same time is listed as impaired because of periodic low dissolved oxygen events. The DWR North Central Office maintains a chlorophyll sensor station in this stretch of the river, and opportunities for coordination should be explored.

Volumetric results for the North Central Delta (see North Central Delta section above) suggest that merging areas upstream of the Old River with the South Delta subregion (to form a larger San Joaquin River region) would improve the alignment of subregional boundaries with source water profiles (Figure 16).

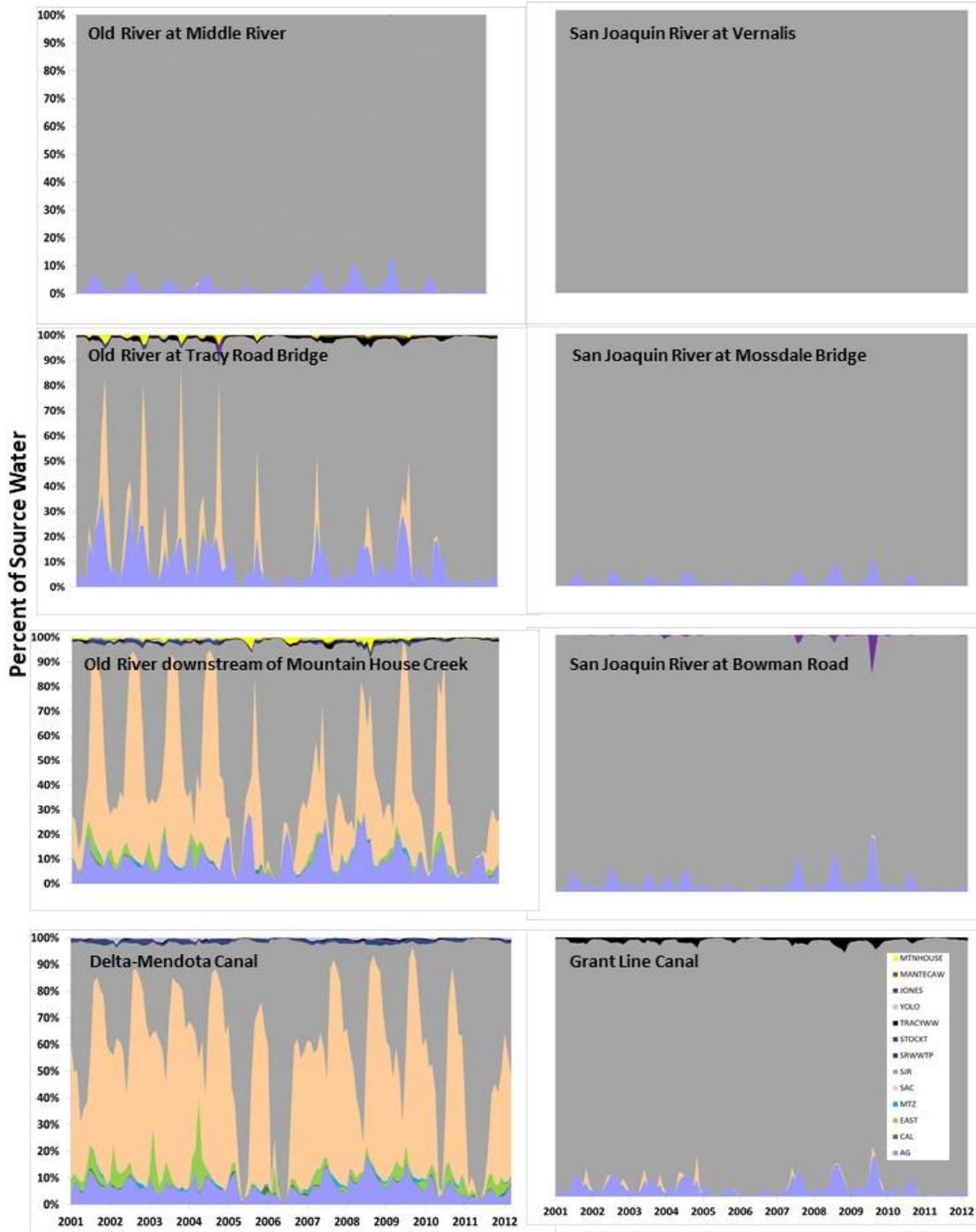


Figure 19. DSM2 volumetric fingerprints at representative stations in the South Delta subregion.

Key to water sources: AG = irrigation return flows, CAL = Calaveras River, EAST = Eastside tributaries (Cosumnes and Mokelumne rivers), MTZ = tidal source (originating at Martinez boundary condition), SAC = Sacramento River, SJR = San Joaquin River, SRWWTP = Sacramento Regional Wastewater Treatment Plant, STOCKT = Stockton WWTP, TRACYWW = Tracy WWTP, YOLO = Yolo Bypass, JONES = Jones Tract, MANTECA = Manteca WWTP, MTNHOUSE = Mountain House WWTP.

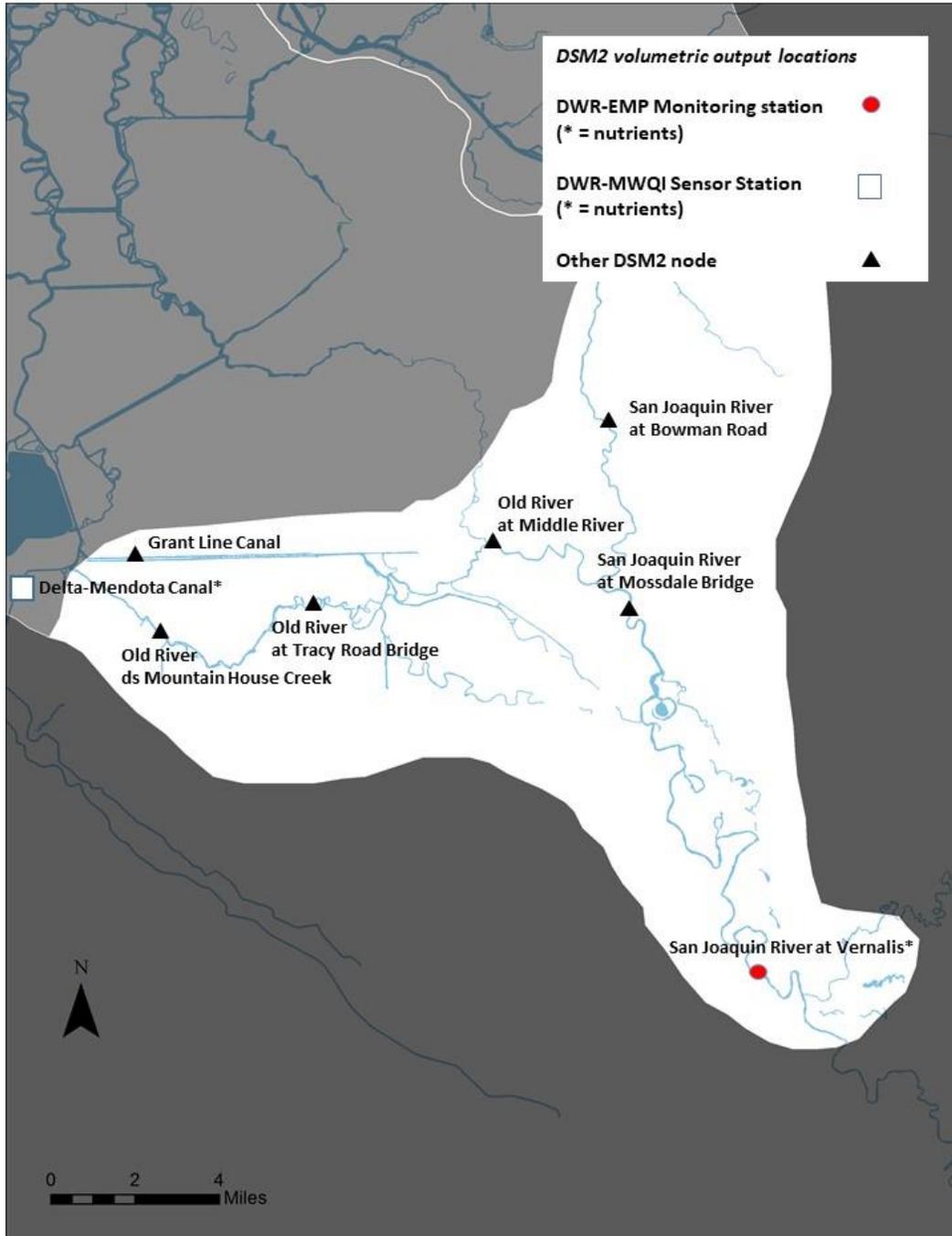


Figure 20. Map of the South Central Delta subregion showing the locations represented in Figure 19.

Particle Tracking Simulations

This section outlines the results of the particle tracking simulations. The model simulation results were used for two types of analyses: 1) residence time analysis, and 2) age and exposure time analysis.

Residence Time Analysis (Water Fate Simulations) – The residence time analysis addresses the questions:

1. What is the residence time of water within the subregions under different flow regimes?
2. What are potential high-residence-time areas within each subregion?

The spatial variability in residence time within the subregion is another indication of whether the region is homogeneous or not. Maps of water fate simulations can be used to identify potential high-residence-time areas within each subregion.

Age and Exposure Time Analysis - The age and exposure time analysis further evaluates source water characteristics in each of the subregions. The age and exposure time analysis addresses the questions:

1. How long does water from different sources typically spend in each of the subregions?
2. How “young” or “old” is the water?

Statistics on the age and exposure of particles in a subregion were qualitatively compared with “Volumetric Water Source” statistics to better define source waters in each of the subregions.

