An Historical Perspective of Nutrients and Dissolved Oxygen: Changes in Wastewater Loads and Water Quality in Lower South San Francisco Bay, 1957-2013

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The San José-Santa Clara Regional Wastewater Facility (Facility), located in the Lower South Bay (LSB), is the largest advanced wastewater treatment plant in San Francisco Bay. From 1957 to 2013, the Facility added a series of expansions and upgrades that increased treatment capacity and improved the quality of treated effluent.

Using long term data sets of BOD, DO, TSS, NH_4^+, NO_3^-, and PO_4 in wastewater effluent and LSB surface water, this study addressed two primary questions: (1) To what extent have treatment plant expansions and upgrades during the past six decades resulted in improvements to Facility effluent quality? (2) How and to what extent have the changes in the Facility effluent translated into changes in the water quality of the LSB? Five hypotheses were formulated to evaluate long-term trends and correlations regarding wastewater loads and concentrations of BOD, TSS, NH_4^+, NO_3^-, and PO_4 in the LSB on spatial, seasonal, and annual scales. R software was used to analyze the data.

All five hypotheses were confirmed by the data, with a few qualifications that can be readily explained. The first major finding is that, in spite of substantial increases in population, both influent and effluent flow to the Bay decreased in the past decade. A second major finding is that the data show major load reductions in BOD, TSS, and nutrients corresponding to Facility improvements. Third, anoxia and hypoxia were virtually eliminated following the Facility's upgrade to nitrification, significantly improving DO concentrations in the LSB. Fourth, LSB nutrient concentrations showed significant decreases corresponding to capital improvements of the Facility.

Keywords: Wastewater, BOD, TSS, Nutrients, Lower South Bay, Dissolved Oxygen
Session Title: Trends in Water Quality
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Trends and Environmental Implications of X_2 in Northern San Francisco Bay, 1988-2012

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The need for a sensitive habitat indicator to manage the threatened biological resources in northern San Francisco Bay first motivated the interest in X_2, the 2 psu bottom salinity position, two decades ago. While early studies quantified the relationship between X_2, freshwater flow rate (Q), and estuarine resources, there has not been an updated and comprehensive review of X_2 using real-time data since 1993. It is important from a water users' perspective that the connection between salinity and freshwater flow rate be as accurately known as possible. Using water quality data made available by the U.S. Geological Survey, U.S. Bureau of Reclamation, and California Department of Water Resources, we were able to: 1) identify and address irregularities from previous analyses; 2) determine the temporal and spatial evolution of X_2 in the upper estuary from 1988 to 2012; 3) update the power-law relationship between X_2 and Q by including more extreme flow events; and 4) explore the implications of X_2 on turbidity levels, stratification, and phytoplankton growth due to light limitations. Comparison with historical data shows that the mean decadal X_2 position has undergone significant changes. Maximum turbidity levels also appear to be positively linked to the nose of the salinity intrusion, but the relationship between X_2 and chlorophyll a is less distinct due to strong biological controls. As the low-salinity zone in San Francisco Bay continues to respond and adjust to changes in physical and biological drivers, the expected challenges to proper management of salinity-sensitive habitats and organisms will require even more diligent monitoring and synthesis of the collected data.

Keywords: X2, salinity, freshwater flow, sediment, chlorophyll *a*
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The Effect, or Lack Thereof, of Sediment Supply and Deposition on Subsequent Fall Turbidity in Suisun Bay

