Appendix R

Spatial and Temporal Nitrogen and Phosphorus Dynamics in the San Joaquin River Watershed, 2005-2007

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Abstract

The San Joaquin River (SJR) is a hypereutrophic river with peak summer mineral nitrogen (NH_4^+ + NO_3^-) concentrations ranging between 2 to 4 mg N L^{-1} and soluble reactive phosphorus ranging between 0.15 and 0.20 mg P L^{-1}. These nutrient levels are non-limiting with respect to algae growth. The nutrient monitoring program associated with the SJR dissolved oxygen TMDL is designed to determine the primary forms and sources of nutrients, namely N and P. This investigation provides a basis for any future nutrient load allocation strategies aimed at reducing nutrient levels in an attempt to reduce algal loads from the upstream watershed. This report evaluates the spatial and temporal patterns in nitrogen and phosphorus for 7 mainstem and 17 tributaries and drains in the SJR watershed for the period March 2005 to December 2007. Nutrient concentrations demonstrate appreciable temporal variability at the seasonal and inter-annual time scales that must be considered in designing monitoring and load reduction strategies. The major sources of nitrogen and phosphorus loads were identified: SJR above Lander, Stanislaus, Tuolumne, Merced, San Luis Drain (N source), Salt Slough, Harding Drain, TID Laterals 6/7, and Westport Drain. The other tributaries and drains accounted for less than 10% of the total load as measured at Vernalis. The measured tributary/drain sources and cumulative longitudinal loads calculated for SJR mainstem sites were within 11% of the expected Vernalis loads for total N and total P indicating that the monitoring program identified the majority of the major nutrient sources contributing to total nutrient loads in the SJR.

Introduction

The San Joaquin River (SJR) is a hypereutrophic river with peak summer chlorophyll-*a* concentrations generally in the range of 75 to 150 μg L^{-1} (Kratzer et al., 2004; Ohte et al., 2007). The phytoplankton community in the SJR during the summer months is dominated by centric diatoms (*e.g., Cycotella meneghiniana*) having a 10 to 15 μm diameter (Leland et al., 2001; Henson, 2006). Centric diatoms in 2004 contributed 76 to 89 percent of the total algal biovolume within the mainstem of the SJR (Henson, 2006). Pennate and filamentous diatoms, as well as blue-green algae, were the next most abundant taxa in 2004, with higher proportions found in the agricultural drains, as well as the Merced and Tuolumne Rivers (Henson, 2006).

The high standing biomass of algae is fueled in part by the high availability of nutrients, including available forms of nitrogen, phosphorus and silicon. Peak summer mineral nitrogen (NH_4^+ + NO_3^- + NO_2^-) concentrations ranged between 2 to 4 mg N L^{-1}, soluble reactive phosphorus ranged between 0.15 and 0.20 mg P L^{-1}, and Si ranged between 5.5 and 9.5 mg Si L^{-1} (Kratzer et al., 2004; Ohte et al., 2007). These values far exceed the nutrient levels suggested to limit algae production: <0.1 mg N L^{-1}, <0.01 mg P L^{-1}, <0.06 mg Si L^{-1} (Lohman et al., 1991; Borchardt, 1996). Given the high concentrations of nutrients relative to algal growth limiting concentrations, the efficacy of nutrient reduction strategies to control eutrophication appear challenging. These nutrients originate from surface and subsurface irrigation return flows, runoff and leaching from livestock operations, nitrogen-rich bedrock in the Coast Ranges, municipal wastewater treatment facilities, and urban runoff (Kratzer et al., 2004).

To assess nutrient dynamics at the watershed scale, water quality must be evaluated at several spatial and temporal scales in order to comprehend the full range of variability within the watershed and the physical, chemical and biological processes that control this variability (Dahlgren et al., 2004). As a first step, a source-search monitoring strategy may be employed to examine spatial patterns in water quality parameters across a representative range of land use/land cover characteristics within a watershed (Ahearn et al., 2005). The synoptic sampling scheme is often employed at a biweekly to monthly time-step throughout the year. While the source-search strategy can often identify the primary pollutant sources, it does not provide an adequate level of detail concerning temporal fluctuations. Various water quality parameters may display diel, storm-event, seasonal and inter-annual variations that could greatly affect the evaluation process (Dahlgren et al., 2004).