Residence Time Analysis

The particle tracking simulation results (summarized in Table 3 and Table 4) indicate that residence time varies considerably among subregions. The regions with the longest median residence times are the peripheral subregions North Delta (>28 days in low and average flow conditions) and Eastside (>28 d in low flow conditions). The regions with the shortest median residence times are the subregions along the flowpath of the Sacramento River towards San Francisco Bay: the Sacramento River, Confluence, and Suisun Bay subregions (zero to 5 days in all flow scenarios). Residence time estimates in subregions with longer or intermediate median residence times are more variable and more strongly affected by flow condition than those for subregions with short residence times. For example, the median residence time in the Eastside subregion is 0-5 days for the low and average flow scenario and >28 days for the low flow scenario.

The residence time estimates for a subregion provides one of several initial measures (others include water source mixing and water exposure/age) that may be used to develop hypotheses about its relative significance for biogeochemical transformations on a larger regional scale. Another measure water residence time is apparent flushing time, which is approximated as the time for 63% of particles to exit the subregion, also known as e-folding time (see Table 4). The flushing time could not be calculated for some simulations because less than 63% of the particles exited the subregion in the 28 day simulation. It is important to keep in mind that the size and delineation of subregions affect the residence time estimate and therefore, the residence time estimates provided here are relative and approximate. The purpose of the residence time calculations in this report is only to highlight which general areas of the Delta have longer residence times than others. Therefore, the residence times and flushing times for each subregion are reported as ranges with 5 days as the smallest unit of measure.

The distribution of particles across residence time ranges (Table 4) provides a measure for the variability of residence time inside each of the subregions. For example, 96% of particles in the Sacramento subregion are in the 0-5 days residence time range, indicating a homogeneous subregion with regards to residence time. In the Eastside subregion, 34-50% of particles are in the 0-5 days residence time range and 44-55% in the 28+ days range, indicating a heterogeneous subregion with regards to residence time.

Subregions with a high degree of variability in residence time include the Eastside, the North Delta, and the North Central Delta. Therefore, these areas are the most likely to contain pockets of high-residence-time waters, such as backwater sloughs. However, there is some degree of variability in residence time in all of the subregions. In all subregions, a portion of particles remains in the subregion more than 28 days. The estimated percentage of particles remaining in each of the subregions varies with flow and ranges from 4% (in the low flow simulation for the Sacramento River subregion) to 89% (in the average flow simulation for the North Delta). This result suggests that all subregions have areas with potentially longer residence times that may

be biogeochemically important. The following subsections provide short summaries of the residence time analysis for each subregion and identify potential high-residence-time areas in each of the subregions.

Table 3. Median estimated residence time of water in each subregion in different flow scenarios (see also Figure 21).

	Typical Residence Time (Interval in Days)							
Flow Scenario	Sacramento River	North Delta	Confluence	Suisun Bay	Eastside	North Central Delta	South Central Delta	South Delta
Low	0–5	>28	0–5	0–5	>28	5–10	5–10	5–10
Average	0–5	>28	0–5	0–5	0–5	0–5	0–5	0–5
High	0–5	10–15	0–5	0–5	0–5	0–5	0–5	0–5

Table 4. Residence time summary statistics.

A. Results for low-flow simulation								
	Residence Time Range (% Particles in Range) ¹							
Subregion	0–5 days	5–10 days	10–15 days	15–20 days	20–25 days	25–28 days	Typical Residence Time (mode)	Apparent Flushing Time ² (63% removed)
Sacramento River	96	0	0	0	0	0	0-5 days	<5 days
North Delta	10	5	6	4	4	2	28+ days	undetermined
Confluence	50	23	13	6	3	1	0-5 days	<10 days
Suisun Bay	66	17	5	3	2	1	0-5 days	<5 days
Eastside	31	5	4	2	2	1	28+ days	undetermined
North Central	46	22	11	6	3	1	0-5 days	<10 days
South Central	44	27	11	6	3	0	0-5 days	<10 days
South Delta	38	39	6	0	0	0	5-10 days	<10 days

¹ Percentages do not necessarily add up to 100%. Particles remaining longer than 28 days are not included because their fate is difficult to interpret. ² Flushing time is approximated by the e-folding time of 63% of particles removed.

Table 4 (continued)

B. Results for average-flow simulation								
	Residence Time Range (% Particles in Range)							
Subregion	0–5 days	5–10 days	10–15 days	15–20 days	20–25 days	25–28 days	Typical Residence Time (mode)	Apparent Flushing Time (63% removed)
Sacramento River	Statistics not computed						0-5 days	<5 days
North Delta	0	4	6	2	1	0	28+ days	undetermined
Confluence	60	21	10	4	2	1	0-5 days	<10 days
Suisun Bay	67	12	6	3	3	2	0-5 days	<5 days
Eastside	50	2	1	1	1	1	0-5 days	undetermined
North Central Delta	59	19	8	2	1	0	0-5 days	<10 days
South Central Delta	66	20	6	2	1	0	0-5 days	<5 days
South Delta	75	4	0	1	1	0	0-5 days	<5 days

C. Results for high-flow simulation								
	Residence Time Range (% Particles in Range)							
Subregion	0-5 days	5-10 days	10-15 days	15-20 days	20-25 days	25-28 days	Typical Residence Time (mode)	Apparent Flushing Time (63% removed)
Sacramento River	Statistics not computed						0-5 days	<5 days
North Delta	30	16	11	5	3	1	28+ days	<25 days
Confluence	88	10	1	0	0	0	0-5 days	<5 days
Suisun Bay	83	6	3	2	1	1	0-5 days	<5 days
Eastside	50	2	1	0	1	0	0-5 days	undetermined
North Central Delta	67	16	6	1	0	0	0-5 days	<5 days

South Central Delta	55	21	10	5	2	1	0-5 days	<10 days
South Delta	Statistics not computed						0-5 days	<5 days

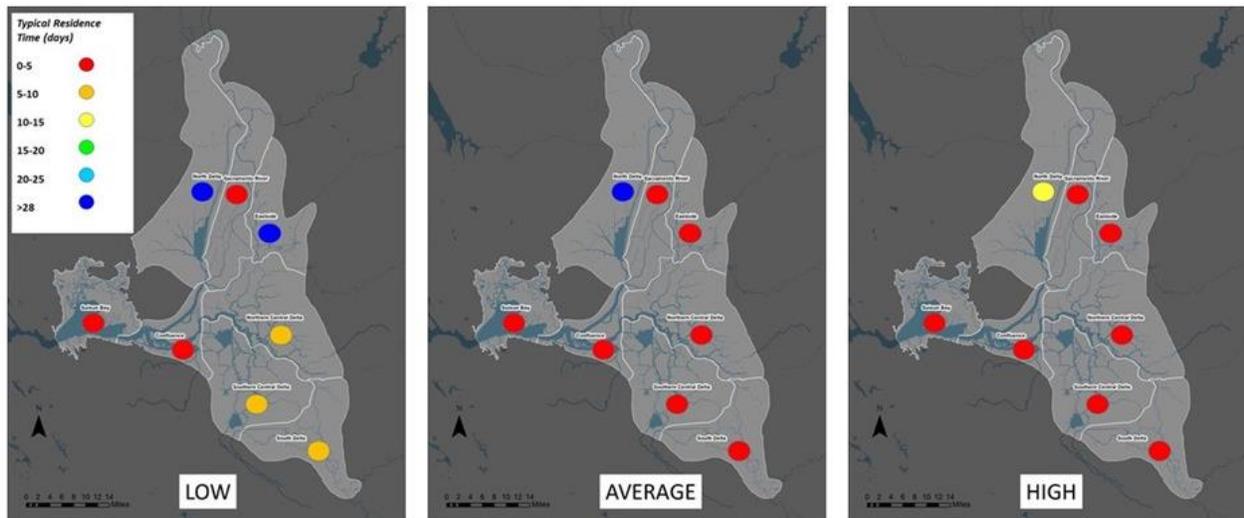


Figure 21. Median estimated residence time of water in each subregion in different flow scenarios (see also Table 3).

Sacramento River

Residence times in the Sacramento River region are short. In the low flow scenario, 96% of the particles in the fate simulations exit the Sacramento River subregion within the first 5 days of the simulation (Figure 22). Only 4% of particles remain after 28 days.

Implications for Monitoring

Modeling does not indicate major gaps for this subregion.

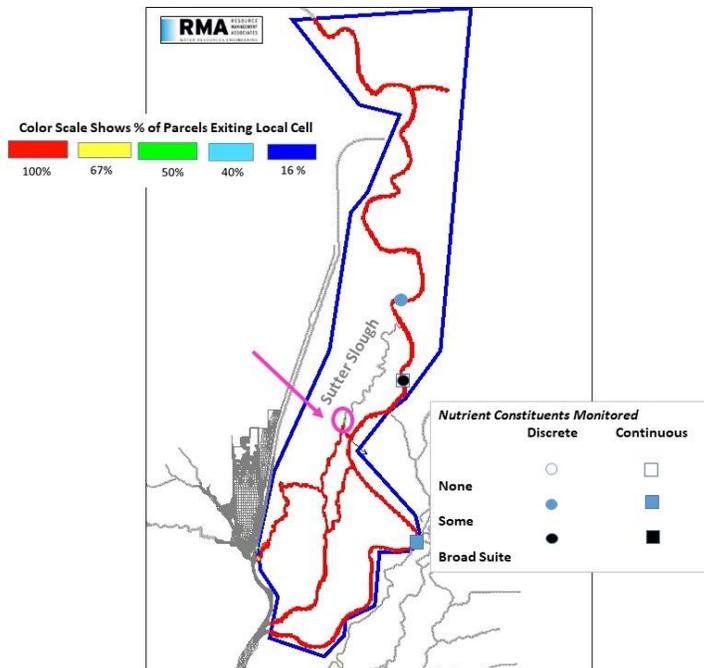


Figure 22. Sacramento River water fate simulation, low flow period. A total of 100,000 parcels were uniformly distributed across the subregion (“local cell”) at the beginning of the simulation. Simulation time span: September 01, 2008, 00:15 to September 28, 2008, 23:45. The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

North Delta

Potential high-residence-time areas include the northern portion of Liberty Island, the stair steps area, the Yolo Bypass, the Sacramento Deep Water Ship Channel, upper Cache Slough and Lindsey Slough. The extent of potential high-residence-time areas gets smaller as flow increases (Figure 23).