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During fall, delta smelt occupy the low salinity zone (salinity 1-6) of the San Francisco Estuary which is located (X2) in eastern Suisun Bay or landward at the river confluence. Delta smelt favor more turbid water and turbidity is primarily a function of suspended-sediment concentration (SSC) in the estuary. Mean September and October (fall) SSC at the landward boundary of Suisun Bay (Mallard Island) decreased by about one-half from 1994 to 2011 due to a limited erodible sediment supply. In this work, the hypothesis that wet years deliver and deposit sediment, increasing the erodible sediment pool and subsequent fall SSC, is explored. Suspended-sediment flux at the landward and seaward (Benicia) boundaries of Suisun Bay for water years 1997, 1998, and 2002-2012 were estimated using surrogate relations dependent on Delta outflow, SSC, and the longitudinal salinity difference across Suisun Bay (ΔS). There were three groups of water years: 1) large inflow, large sediment supply, net erosion, seaward X2 in fall, small fall ΔS, and large fall SSC compared to the trend line (1998 and 2011); 2) large inflow, large sediment supply, net erosion, landward X2 in fall, large fall ΔS, and small fall SSC compared to the trend line (1997 and 2006); and 3) small freshwater flow, small sediment supply, net deposition, landward fall X2, large fall ΔS, and fall SSC near the trend line (2002-2005 and 2007-2010). Neither sediment supply nor deposition affected fall SSC. The salinity difference was relatively low in turbid falls, indicating that gravitational circulation in Suisun Bay and associated sediment trapping was not likely any stronger than less turbid falls. From 1994-2011, only 1998 and 2011 had seaward fall X2 and those were the only two water years with an anomalously large fall SSC. Thus, when fall X2 was in Suisun Bay, fall SSC was elevated.

Keywords: turbidity, Suisun Bay, sediment, habitat, delta smelt, suspended-sediment
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Status and Implications of Stormwater Quality Monitoring in the Cache Slough Watershed (2010-2014)

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Solano County Water Agency as part of the Cache Slough Watershed Group (CSWG) has implemented a watershed-wide wet-weather stormwater sampling program since 2010 to characterize water quality contaminants detected within the Cache Slough watershed by sampling tributary creeks during substantial storm events. The program builds on prior monitoring to inform watershed management while evaluating implications for proposed pelagic fish habitat restoration in Cache Slough, part of the Sacramento-San Joaquin Delta. Along with physical stressors, observed water quality toxicity in Cache Slough is a potential factor in declining native fish species including delta smelt (Werner et al. 2010). Sampling results indicate that TSS, bacteria, metals, nutrients, and pesticides continue to be primary constituent groups detected and that locations downstream of urbanized and agricultural areas typically exhibit lower water quality conditions than those in the upper watershed. The Upper Putah Creek location in relatively undeveloped conditions consistently exhibited the most favorable water quality conditions, whereas observed conditions at the Upper Ulatis Creek location in a suburban area were moderately impacted. Excluding the Upper Putah Creek location, bacteria detections also influenced by natural phenomena were consistently elevated. Pyrethroids and other pesticide detections observed throughout the watershed were generally poorly correlated with TSS data, and yielded lower, potentially diluted concentrations after intense rainfall. However, higher-intensity rainfall events yielded higher TSS and closely correlated metals concentrations. Observed TSS levels are associated with pollutants of concern but also provide turbid conditions favorable to delta smelt. Legacy pesticide detections decreased in favor of pyrethroids, the local dynamics of which require more research. Urbanized and agricultural areas in the contributing watershed greatly influence the variety and concentration of metals, pesticides, and nutrient detections. Findings indicate that careful management of urbanized and agricultural areas is imperative to overall Delta water quality and to sensitive biological receptors in Cache Slough.

Keywords: water quality, stormwater, pyrethroids, sediment, Cache Slough, sampling, toxicity, watershed
Session Title: Trends in Water Quality
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South San Francisco Bay: Status, Trends, and a 21st Century Baseline

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Our USGS research project has regularly measured water quality in South San Francisco Bay since 1978. We will describe a synthesis of this long-term data set to identify patterns of variability in water temperature, salinity, nutrients, suspended sediments and turbidity, dissolved oxygen, and phytoplankton biomass as chlorophyll *a*. The synthesis includes measures of water-quality changes over time, and uses simple models to identify potential drivers of those changes. The synthesis answers a set of fundamental questions, such as: (1) has South San Francisco Bay warmed in response to recent decades of global warming; (2) do signals of oceanic variability, such as the past decade of low dissolved oxygen in coastal waters, propagate into the Bay; (3) has the South Bay become more efficient at converting nutrients into phytoplankton biomass; (4) are stratification events more frequent and water transparency higher; how do these patterns influence changes in chlorophyll *a* trends? Our purpose is to assess status and trends of water quality across the South Bay system, and to establish a 21st century baseline from which we can measure future responses to climate change and human actions.