Nutrient monitoring in the SJR watershed has been conducted on a wide range of spatial and temporal scales in an attempt to understand specific nutrient sources and their temporal patterns throughout the year. This report presents a summary of nitrogen and phosphorus concentrations and loads for the period March 2005 to December 2007 from 7 mainstem sites and 17 tributaries and drains discharging into the SJR. The major goal of this component of the overall SJR TMDL research is to identify the contribution of nutrients from various sources within the watershed. Once the major sources are identified, nutrient reduction strategies (*i.e.* load allocation) can be evaluated as to their potential for addressing the overall goal of reducing algae biomass exports from the upper watershed to the lower watershed where they contribute to hypoxia in the Stockton Deep Water Ship Channel.

The following report is divided into four sections:

- Forms of nitrogen and phosphorus in waters from the mainstem, tributaries and drains
- Spatial patterns in nutrient concentrations in the mainstem, tributaries and drains
- Evaluation of nutrient loads along the San Joaquin River mainstem and inputs from tributaries and drains, and
- Temporal patterns in nutrient concentrations.

Methods

Study area

Water samples were taken from 7 locations along the mainstem of the San Joaquin River and 17 locations in tributaries and drains (Table 1). All sampling points in tributaries and drains were located near the confluences with the mainstem of the San Joaquin River. Thus, the constituent concentrations and water flow rates measured at these sampling points were used as representative values for each tributary merging into the SJR mainstem. Detailed sampling protocols are described in the DO TMDL QAPP (Stringfellow, 2005). Mud Slough, Salt Slough, Los Banos Creek and San Luis Drain receive discharge from the Grasslands Ecological Area. Mud Slough receives tile drainage from 393 km^2 of the Grasslands Ecological Area (Kratzer et al. 2004), which includes not only wetlands, but also pasture of native vegetation (Quinn et al. 1998).

Drainage canals, such as Harding Drain (east-side), TID Laterals 6/7 (east-side), MID Lateral 5 (east-side), MID Main Drain (east-side), Westport Drain (east-side), Ramona Lake (west-side), Orestimba Creek (west-side), and Hospital Creek (west-side), run through agricultural fields to the San Joaquin River. The west-side drains (Orestimba Creek, Ramona Lake, Ingram Creek, Del Puerto Creek and Hospital Creek) receive mainly surface runoff from row crops and orchards, and Hospital Creek contains some tile drainage as well. The east-side Harding Drain receives treated effluent from the City of Turlock wastewater treatment plant in addition to runoff from agricultural areas (Kratzer et al., 2004).

Analytical analyses

Total nitrogen (TN) and total phosphorus (TP) were determined following oxidization with a 1% potassium persulfate solution (APHA, 1998). TN was determined spectroscopically with a single reagent containing vanadium chloride (VCl_3) (MDL = 0.01 mg N L^{-1}) (Doane and Horwath, 2003). TP was determined spectroscopically with the stannous chloride method (MDL = 0.005 mg P L^{-1}) (APHA, 1998).

Dissolved constituents were determined on a sample filtered through a 0.2 μm polycarbonate membrane (Millipore – formerly Nuclepore). Nitrate plus nitrite were determined using the vanadium chloride method (MDL = 0.01 mg N L^{-1}) (Doane and Horwath, 2003). Since nitrite was always a very small portion (generally <3%) of the nitrate+nitrite concentration, we report this measure as "nitrate" throughout the remainder of this report. Ammonium was determined spectroscopically with the Berthelot reaction, using a salicylate analog of indophenol blue (MDL = 0.01 mg N L^{-1}) (Forster, 1995). Soluble-reactive PO_4 (SRP) was determined spectroscopically with the stannous chloride method (MDL = 0.005 mg P L^{-1}) (APHA, 1998).

Laboratory quality assurance/quality control followed the Surface Water Ambient Monitoring Program protocols (SWAMP) set by the California State Water Resources Control Board (http://www.swrcb.ca.gov/swamp/qapp.html). This includes implementation of standard laboratory procedures including replicates, spikes, reference materials, setting of control limits, criteria for rejection, and data validation methods. Detailed sampling, handling and analytical protocols are described in the DO TMDL QAPP (Stringfellow, 2005).