Implications for Monitoring

Areas in the North Delta with long retention times where mixing occurs should be targeted (e.g., with transectional high-frequency [HF] sensor monitoring) to explore potential transformation “hotspots”. Results from USGS studies and HF sensing should provide additional insight where to target monitoring and when to go. The USGS has installed sensors at Liberty Cut, Liberty Island, in the Toe Drain, and the Deep Water Ship Channel.

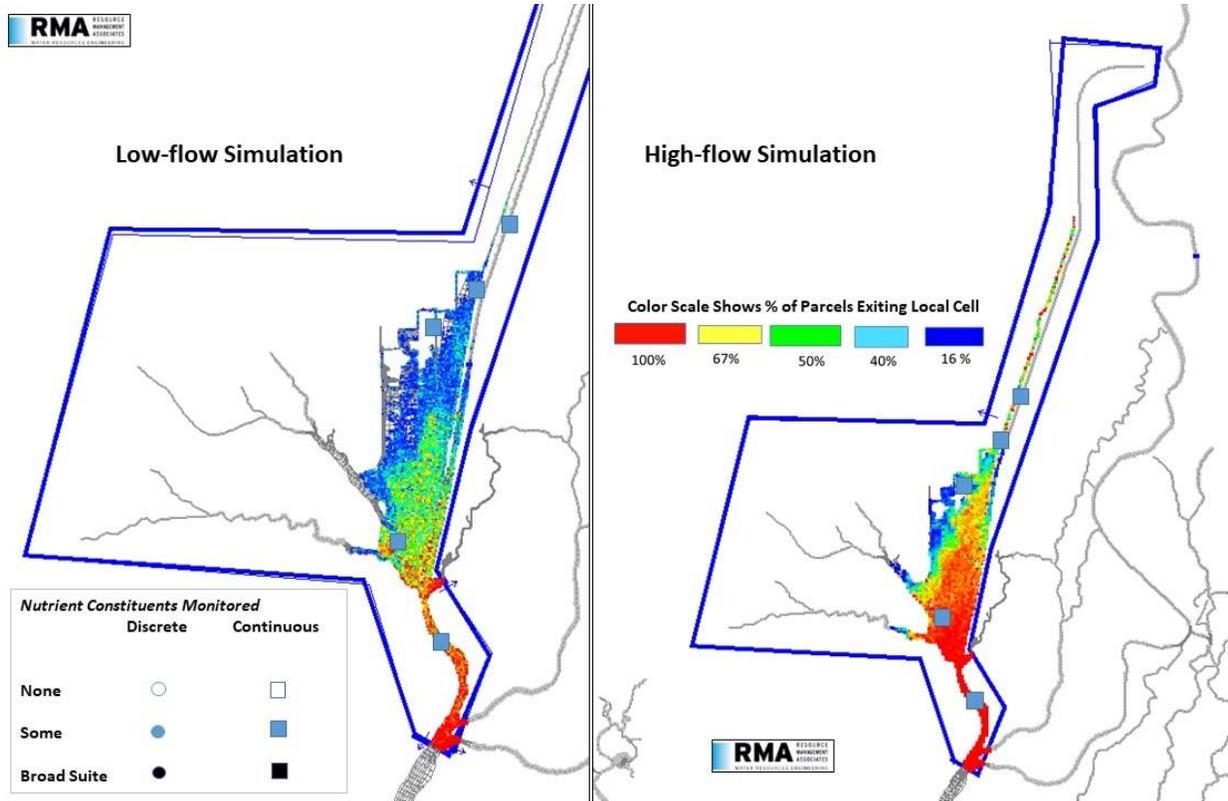


Figure 23. North Delta water fate simulation, low flow and high-flow simulations. A total of 150,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of each simulation. Simulation time spans: September 01, 2008, 00:15 to September 28, 2008, 23:45 (low-flow simulation); June 01, 2011, 00:15 to June 28, 2011, 23:45 (high-flow simulation). The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

Confluence

The fate simulations suggest short residence times in the Confluence region overall, only 4% of particles remained in the region after 28 days in low flow conditions (Figure 24).

Implications for Monitoring

Modeling does not indicate major gaps for this subregion.

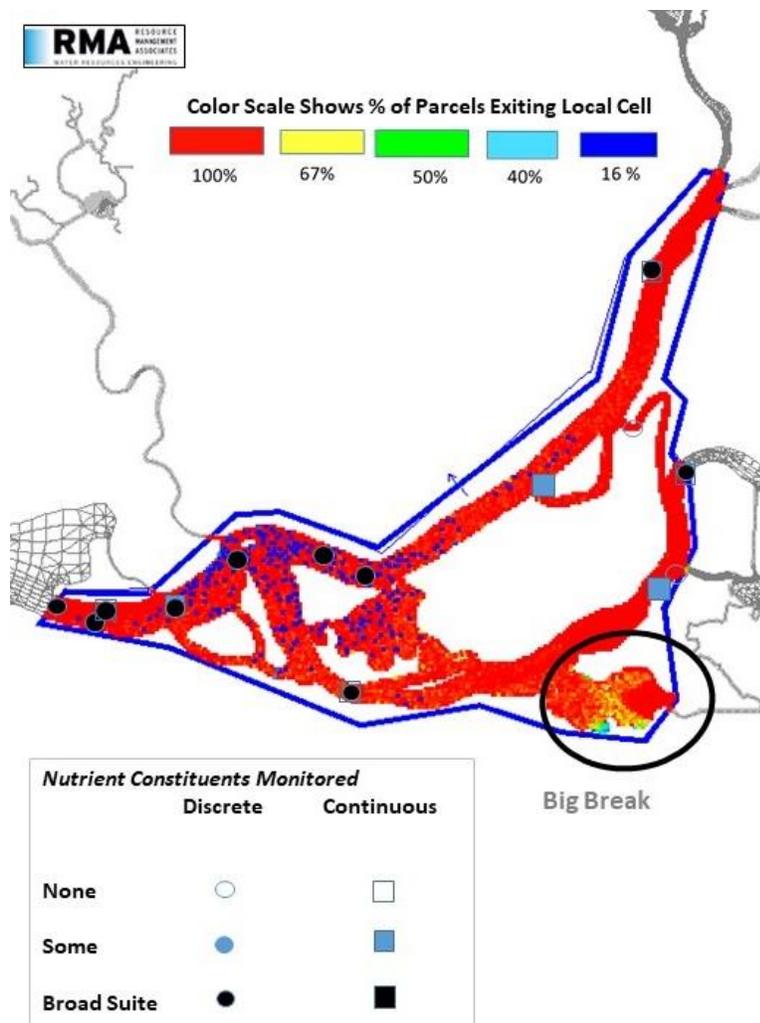


Figure 24. Confluence water fate simulation, low flow simulation. A total of 150,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of the simulation. Simulation time span: September 01, 2008, 00:15 to September 28, 2008, 23:45. The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

Suisun Bay

Residence times for the majority of particles released in Suisun Bay are short, but there are several potential high residence areas (Figure 25). Between 66 to 83% of particles exit the subregion within 5 days. The fate simulation results for this region should be interpreted with caution because of the proximity of the model domain boundary at Martinez. Particles that exit the region at Martinez are assumed to not return, but, in reality, tidal flows may carry water parcels back into Suisun Bay. This

Implications for Monitoring

Modeling does not indicate major gaps for this subregion.

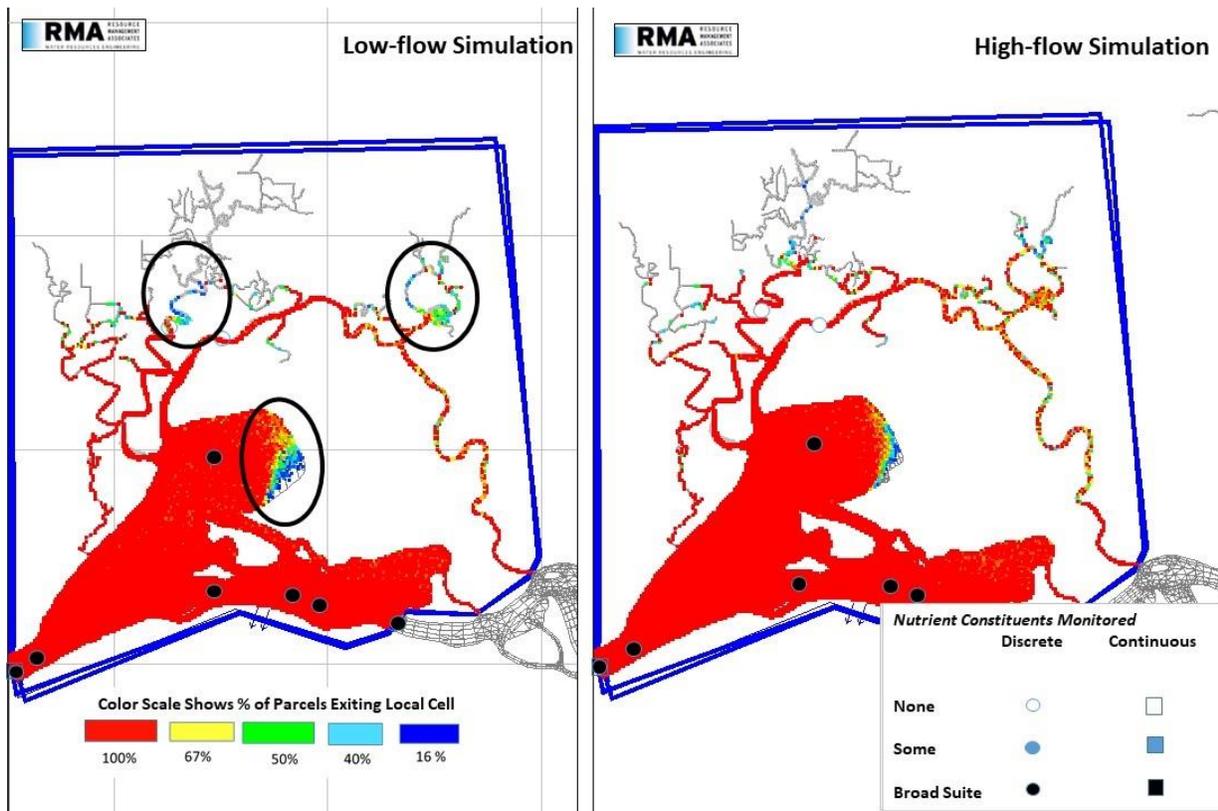


Figure 25. Suisun Bay water fate simulation. A total of 100,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of each simulation. Simulation time spans: September 01, 2008, 00:15 to September 28, 2008, 23:45 (low-flow simulation); June 01, 2011, 00:15 to June 28, 2011, 23:45 (high-flow simulation). The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