Keywords: water-quality, phytoplankton, long-term trends, global changes
Session Title: Trends in Water Quality
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Tracing Nitrate and Ammonium Dynamics within the San Joaquin-Sacramento River Confluence Region Using Stable Isotopes

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The stable isotopic composition of dissolved nitrate (δ^{15}N- and δ^{18}O-NO_3) and ammonium (δ^{15}N-NH_4) was measured in the lower San Joaquin River, the Sacramento River, and north San Francisco Bay during three separate trips in April 2010, October 2010, and April 2011 in order to trace differences in nitrogen sources and dominant biological processes throughout the region and between different seasons. In the San Francisco Bay and Delta, high concentrations of nitrate are transported from the San Joaquin River, while the Sacramento River contains elevated ammonium concentrations from wastewater treatment plant discharge. Concentrations and distributions of different nitrogen forms can influence algal growth rates and community compositions. δ^{15}N-NH_4 increased downstream in the Sacramento River, indicating nitrification, and creating a distinct difference between the δ^{15}N-NO_3 and δ^{15}N-NH_4 within the confluence region and north San Francisco Bay. A much more pronounced increase in δ^{15}N-NH_4 was observed in October in comparison to April, suggesting seasonal controls on the extent of nitrification. δ^{15}N-NO_3 of nitrate was consistently higher in the San Joaquin River in comparison to the Sacramento River and north San Francisco Bay, making it a strong tracer for San Joaquin-derived nitrate within the Delta. During all trips, δ^{15}N-NO_3 in the San Joaquin River channel decreased towards the confluence with the Sacramento River. Volumetric flow calculations from the DSM2 model, along with geochemical and water stable isotope data indicated that this shift was driven primarily by a change in water sources. The shift in δ^{15}N-NO_3 reflects higher contributions of Sacramento River water and nitrate, rather than spatial differences in biological nitrate cycling. The Delta is a highly complex region, and combining concentration and stable isotope measurements with hydrodynamic modeling provides insights into how nutrients from the two major rivers move and cycle through the Delta.

Keywords: nutrients, stable isotopes, nitrate, ammonium, Sacramento River, San Joaquin River
Session Title: Water Quality in Space and Time
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Salinity and Flow Variability in Suisun Bay during FLaSH

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Problem: The goal of this work is to how Suisun Bay "works" in the fall, particularly focusing how the salinity and velocity fields respond to variations in flow.

Approach
We deployed a set of 26 salinity loggers (CTDs), and 12 Acoustic Doppler Current Profilers (ADCPs) throughout Suisun Bay during the 2011-12 Fall Low Salinity Habitat Study (FlaSH) that logged data continuously from 11/17/11 to 1/9/12.

Results:
Our FLaSH hydrodynamic data provide a uniquely detailed view of the spatial and temporal variability of the salinity field in Suisun Bay, including stratification, as well as of tidal and sub tidal flows, including gravitational circulation. Firstly, our observations showed a significant difference in the X2 calculated using Dayflow and what was directly recorded by bottom CTDs. The overall time variability appears to be better predicted using USGS UVM data, although even then the transient associated with increasing X2 was much more abrupt and of longer duration in the observations than in predictions. Depth-averaged subtidal flows recorded by the ADCP at Chipps Island agree better with the UVM flows. Estimates of subtidal drag there are in balance with subtidal free surface pressure gradients associated, suggesting that ADCP-derived mean flows were likely closer to the real outflow rates than were Dayflow derived values. Additionally, there are pronounced north-south differences in salinity, with salinities being somewhat lower in the northern channels and perimeter habitats than in the main channel, behavior that may be due to freshwater coming from Montezuma Slough.
Conclusions/Relevance:
(1) During low flow periods Dayflow may not accurately represent Delta outflows to Suisun Bay affecting its utility as a metric of flow; (2) Salinities in shallow water habitats of Suisun Bay differ from salinities in the main channel such that calculations of LSZ habitat may differ from what is calculated assuming no North-South variation.