Results and Discussion

Forms of Nutrients in the SJR mainstem, tributaries and drains

A summary of the overall nutrient concentration data for the seven mainstem and 17 tributaries and drains is shown in Table 1. The sampling period generally represents weekly to biweekly sampling for the time period March 2005 to December 2007 (n=50-101). A few sampling sites, TID Laterals 6/7, Ramona Lake, and Hospital Creek, were added later in the monitoring program and therefore have a lower number of samples (n=17-35).

The primary forms of nitrogen in waters of the SJR watershed are ammonium (NH_4), nitrate (NO_3), and organic (particulate [>0.2 μm] and dissolved [<0.2 μm]) forms. The organic component is defined as total nitrogen minus the NH_4 + NO_3. While NH_4 and

NO_3 are readily available for algae utilization, organic nitrogen must first undergo mineralization to mineral forms (NH_4 and NO_3) prior to algae uptake.

Nitrate was the primary form of nitrogen at six of the seven SJR mainstem sites (Table 2). With the exception of the upper most mainstem site (SJR at Lander), NO_3 represented from 71 to 78% of the total N pool. The upstream SJR site at Lander Avenue had lower median total N concentrations with only 57% in the form of NO_3. Inputs of high NO_3 agricultural drainage waters below Lander Avenue likely contribute to the higher proportion of NO_3 below this site. In addition, the high residence time of water at the Lander Avenue site further allows ample time for conversion of mineral N forms into organic N forms via algae primary production. Ammonium concentrations were less than 2.8% of the total N pool in the SJR mainstem sites. The low proportion of NH_4 is attributable to preferential uptake of NH_4 by algae as a nitrogen source and rapid nitrification of NH_4 to NO_3 in aerobic waters. Organic forms of nitrogen ranged between 20 and 27% at the six SJR downstream sites compared to 41% at the Lander Avenue site.

The three major east-side tributaries (Merced, Tuolumne, Stanislaus) were similarly dominated by NO_3 (54-78%) with organic forms representing 14 to 38%. The creeks and drains had more variable distributions of nitrogen with the San Luis Drain, Harding Drain, TID Laterals 6/7, and Westport Drain having greater than 88% of total N in the form of NO_3. In contrast, Los Banos Creek has a large component of wetland drainage that is reflected in the higher proportion of both organic N (61%) and NH_4 (10.7%) species and a decreased importance of NO_3 (29%).

The primary forms of phosphorus in waters of the SJR are ortho-phosphate and particulate+organic (particulate [>0.2 μm] and dissolved [<0.2 μm]). The particulate+organic component is operationally defined as total P minus SRP. The particulate fraction may include PO_4 adsorbed on inorganic particles and colloidal and dissolved organic P. Since phytoplankton utilize P almost exclusively as orthophosphate, the availability of particulate+organic forms of phosphorus depends on the extent to which it is transformed into bioavailable forms.

SRP (36 to 63%) was generally the dominant form of total P with particulate+organic (37 to 56%) in the mainstem sites, especially below the Harding Drain. The P fractions in the three major east-side tributaries were similarly distributed between SRP (33 to 67%) and particulate+organic (33 to 67%). Among the remaining tributaries and drains, the distribution of SRP (9 to 89%) and particulate+organic (11 to 91%) were highly variable. At the one extreme, the San Luis Drain had generally <10% SRP owing to the origin of these waters largely as subsurface tile drainage. In contrast, the Harding Drain and TID Laterals 6/7 have SRP fractions representing ~89% of total P. In the case of the Harding Drain, the high proportion of SRP results from the contribution of treated wastewater effluent.

The use of total or SRP measurements to predict the effect of agricultural runoff on algal growth is complicated due to the varying bioavailability of the particulate+organic fraction. In agricultural watersheds, particulate+organic has been found to be the dominant fraction of total phosphorus transported in surface runoff (Hart et al., 2004; Sharpley et al., 1992; Uusitalo and Ekholm, 2003). The particulate+organic fraction is associated with soil particles and organic matter eroded from fields during irrigation events. The percentage of particulate+organic P that is bioavailable is generally reported to range between 5 and 30% for agricultural runoff (DePinto et al., 1981; Dorich et al., 1985; Uusitalo et al., 2000).