Eastside

Residence times in the Eastside subregion are either very short (31 -50% of particles are in 0-5 day range) or long (44% to 55% of particles are in the 28+ days range), depending on the location. Potentially long residence times are found upstream of the DCC, including reaches of the Mokelumne River, Cosumnes River, and Snodgrass Slough, Meadows Slough, and Railroad Slough (Figure 26). Volumetric results (discussed in Section 3.1.) indicate that water source contributions are also different in this area from other areas below the DCC (Figure 11).

Implications for Monitoring

There are some areas with potentially long residence times where source water mixing occurs that could be targeted with high-frequency mapping to evaluate potential transformation zones.

They are all ecologically important areas upstream of the Delta Cross Channel and include lower reaches of the Mokelumne River, Cosumnes River, and Snodgrass Slough.

These findings also support the recommendation from the volumetric analysis for a long-term monitoring station in the Eastside above the DCC.

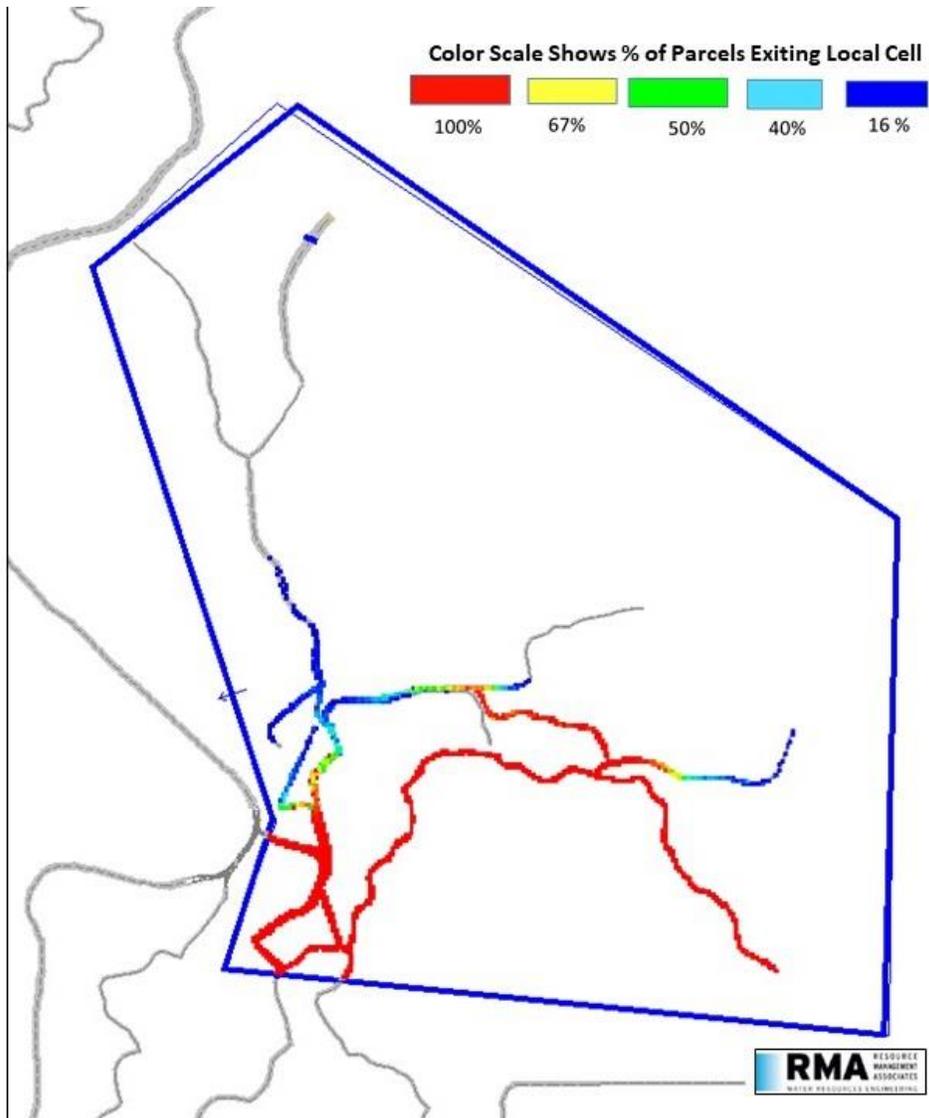


Figure 26. Eastside water fate simulation, low flow period. A total of 100,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of the simulation. Simulation time span: September 01, 2008, 00:15 to September 28, 2008, 23:45. The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

North Central Delta

Although residence time in the North Central Delta is generally short, there are some backwater areas with longer residence times (Figure 27) and source water mixing (Figure 14). From 9 to 12 percent of the particles released here remain in the subregion after 28 days. Potential high residence areas include back sloughs around Terminous Tract, including Sycamore Slough and Disappointment Slough; and in and around the Stockton urban area, including Mosher Slough, Fourteenmile Slough, Smith Canal, and the Stockton Deep Water Ship Channel and its backwaters.

Implications for monitoring. Cross-Delta HF monitoring funded by the Delta RMP and conducted by USGS in FY17/18 will cover most of this area and provide insight whether any of these locations should be further investigated as “hotspots” of nutrient transformation.

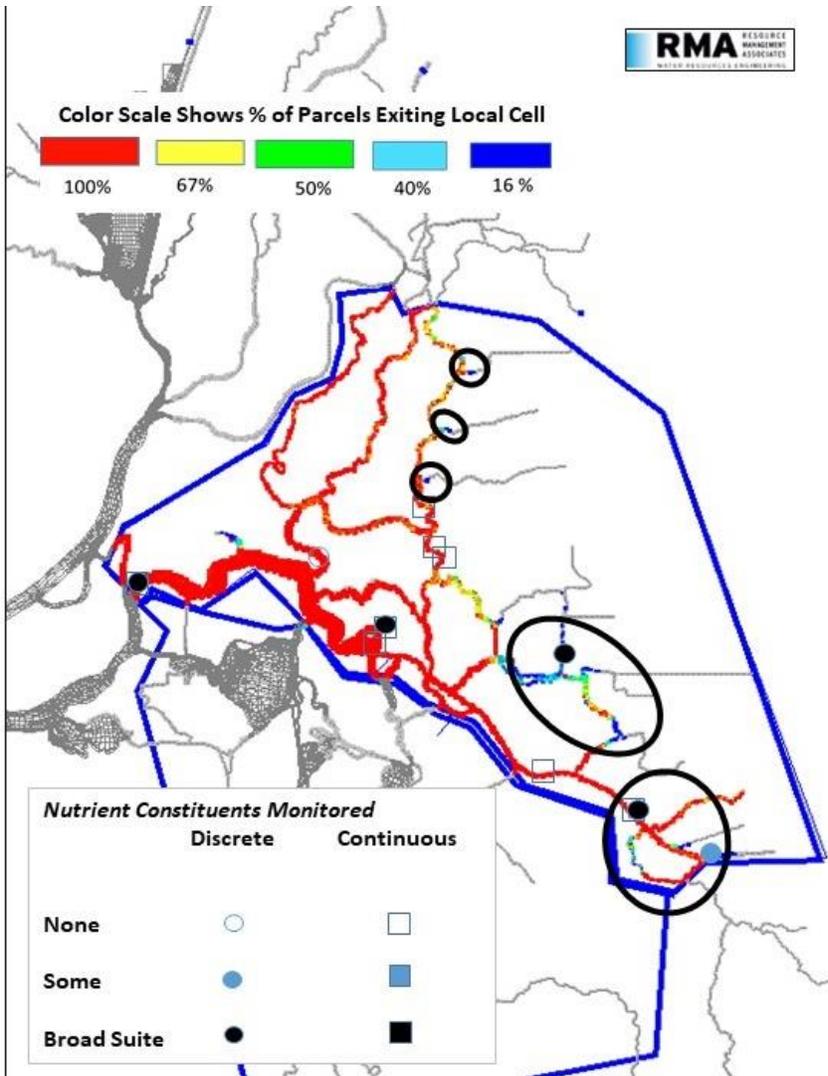


Figure 27. North Central Delta water fate simulation, low flow period. A total of 150,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of the simulation. Simulation time span: September 01, 2008, 00:15 to September 28, 2008, 23:45. The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

South Central Delta

Several different fate simulations were run for the South Central Delta. The water fluxes in this subregion are highly dependent on the water pumping rates for exported water. The type of water year (e.g., low flow or high flow) has less of an effect on conditions. Figure 28 shows the fate simulation for an average flow condition with water withdrawals of approximately 10,000 cfs. Water that is pumped from the subregion is considered to have exited the Delta for the purposes of the residence time calculation. In this case, 66% of the particles have residence time of 0-5 days. The spatial distribution of residence times plotted on Figure 28 shows only a few

small areas with longer residence times. Due to the sensitivity of the flow dynamics to water pumping rates, the simulation presented in Figure 28 may not be representative of typical conditions. Regardless, the results indicate a relatively homogeneous subregion with short residence time when there are moderate water exports.