Keywords: hydrodynamics, salinity, tides, X2, Dayflow, habitat
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Real-Time Water Quality Mapping in the Cache Slough Complex: High Resolution Data across Space and Time

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Water-quality measurements collected over both fine temporal and spatial scales are needed to understand biogeochemical processes in hydrologically complex environments, such as the Sacramento-San Joaquin Delta, in order to adequately resolve sources and processes. Recently established real-time water-quality stations operated by the U.S. Geological Survey are providing temporally-rich data for fixed points in the Cache Slough complex. To complement these data, we collected spatially-intense data by using a boat configured with flow-through monitoring tools, enabling real-time mapping of water quality. Real-time mapping can spatially resolve, for example, different sources and sinks for nutrients and phytoplankton, such as agricultural drains, wastewater, and wetlands. We will present data collected over two sampling events in October 2013 and May 2014 across Liberty Island and its surrounding wetlands and sloughs using the boat-mounted in-situ sensor package. Nitrate, dissolved organic matter and chlorophyll were measured along with standard water-quality measurements (temperature, dissolved oxygen, pH, specific conductance, turbidity). Real-time mapping of water quality has the potential to provide valuable information about key processes occurring in dynamic systems, such as the Cache Slough complex, to better inform those making water-management decisions.

Keywords: real-time water quality mapping, nitrate, chlorophyll, dissolved organic matter
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Application of an Estuary Model to Quantify Factors Contributing to Low Dissolved Oxygen Conditions in the San Joaquin River Deep Water Ship Channel

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The Stockton Deep Water Ship Channel (DWSC), located in the San Joaquin River estuary, has had seasonal and episodic low dissolved oxygen (DO) concentrations for decades. The occurrence of low DO causes the assimilative capacity of the river to be exceeded, impacting ecosystem health and the quality of water supplies that are designated for various uses. To address this impairment, a DO total maximum daily load project was initiated to quantitatively identify the causes of low DO and develop restoration strategies. Here, a one-dimensional link-node model was used to simulate water quality conditions in the DWSC. The model was calibrated and validated using six years of data that reflects both wet and dry conditions in the San Joaquin River Basin. Model simulations were run to determine the effect of four factors influencing low DO conditions in the DWSC: elimination of the deepened ship channel, elimination of import of oxygen-consuming substances (ODS) from the San Joaquin River watershed, elimination of import of ODS from the urban tributaries, and elimination of discharge of ODS from the regional wastewater treatment plant. The model results suggest that the deepening of the ship channel has had the largest impact on low DO conditions, followed by ODS from the agricultural watershed. Since the Stockton wastewater treatment plant was upgraded in the 2007, the impact of ODS from this facility has been significantly reduced. The estimated impact of stormwater from the City of Stockton appears much smaller than the other factors. The study results are useful for assigning responsibility for low DO conditions in the DWSC and for formulating effective restoration strategies. The study results also suggest that removal or elimination of any single variable would not result in a complete resolution of low DO events.

Keywords: Dissolved oxygen, TMDL, San Joaquin River
Session Title: Water Quality in Space and Time
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Spatial and Temporal Patterns in Bay-Delta Sediment Quality: Relationship to CA Sediment Quality Objectives

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California became one of the first states in the U.S. to establish regulatory objectives for sediment quality when the State Water Resources Control Board adopted sediment quality objectives (SQOs) in 2008. These objectives included a new sediment quality assessment framework for benthic community protection based on the evaluation of sediment chemistry, sediment toxicity, and benthic community condition, as well as a narrative objective for protecting human health related to seafood consumption. Monitoring data from 2005-12 was evaluated using the SQO assessment framework to evaluate Bay-Delta sediment quality in comparison to other CA bays and estuaries. San Francisco Bay contained the greatest extent of contaminant-impacted sediments in California (52% of area); approximately twice the extent of impacts present in southern California bays and estuaries. Better sediment quality was present in the Delta, with lower levels of chemical contamination and sediment toxicity. Temporal analyses indicate some improvement in San Francisco Bay sediment quality that appears to be related to changes in sediment toxicity. Widespread sediment toxicity in San Francisco Bay has been observed since the 1980s and studies have associated sediment contamination with benthic community degradation in portions of San Francisco Bay. The specific cause of adverse impacts on San Francisco Bay sediment quality remains elusive, and may be due to multiple factors. Additional studies to identify the stressors responsible for these biological responses are needed to help inform environmental management agencies regarding strategies to improve sediment quality in the Bay-Delta system.