Implications for monitoring. There are two EMP monitoring stations in this subregion already. Given the apparent homogeneity of the region illustrated by the fate simulations, these two stations should be sufficient. However, it is difficult to make broad inferences about conditions in this subregion because it is so heavily influenced by water management. Fortunately, one of the planned cruise tracks of the USGS high-frequency cross-Delta monitoring project funded by the Delta RMP will be focusing on this region. These data will help to identify any hotspots of nutrient transformation.

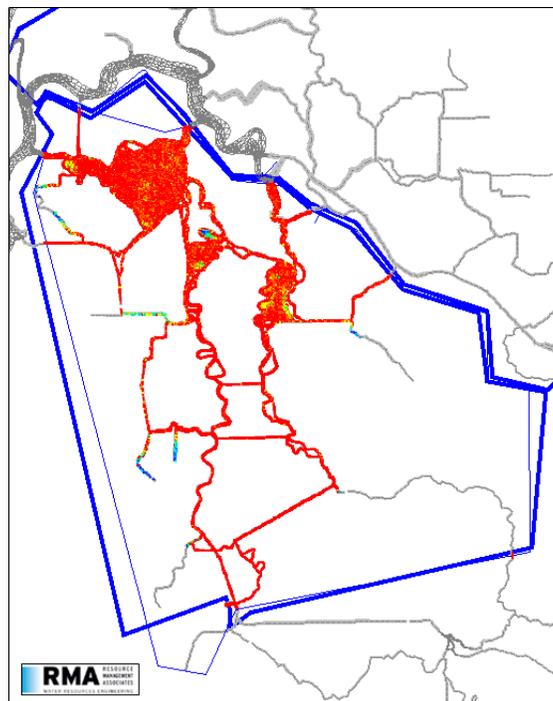


Figure 28. South Central Delta water fate simulation. Average inflow scenario (September 2010) and combined water exports of 10,403 cfs. A total of 150,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of the simulation. Simulation time spans: September 01, 2008, 00:15 to September 28, 2008, 23:45 (low-flow simulation); September 01, 2010, 00:15 to September 28, 2010, 23:45 (average-inflow simulation). The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

South Delta

Residence times in the South Delta appear to be relatively short overall (Figure 29) but there are some potential high residence areas with source water mixing along the Old River. Results for the fate simulations show that 16% and 19% of particles remain in the subregion after 28 days in the low flow and average flow period, respectively. Potential high-residence-time areas include the Old River in the Tracy area, Tom Paine Slough, and Paradise Cut.

Implications for monitoring

Some areas in the South Delta should be further explored with high-frequency mapping as potential long retention time areas and “hot spots”; including the Old River in the Tracy area, Tom Paine Slough, and Paradise Cut.

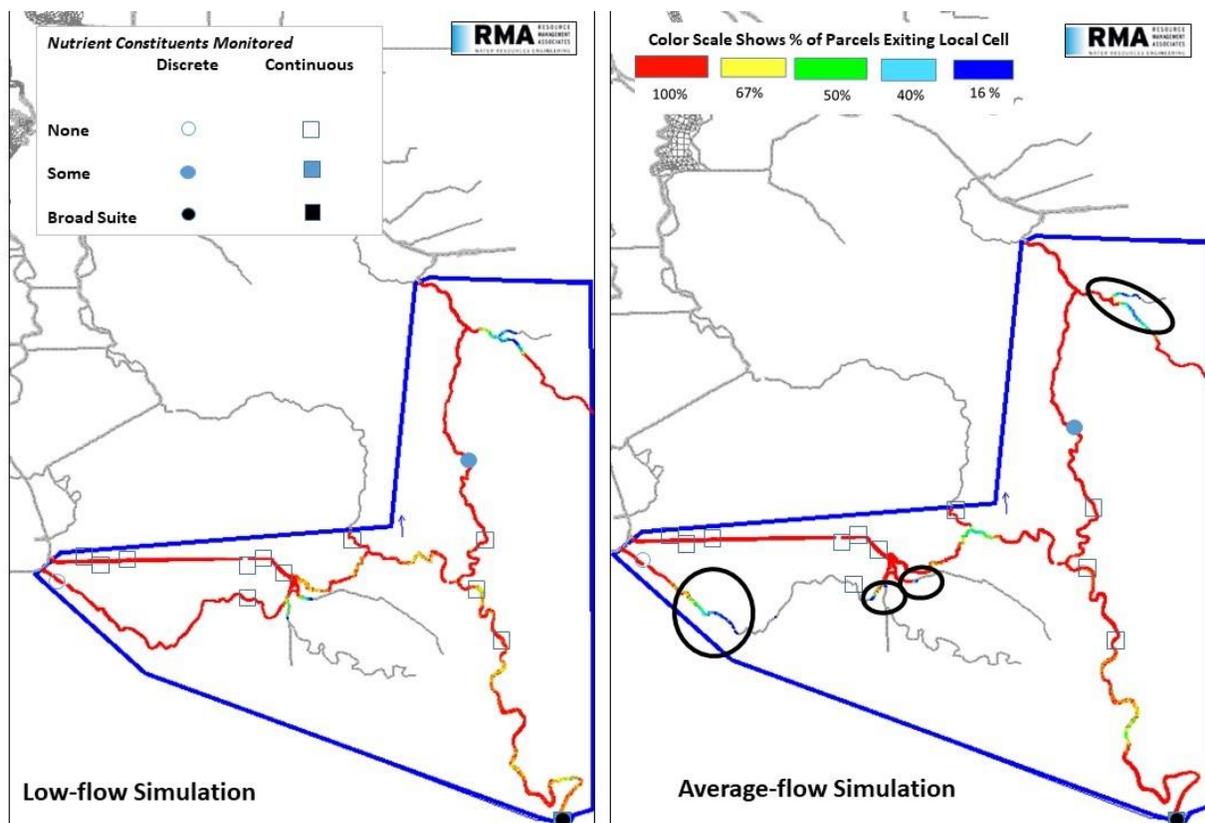


Figure 29. South Delta water fate simulation, low flow and average flow period. A total of 150,000 parcels was uniformly distributed across the subregion (“local cell”) at the beginning of each simulation. Simulation time spans: September 01, 2008, 00:15 to September 28, 2008, 23:45 (low-flow simulation); September 01, 2010, 00:15 to September 28, 2010, 23:45 (average-inflow simulation). The color coding represents the number of parcels exiting the subregion. (Gray waterbodies within subarea model boundary: no particles exiting subregion during the simulation period).

Age and Exposure Time Analysis/Source Water Characteristics

Table 5 summarizes the results of a water age and exposure analysis. The analysis addresses the questions:

1. How long does water from different sources typically spend in each of the subregions?
2. How “young” or “old” is the water?

Table 5 reveals that water from most sources typically spends less than 5 days in most subregions. Table 5 also reveals that “aged” Sacramento River occurs in downstream subregions such as the Confluence, Suisun Bay, and the Central Delta (Figure 30), where it mingles with mostly “younger” water from other sources. The oldest Sacramento River water occurs in the Central Delta (aged 25-28 days), where it mingles with younger water from other sources. Sacramento River water is the only water source that is at the same time significant in magnitude and typically “aged” by the time it arrives in downstream regions. Most of the other water sources in most of the other subregions is less than 5 days old. Yolo Bypass water is also aged significantly by the time it arrives in the Confluence (15-20 days), but it is only a minor water source in this subregion (1% of total in average flow scenario).

Table 5. Source water characteristics summary: results for average flow simulation.

Subregion	Source Water	Percent of Total (Average Flow Conditions)	Typical Age (days)	Typical Time in Subregion (days)	Comments
Sacramento	SAC	99	<5	<5	A small fraction (<1%) of Sacramento source water remains in Sutter Slough for up to 28 days.
	SRWWTP	1	*	*	
North Delta	AG	6	*	*	Small fractions (<1%) of older (>25 days) Sacramento River water and Yolo Bypass water mix in Liberty Island, the upper Cache slough, Lindsey Slough, and the Sacramento Deep Water Ship Channel, and are spending more than 15 days in this region.
	SAC	91	0-5	0-5	
	SRWWTP	1	*	*	
	YOLO	1	0-5	0-5	
Confluence	AG	3	*	*	The Confluence is a region with relatively short residence times, dominated by Sacramento River water aged 10-15 days.
	MTZ	9	0-5	0-5	
	SAC	86	10-15	0-5	
	WWTP	1	*	*	
	YOLO	1	15-20	0-5	
Suisun Bay	AG	1	*	*	The source water composition in Suisun Bay is typically $\frac{2}{3}$ Bay water and $\frac{1}{3}$ Sacramento River water. Older Sacramento water is scattered across the entire subregion, and mixes with Bay water and other minor sources.
	MTZ	66	0-5	0-5	
	SAC	32	15-20	0-5	
	WWTP	1	*	*	
Eastside	AG	2	*	*	A small fraction (<1%) of Eastside source water remains in lower reaches of tributaries and backwater sloughs near the Delta Cross Channel. Mixing with young Sacramento source water occurs in these areas.
	EAST	26	0-5	0-5	
	SAC	71	0-5	0-5	
	SRWWTP	1	*	*	
Central Delta	AG	6	*	*	Most of the Sacramento source water in the Central Delta is older than 25 days and has spent more than 25 days within the Central Delta model domain.
	EAST	2	0-5	0-5	
	MTZ	1	*	*	
	SAC	77	25-28	25-28	
	SJR	13	0-5	0-5	
	WWTP	2	*	*	
North Central Delta	AG	6	*	*	Sacramento source water older than 25 days resides in backwaters of the North Central Delta, where it mixes with younger water from other sources.
	EAST	2	*	*	
	MTZ	1	*	*	
	SAC	70	*	*	
	SJR	19	*	*	
	WWTP	2	*	*	
South Central Delta	AG	5	*	*	Sacramento source water older than 25 days resides in large areas of the South Central Delta and mixes with younger water from other sources
	EAST	1	*	*	
	MTZ	2	*	*	
	SAC	86	*	*	
	SJR	5	*	*	
	WWTP	2	*	*	

Subregion	Source Water	Percent of Total (Average Flow Conditions)	Typical Age (days)	Typical Time in Subregion (days)	Comments
South Delta	AG	5	*	*	In average flow conditions, 76% of the water in the South Delta is "young" San Joaquin River source water (<5 days old) that exits the region fast (in <5 days).

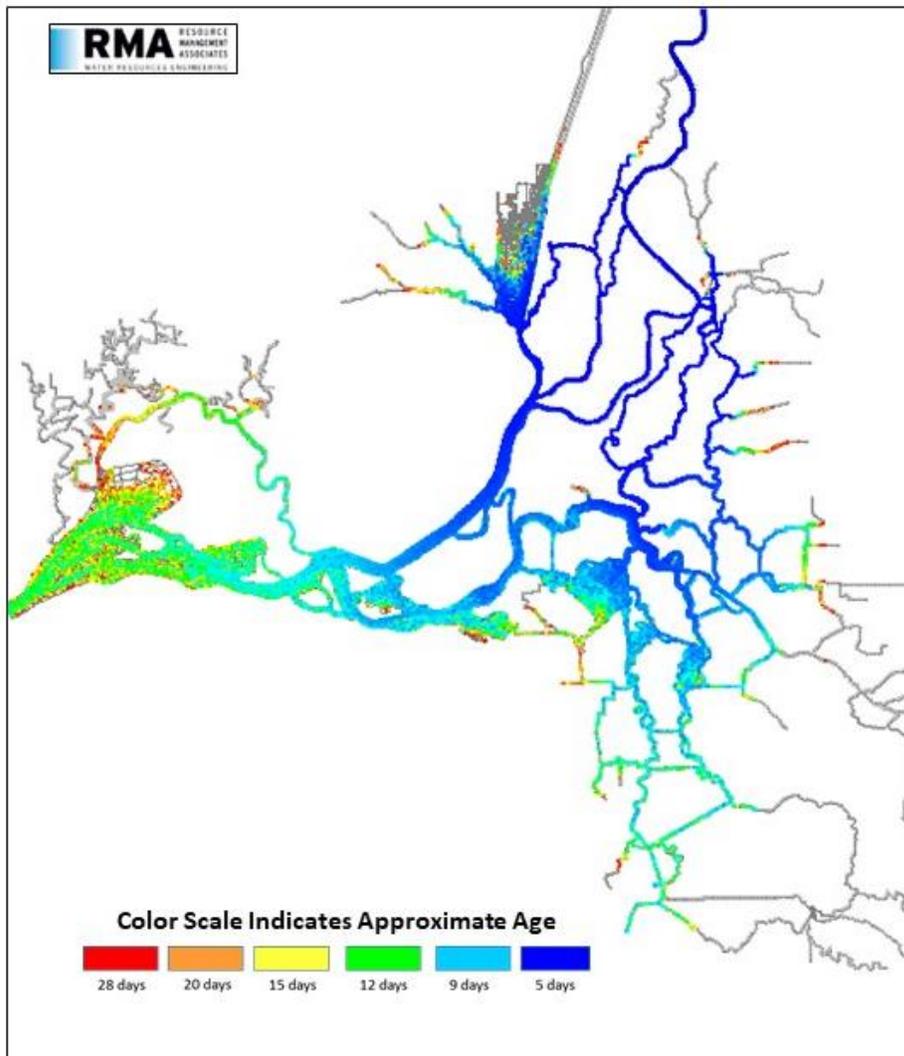


Figure 30. Water age simulation for Sacramento River source water, average flow scenario. Fifty parcels were inserted at the Sacramento model inflow boundary every 15 minutes for the entire simulation time span (September 1, 2008, 0:15 to September 28, 2008, 23:45). (Gray-colored waterbodies = Sacramento source water has not reached these areas during the simulation span).

Synthesis and Recommendations for Monitoring

The purpose of this report was to use hydrodynamic model outputs to refine recommendations for water quality monitoring. The premise was that source waters and residence times can serve as a proxy for water quality. Using existing hydrodynamic models that are highly resolved in space and time was a cost-effective way to get information about likely spatial and temporal variability in water quality.

The major findings from this report fall into three categories:

- The subregions that are being used to divide the update for status and trends monitoring need to be redrawn to better reflect the mixtures of source waters.
- Long-term water quality stations are needed in the North Delta, Eastside, and South Delta subregions. The modeling outputs helped to pinpoint the best locations in these regions to monitor.
- Locations for high-frequency water quality mapping were identified. Long residence times in these areas indicate the potential for nutrient transformation hotspots.

Recommendation #1: The subregions used by the Delta RMP for status and trends monitoring should be redrawn to better reflect the mixtures of source waters.

Relatively homogeneous regions where source water composition is similar between locations include the Sacramento River, North Delta, Confluence, Suisun Bay, Eastside (Mokelumne and Cosumnes Rivers), and the South Central Delta. In the Sacramento River subregion, water sources other than the Sacramento River are trivial in terms of their volumetric contributions and there is little variability overall. In the North Delta, Confluence, Suisun Bay, the Eastside, and the South Central Delta, source water composition is similar across most locations, but the relative composition of source water shows substantial spatial, seasonal, and interannual variation. Sacramento River is the dominant water source in most subregions and a significant source in all subregions.

Contributions from additional sources vary seasonally and along spatial gradients. In the Eastside subregion, water source composition is largely controlled by the operation of the Delta Cross Channel (DCC) gates and either the Sacramento River or the Eastside tributaries are the dominant water source. Suisun Bay is dominated by tidal exchange.

Heterogeneous subregions with more variability in source water composition between stations include the South Delta and the North Central Delta. The San Joaquin River is the dominant water source in the South Delta. The contributions from other sources to the South Delta varies along gradients, seasonally, and interannually. For example, the relative source water contribution of the San Joaquin River ranges from 57% in drought conditions (August 2009) to 100% in spring runoff conditions in a wet year (May 2006).

The volumetric results indicate that splitting the North Central subregion apart and merging the parts with other subregions would improve the alignment of subregional boundaries with different water source influences. The split portions would be merged with the South Central Delta, South Delta, and Eastside subregions and result in expanded Central Delta, San Joaquin River, and Northeast Delta subregions (Figure 16).

Recommendation #2: Long-term water quality stations are needed in the North Delta, Eastside, and South Delta subregions.

The modeling outputs helped to pinpoint the best locations in these regions to monitor. Results suggest that existing monitoring stations adequately capture spatial variability in certain subregions. However, water quality varies a great deal in other subregions and the range of conditions cannot be captured at a single monitoring location.

The analysis also identified several redundancies, for example, in the South Central Delta and Suisun Bay. Subregions with adequate coverage include the Sacramento River, the Confluence, the South Central Delta, and Suisun Bay. The North Delta and the Eastside are currently not monitored and therefore are data gaps. These gaps have been previously identified in the 2016 Delta RMP Nutrient Monitoring Planning Workshop (Delta RMP 2016).

At least one permanent monitoring station is recommended for comparing nutrient trends in the North Delta to those in other subregions with different source water composition, and ideally two to better capture the range of hydrological conditions. The stations could be established by ensuring long-term funding for current USGS nutrient sensor stations and adding co-located discrete water sampling. Two stations are recommended in the Eastside subregion, because there are distinctly different relative contributions of source waters upstream and downstream of the Delta Cross Channel. One additional station is recommended in the South Delta subregion. The South Delta has also been previously identified as a data gap (Delta RMP 2016). The recommended monitoring stations to be added are shown in **Figure 31**.

Recommendation #3: Areas with a long-residence time and source water mixing are potential for nutrient transformation hotspots. High-frequency water quality mapping of these areas has the potential to increase our understanding of sources and sinks of nutrients in the Delta.

Subregions with a high degree of variability in residence time and source water mixing include the Eastside, the North Delta, and the North Central Delta. Therefore, these areas are the most likely to contain pockets of high-residence-time waters composed of different sources, such as backwater sloughs. There are also some potential high-residence-time areas with source water mixing in the South Delta; including the Old River in the Tracy area, Tom Paine Slough, and Paradise Cut. These areas could be targeted with high-frequency water quality mapping to evaluate potential transformation zones (**Figures 32**), as recommended at the 2016 Delta RMP Nutrient Monitoring Planning Workshop (Delta RMP 2016).