Keywords: sediment quality, San Francisco Bay, toxicity, contamination
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The Contribution of Sacramento Valley Rice Systems to Methylmercury in the Sacramento River

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In anoxic, mercury contaminated sediments, sulfate reducing bacteria and iron reducing bacteria convert inorganic mercury to toxic methylmercury (MeHg). MeHg is readily absorbed by living organisms, particularly at higher trophic levels, and is a concern for wildlife in the Delta. In the Sacramento watershed, the conjunction of significant acreage of paddy rice and wetlands with mercury contaminated soils from historical gold and mercury mining enhances production of MeHg. This study sought to quantify the contribution of rice systems to MeHg entering the Delta through a meta-analysis of published data from 1996-2007. The analysis focused on sample sites located on tributaries carrying agricultural drainage waters, and sites on the Sacramento and Feather Rivers immediately upstream and downstream of agricultural drainages. Tributaries carrying agricultural drainage waters had higher MeHg concentrations than sites on the Sacramento River, and concentrations were lower at mainstream sites upstream of agricultural drainages, compared to downstream sites. All locations showed low concentrations of MeHg from June through October, and higher, more variable MeHg concentrations November through May. These patterns are consistent with studies of MeHg exports from rice systems in the Yolo Bypass and the Delta. However, MeHg loads from agricultural drainages were significantly lower than what would be predicted from field scale load measurements from rice systems in the Yolo Bypass and the Delta. Future studies will be needed to determine the reason for the discrepancy between this and other studies. Results from this study suggest that the contribution of rice systems to MeHg loads occurs primarily in November through May. Management practices designed to reduce loads are likely to be more effective during this season.

Keywords: methylmercury, rice, Sacramento Valley
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Using Biosentinels to Assess Mercury Risk in Wetland Restoration Projects

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Methylmercury contamination in food webs is one of the primary water quality issues in the San Francisco Bay. Wetlands have been shown to be important sites of methylmercury production and there is concern that wetland projects may result in increased mercury bioaccumulation. Biosentinel monitoring can be used to provide a direct link between marsh projects and the protection of marsh wildlife at risk of mercury contamination. Here we present data from a two-year project that used a region-wide approach to monitoring wetland restoration in San Pablo Bay. Our data showed concentrations above levels of concern in most species. The design for this project was developed with input from a Science Advisory Group consisting of experts in biosentinel monitoring for mercury and the ecology of potential biosentinel species. The approach and sampling plan were also vetted with local stakeholders, who expressed interest in the following four management questions: 1) *What is the current potential for impairment of beneficial uses due to methylmercury in each major habitat of interest in the North Bay intertidal habitat restoration projects? 2) How will the status of impairment due to methylmercury in each major habitat of interest change over a timescale of years in response to the project? 3) How do the status and trends in impairment due to methylmercury at this project compare to status and trends in impairment in other project and non-project wetlands in the region? and 4) Will tidal marsh restoration introduce a problematic amount of methylmercury into the Bay?* We evaluated the ability of this biosentinel approach to answer each of these management questions in a cost-effective way.

Keywords: Methylmercury, monitoring, wetland restoration, biosentinel, small fish
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The Potential Influence of Pyrethroids, Metals, and Sediment Characteristics on Benthic Communities in Cache Slough

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Benthic communities in the Cache Slough area of California's Bay Delta are critical for the diet of various key fish populations. Research was conducted at 12 sites in the Cache Slough area during the spring and fall of 2012 and 2013 to determine the influence of 8 pyrethroids, 8 metals, and 4 sediment characteristics on native benthic communities. Forty-three to 56 different benthic taxa were collected during the spring and fall of both years and the most dominant taxa collected was the amphipod *Americorophium*. The sum of pyrethroid Toxics Units (TUs) in the sediment based on *Hyalella azteca* (a pyrethroid sensitive species) exceeded a value of 1 (suggesting toxicity) at 4 of the 12 sites during the spring of 2012 but did not exceed 1 at any site for the three other sampling periods. The highest number of metals Threshold Effects Level (TEL) exceedances in sediment were reported for nickel, chromium, copper and arsenic. The predominant type of sediment collected at all sites during random sampling was fine grain material (depositional areas) where hydrophobic chemical concentrations could be greatest. A series of statistical analyses were employed to examine relationships between benthic metrics and environmental variables (pyrethroids, metals and sediment characteristics). Relatively few statistically significant and ecologically meaningful relationships were observed. The benthic metric *% Collectors/Filterers & Collectors/Gatherers* was directly related to concentrations of arsenic. The benthic metric *Abundance* was inversely related to % silt and total organic carbon, suggesting that numbers of benthic organisms tended to be greater in the coarser, less organic-rich sediments. The results from this research are relevant for Bay Delta science because important variables influencing benthic communities, arsenic and sediment characteristics, were identified within a multiple stressor context.