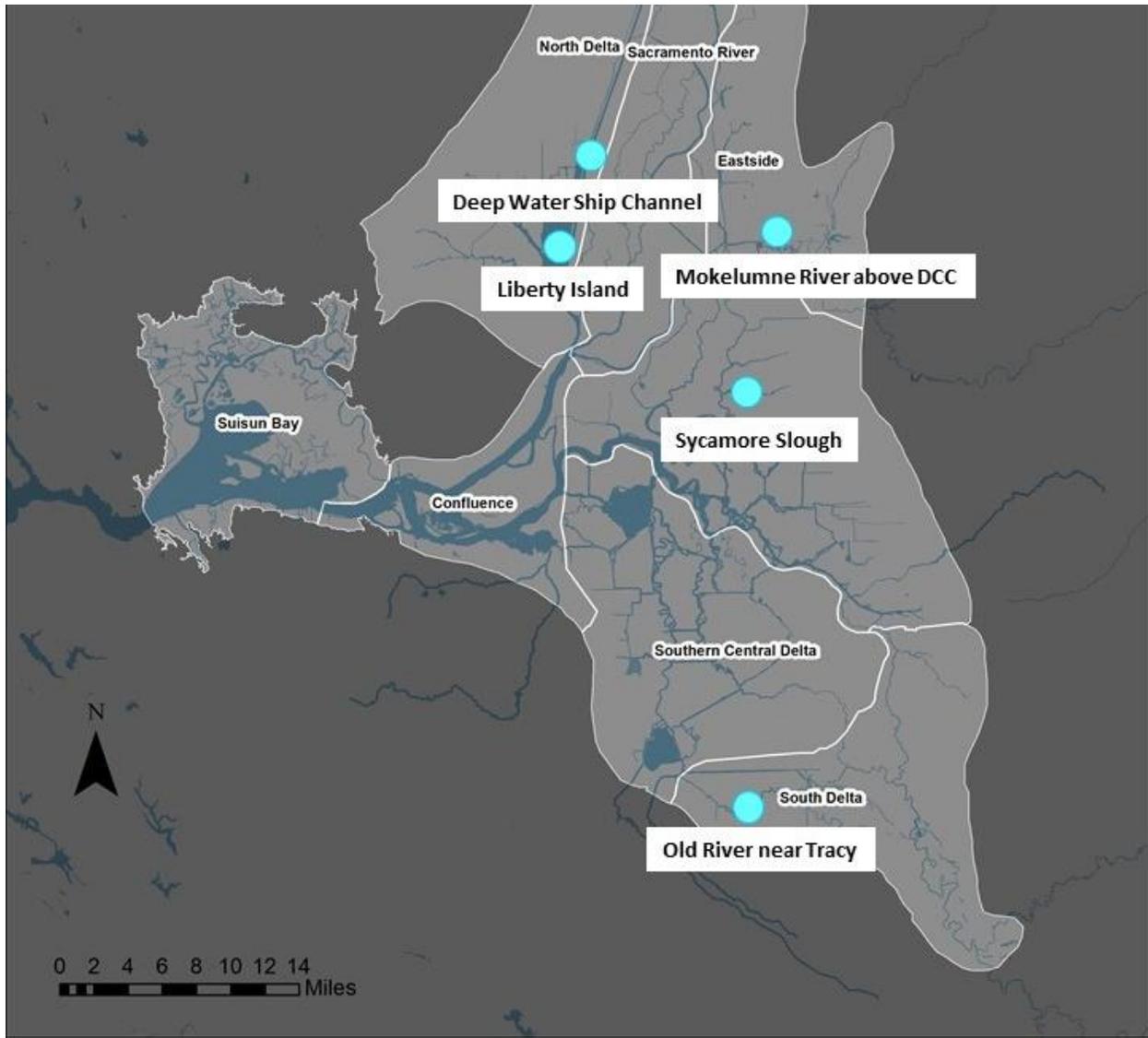


Figure 31. Recommended water quality monitoring stations to be added for nutrients. The proposed long-term water quality monitoring stations in the North Delta and in the South Delta are located at existing USGS and DWR sensor sites. They could be established by ensuring continued funding for sensors, co-located with discrete sampling.

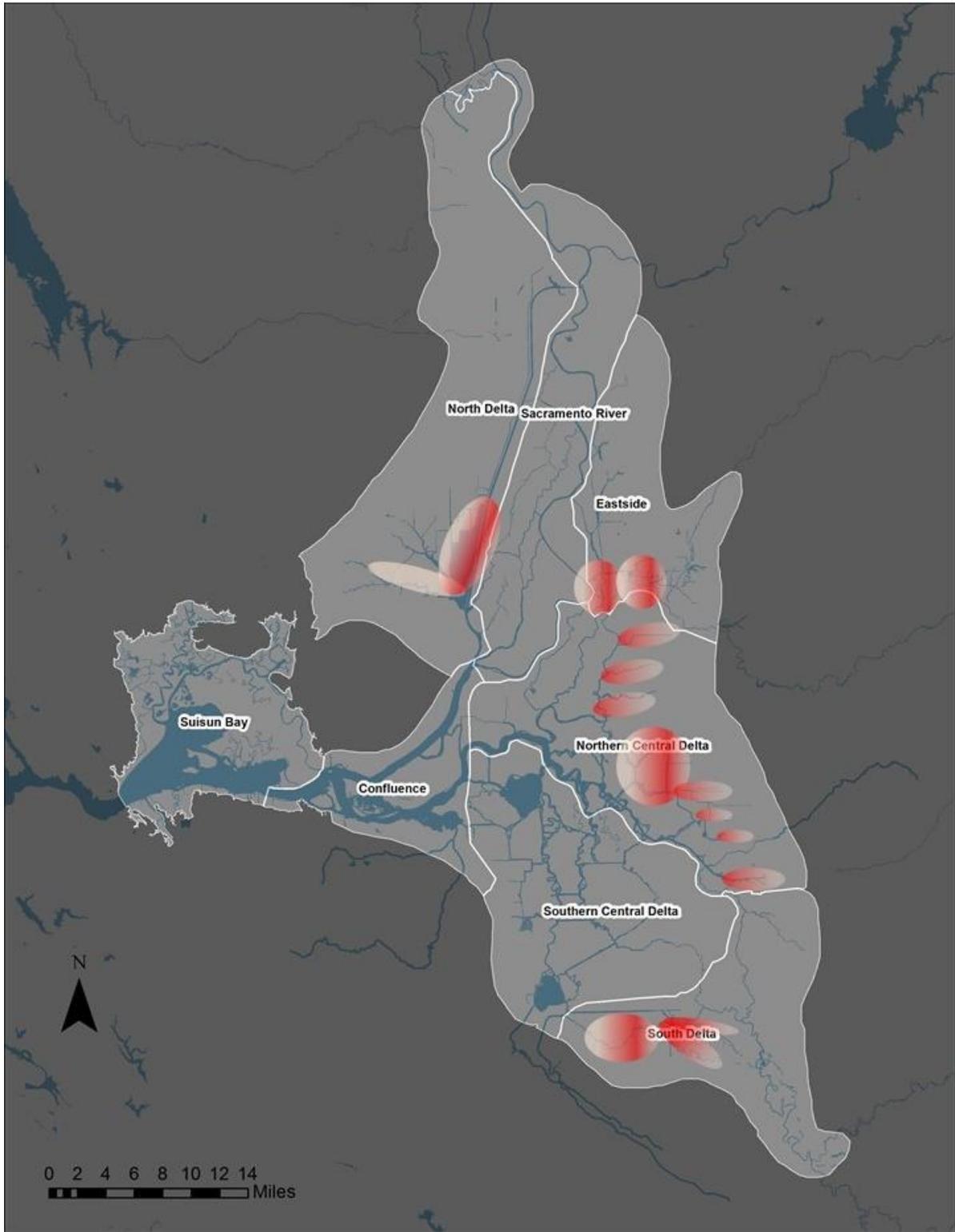


Figure 32. Areas in the North Delta, Northeast Delta, and South Delta, where high-frequency water quality monitoring is recommended to investigate transformation hotspots.

References

- Anderson, J. 2002. DSM2 Fingerprinting Methodology. Anderson, Jamie. "DSM2 Fingerprinting Methodology." In *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh*, by P. Hutton and M. Mierzwa. Sacramento, California: California Department of Water Resources, Bay-Delta Office, 2002.
<http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/delta/reports/annrpt/2002/2002Ch14.pdf>
- Delta RMP. 2016. Summary of existing nutrient monitoring programs, data gaps, and potential Delta RMP "no regrets" monitoring activities. Background report for the *Delta Nutrient Planning Workshop*, October 2016. Aquatic Science Center, Richmond, CA.
http://www.waterboards.ca.gov/centralvalley/water_issues/delta_water_quality/delta_regional_monitoring/studies_reports/drmp_workshop_rpt_20161017.pdf
- Guerin, M. 2006. "Appendix 6: Modeling the Fate and Transport of Nutrients Using DSM2: Calibration/Validation Report." In *Characterizing and quantifying nutrient sources, sinks and transformations in the Delta: Synthesis, modeling, and recommendations for monitoring*. San Francisco Estuary Institute, Richmond, CA.
- Jabusch T., P. Bresnahan, P. Trowbridge, A. Wong, M. Salomon, and Senn D. 2016. Summary and Evaluation of Delta Subregions for Nutrient Monitoring and Assessment. San Francisco Estuary Institute, Richmond, CA. <http://www.sfei.org/documents/summary-and-evaluation-delta-subregions-nutrient-monitoring-and-assessment>
- McClain M, Boyer EW, Dent CL, Gergel SE, Grimm NB, Groffman PM, Hart SC, Harvey JW, Johnston CA, Mayorga E, McDowell WH, Pinay G. 2003. "Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems." *Ecosystems* 6(4): 301–312.
- Novick E., R. Holleman, T. Jabusch, J. Sun, P. Trowbridge, D. Senn, M. Guerin, C. Kendall, M. Young, and S. Peek. 2015. *Characterizing and quantifying nutrient sources, sinks and transformations in the Delta: Synthesis, modeling, and recommendations for monitoring*. San Francisco Estuary Institute, Richmond, CA. <http://www.sfei.org/documents/characterizing-and-quantifying-nutrient-sources-sinks-and-transformations-delta-synthesis>
- RMA. 2005. *Flooded Islands Pre-feasibility Study, RMA Delta Model Calibration Report*. Resource Management Associates, Davis, CA.
- Siegel S., M. Carter. 2012. "Appendix A: Alternatives Screening Criteria Report." In *Prospect Island – Phase I Screening-Level Modeling Results Synthesis*. Siegel Environmental, San Rafael, CA.

Key to Data Files

Links to files provided under “Supplemental materials” online at sfei.org.