Keywords: Cache Slough, metals, pyrethroids, sediment characteristics, benthic communities
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Concentrations and Loads of Current-Use Pesticides Entering the Sacramento/San Joaquin Delta May 2012-April 2013

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Current-use pesticides pose a potential threat to aquatic organisms, highlighting the need for up-to-date and robust data characterizing inputs of these contaminants to the Sacramento/San Joaquin Delta. A recent USGS study measured concentrations of 99 pesticides and degradates in filtered water samples collected bimonthly (May 2012 – April 2013) from the Sacramento and San Joaquin rivers where they enter the Delta. Thirty-four pesticides and pesticide degradates were detected during the study, with samples containing mixtures of 3 to 14 pesticides. Herbicides, herbicide degradates, and fungicides were detected most frequently, while insecticides were rarely detected.

Herbicide concentrations in the Sacramento River were greatest in samples from the late spring through early summer, while fungicide concentrations were greatest in late summer. Pesticides applied to rice were the main compounds detected during these periods and included the herbicides clomazone, thiobencarb, and propanil (along with its degradate 3,4-DCA), and the fungicide azoxystrobin. Herbicide and fungicide loads were elevated during these periods, and again in the early winter.

Pesticide concentrations in the San Joaquin River were greatest in samples from the winter and early spring. Increases in both concentrations and loads correlated with spikes in discharge following rainfall events. Pesticides detected frequently included the herbicides hexazinone (100%), metolachlor (100%), simazine (83%), diuron (96%) and its degradates 3,4-DCA (96%) and DCPMU (83%), and the fungicides azoxystrobin (75%) and boscalid (96%). These compounds are applied to a variety of crops including alfalfa, stone fruits, and vegetables, while diuron is also used for roadside weed control.

With the exception of pesticides used on rice, concentrations were generally higher in the San Joaquin River samples. Pesticide loads to the Delta however, were greater from the Sacramento River. These data provide valuable information to scientists and resource managers working to understand the role of contaminants in the region.

Keywords: Pesticides, Water-quality, herbicide, fungicide, insecticide
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A Multi-Year Temporal and Spatial Evaluation of Pyrethroid Concentrations and Biological Effects in the Lower American River

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Previous studies of the lower American River reported that grab water samples collected over a 30-km reach contained pyrethroid insecticides at concentrations reported to be toxic to the amphipod *Hyalella azteca*. Beginning in 2011, we initiated a multi-year monitoring study with the goal of providing a robust understanding of how pyrethroid concentrations vary spatially and temporally in the lower American River. Water samples have been collected during 11 rain events and 3 dry events along multiple cross-river transects and analyzed for pyrethroids. The sampling design initially included the collection of water samples from multiple depths, and later transitioned to depth-integrated sampling. Samples were also collected during special studies, including a boat-drift study between two key stations, a "loitering" study performed at one transect, and a multi-day sampling study. In addition, water samples were collected from multiple events for toxicity testing with laboratory-reared and field-collected *H. azteca*. In contrast to the conclusions of the previous studies of pyrethroids in the lower American River, we concluded that pyrethroid detections were rare and episodic, and concentrations were generally low and highly spatially variable. Toxicity was only reported for one sample collected during the day of predicted peak runoff, but was not observed in the exposure using sequential days of sample collection or in the exposures with resident organisms. Based on a comparison of grab samples collected both near the bank (i.e., immediately downstream of a discharge) and across the river transect, we concluded that caution should be used when drawing general ecological conclusions based on grab sampling from the bank. In addition, our results suggest that stormwater monitoring programs that include toxicity testing using a single sample collected during the day of projected peak runoff may be overestimating the toxicity for the acute 96-hour toxicity tests.

Keywords: American River, Pyrethoids, Water Quality, Toxicity, Riverine, Sampling, Design
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