Figure or Table in Report	Description	Data Files or Original Source Documents	File Names
Table 1. Summary table of the representative time periods that were selected for the analysis.	Estimated average inflows and outflows in cfs	Background Materials for December 5, 2016, Nutrient Subcommittee Conference Call	RMA model output examples.pdf
Table 2. Average source water composition of Delta subregions in average flow conditions.	Source water (% of total)	Volumetric output, regional average	CENTRAL.REGION.xls: North Central regional average was calculated from stations D16, D26, MD10, MD6, MD7A, P8, RMKL005, and RSAN052; South Central regional average was calculated from stations C9, D19, D28A, P10A, RMIDO15, and ROLD034. CONFLUENCE.REGION.xls, EASTSIDE.REGION.xls, N.DELTA.REGION.xls, S.DELTA.REGION.xls, SACRAMENTO.R.REGION.xls, SUISUN.BAY.REGION.xls: 'AVERAGE' worksheet in each file
Table 3. Median estimated residence time of water in each subregion in different flow scenarios	Typical residence time (interval in days)	Fate maps, % particles in range	June2011.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35 FateMapsSouthCentral.SWPEExport Effect Removed.pptx: Slides 1-3 Sep2008.Results.To.SFEI.03.31.2017.pptx: Slides 25-30, 33 Sep2010.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35
Table 4. Residence time summary statistics.	Residence time range (% particles in range)	Fate maps, % particles in range	June2011.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35 NoSWP.FateMapsSouthCentral.pptx: Slides 1-3 Sep2008.Results.To.SFEI.03.31.2017.pptx: Slides 25-30, 33 Sep2010.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35
Table 6. Source water characteristics summary: results for average flow simulation.	Percent of total (average flow conditions)	Fate maps, % particles in range	CENTRAL.REGION.xls: North Central regional average was calculated from stations D16, D26, MD10, MD6, MD7A, P8, RMKL005, and RSAN052; South Central regional average was

Figure or Table in Report	Description	Data Files or Original Source Documents	File Names
	Typical age (days) and typical time in subregion (days)		<p>calculated from stations C9, D19, D28A, P10A, RMIDO15, and ROLD034; Central Delta results from 'AVERAGE' worksheet CONFLUENCE.REGION.xls, EASTSIDE.REGION.xls, N.DELTA.REGION.xls, S.DELTA.REGION.xls, SACRAMENTO.R.REGION.xls, SUISUN.BAY.REGION.xls: 'AVERAGE' worksheet in each file</p> <p>June2011.Results.To.SFEI.03.31.17.pptx: Slides 5-33, 35 FateMapsSouthCentral.SWPEExport Effect Removed.pptx: Slides 1-3 Sep2008.Results.To.SFEI.03.31.2017.pptx: Slides 5-30, 33 Sep2010.Results.To.SFEI.03.31.17.pptx: Slides 5-33, 35</p>
Figure 1. DSM2 volumetric fingerprints, comparison of regional averages.	Source water (% of total)	Volumetric output, regional average	<p>CENTRAL.REGION.xls: North Central regional average was calculated from stations D16, D26, MD10, MD6, MD7A, P8, RMKL005, and RSAN052; South Central regional average was calculated from stations C9, D19, D28A, P10A, RMIDO15, and ROLD034. CONFLUENCE.REGION.xls, EASTSIDE.REGION.xls, N.DELTA.REGION.xls, S.DELTA.REGION.xls, SACRAMENTO.R.REGION.xls, SUISUN.BAY.REGION.xls: 'AVERAGE' worksheet in each file</p>
Figure 3. DSM2 volumetric fingerprints at representative stations in the Sacramento River subregion.	Source water (% of total)	Volumetric output	<p>SACRAMENTO.R.REGION.xls Worksheets: 'RSAC155' (Freeport), 'C3' (Hood), 'Channel428_L' (Ida Island)</p>
Figure 5. DSM2 volumetric fingerprints for locations in the North Delta subregion.	Source water (% of total)	Volumetric output	<p>N.DELTA.REGION.xls Worksheets: 'SLBAR002' (Barker Slough), 'SLCCH016' (Cache Slough near Hastings Tract), 'CacheRyer' (Cache Slough at Ryer Island), Sac Deep Watr Shp Chl</p>

Figure or Table in Report	Description	Data Files or Original Source Documents	File Names
			(Sacramento Deep Water Ship Channel), Liberty Island (LibertyIsland)
Figure 7. DSM2 volumetric fingerprints for locations in the Confluence subregion.	Source water (% of total)	Volumetric output	CONFLUENCE.REGION.xls Worksheets: 'D24' (Sacramento River at Rio Vista), 'ThreeMileSlough' (Sacramento River at 3-Mile Slough), 'D22' (Sacramento River at Emmaton), 'D4' (Sacramento River above Point Sacramento), 'D15' (San Joaquin River at Jersey Point), 'D14A' (Big Break), 'D12' (San Joaquin River at Antioch Ship Channel), 'D11' (Sherman Lake)
Figure 9. DSM2 volumetric fingerprints for locations in the Suisun Bay subregion.	Source water (% of total)	Volumetric output	SUISUN.BAY.REGION.xls Worksheets: 'D10' (Sacramento River at Chipps Island), 'D9' (Honker Bay), 'D8' (Suisun Bay off Middle Point), 'D2' (Suisun Bay near Preston Point), 'D6' (Martinez), 'SLMZU025' (Montezuma Slough near Molena), 'SLMZU011' (Montezuma Slough near Beldon's Landing), 'NZU032' (Montezuma Slough near Grizzly Bay), 'S42' (Suisun Slough), 'D7' (Grizzly Bay)
Figure 11. Volumetric fingerprints at representative stations in the Eastside subregion.	Source water (% of total)	Volumetric output	EASTSIDE.REGION.xls Worksheets: 'DCC' (Delta Cross Channel), 'RMKL019' (Mokelumne River at Snodgrass Slough), 'P2' (Mokelumne River at Franklin Road Bridge), 'RMKL024' (Mokelumne River, South Fork, near New Hope)
Figure 13. DSM2 volumetric fingerprints, comparison of Sycamore Slough with the regional average in the Eastside subregion.	Source water (% of total)	Volumetric output	EASTSIDE.REGION.xls Worksheet: 'AVERAGE' CENTRAL.REGION.xls Worksheet: 'MD6' (Sycamore Slough)
Figure 14. DSM2 volumetric fingerprints for locations in the North Central Delta subregion.	Source water (% of total)	Volumetric output	CENTRAL.REGION.xls Worksheets: 'D16' (San Joaquin River at Twitchell Island), 'D26' (San Joaquin River at Potato Point), 'RSAN052' (San Joaquin River at Shima Bend), 'P8' (San Joaquin River at Buckley Cove), RMKL005 (Mokelumne River at Georgiana Slough), 'MD6' (Sycamore Slough), 'MD7A' (Mokelumne River, South Fork, near Sycamore Slough), 'MD10' (Disappointment Slough).

Figure or Table in Report	Description	Data Files or Original Source Documents	File Names
Figure 17. DSM2 volumetric fingerprints for locations in the South Central Delta subregion.	Source water (% of total)	Volumetric output	CENTRAL.REGION.xls: Worksheets: 'D19' (Frank's Tract), 'D28A' (Old River at Rancho del Rio), 'ROLD034' (Old River near Byron), 'RMIDO15' (Middle River at Middle River), 'P10A' (Middle River at Union Point), 'C9' (West Canal at Clifton Court Intake).
Figure 19. DSM2 volumetric fingerprints at representative stations in the South Delta subregion.	Source water (% of total)	Volumetric output	S.DELTA.REGION.xls: Worksheets: 'OldRatMiddleR' (Old River at Middle River), 'P12' (Old River at Tracy Road Bridge), 'ROLD047' (Old River downstream of Mountain House Creek), 'CHDMC006' (Delta-Mendota Canal), 'C10' (San Joaquin River at Vernalis), 'C7' (San Joaquin River at Mossdale Bridge), 'RSAN072' (San Joaquin River at Bowman Road), 'CHGRL009' (Grant Line Canal at Tracy Road).
Figure 21. Median estimated residence time of water in each subregion in different flow scenarios	Typical residence time (days)	Fate maps, % particles in range	June2011.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35 FateMapsSouthCentral.SWPEExport Effect Removed.pptx: Slides 1-3 Sep2008.Results.To.SFEI.03.31.2017.pptx: Slides 25-30, 33 Sep2010.Results.To.SFEI.03.31.17.pptx: Slides 28-33, 35
Figure 22. Sacramento River water fate simulation, low flow period	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 25
Figure 23. North Delta water fate simulation, low flow and high-flow simulations	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 26 June2011.Results.To.SFEI.03.31.17.pptx: Slide 29
Figure 24. Confluence water fate simulation, low flow simulation	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 27
Figure 25. Suisun Bay water fate simulation	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 28 June2011.Results.To.SFEI.03.31.17.pptx: Slide 31

Figure or Table in Report	Description	Data Files or Original Source Documents	File Names
Figure 33. Eastside water fate simulation, low flow period	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 29
Figure 27. North Central Delta water fate simulation, low flow period	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 33
Figure 28. South Central Delta water fate simulation	Percent of parcels exiting local cell	Fate map, % particles in range	FateMapsSouthCentral.SWPEExport Effect Removed.pptx: Slide 2
Figure 29. South Delta water fate simulation, low flow and average flow period.	Percent of parcels exiting local cell	Fate map, % particles in range	Sep2008.Results.To.SFEI.03.31.2017.pptx: Slide 30 Sep2010.Results.To.SFEI.03.31.17.pptx: Slide 33
Figure 30. Water age simulation for Sacramento River source water, average flow scenario	Approximate age and location of water parcels at the end of the simulation (days)	Age map	Sep2010.Results.To.SFEI.03.31.17.pptx: Slide 5