Spatial nutrient concentrations

The distribution of the various N and P concentrations measured in this study are shown in Figures 1-5 (Table 1 provides data in a tabular format). Along the mainstem of the SJR, median total N concentrations display an increase from Lander Avenue to Patterson, stepped decreases between Patterson and Maze and again between Maze and Vernalis, and similar concentrations between Vernalis and Mossdale (Figure 1). Because Laird Park data were not collected in 2006-07, its median value is not directly comparable to the other mainstem sites. This pattern is due to inputs of nitrogen-rich waters within the upper reaches (above Laird Park) followed by dilution from the Tuolumne and Stanislaus Rivers above Maze and Vernalis, respectively. According to the USGS streamflow data for 1951-1995, 66% of the average streamflow in the San Joaquin River comes from the three major east-side rivers that originate in the Sierra Nevada: Merced River (15%), Tuolumne River (30%), and Stanislaus River (21%) (Kratzer et al., 2004). Thus, the Tuolumne and Stanislaus Rivers can have a large dilution effect as they contribute up to 50% of the summer flows and they have relatively low nutrient concentrations compared to the SJR mainstem. Because there are no major water inputs between Vernalis and Mossdale, total N concentrations display very similar distributions between these sites.

Among the tributaries and drains, the three major east-side tributaries (median values: Merced = 1.24 mg L^{-1}, Tuolumne = 1.51 mg L^{-1} and Stanislaus = 0.42 mg L^{-1}) have the lowest median total N concentrations. In contrast, some of the major drains have very high median total N concentrations (TID Lateral 6/7 = 15.7 mg L^{-1}, San Luis Drain = 13.6 mg L^{-1}, Harding Drain = 9.8 mg L^{-1}, Westport Drain = 12.3 mg L^{-1}). Nearly all of the measured tributaries and drains delivering agricultural tailwaters and tile drainage have total N concentrations higher than the SJR mainstem sites.

Ammonium concentrations in the SJR mainstem sites were generally less than 0.1 mg N L^{-1}, with most median values on the order of 0.02 to 0.03 mg N L^{-1} (Figure 2). Only a few sites (Los Banos, TID Laterals 6/7, Ramona Lake, Harding Drain and Del Puerto Creek) had median NH_4-N concentrations greater than 0.2 mg N L^{-1}. However, there were a few individual samples (*e.g.*, Harding Drain, Del Puerto Creek, Ingram Creek, MID Main) in which NH_4-N concentrations exceed 1 mg N L^{-1}. These isolated high ammonium concentrations could be of short-term, local significance as high ammonia (NH_3) concentrations are toxic to aquatic organisms. The toxicity level of NH_4/NH_3 is dependent on the pH value, which determines the partitioning between NH_4/NH_3 (pKa = 9.25 at 25^o C).

The distribution of NO_3 concentrations follows a pattern very similar to that of total N because the contribution of NO_3 to total nitrogen was relatively similar among most sites (Figure 3). As with total N, median NO_3-N concentrations along the mainstem sites displayed an increase from Lander Avenue to Patterson, with decreased concentrations between Patterson and Maze and again between Maze and Vernalis due to dilution by the Tuolumne and Stanislaus Rivers, respectively. Because Laird Park data were not collected in 2006-07, its median value is not directly comparable to the other mainstem sites. Nitrate concentrations were similar between Vernalis and Mossdale. The highest median concentrations of NO_3-N originated from the San Luis Drain (12.7 mg N L^{-1}), TID Laterals 6/7 (14.3 mg N L^{-1}), Harding Drain (8.8 mg N L^{-1}), and Westport Drain (10.8 mg N L^{-1}). Median, NO_3 concentrations for the three major east-side tributaries (Merced, Tuolumne and Stanislaus) were below 1.2 mg N L^{-1} providing downstream dilution of NO_3 below their confluence with the SJR.

Median TP and soluble-reactive P concentrations along the SJR mainstem display the effects of dilution below the confluences with the Merced (Crows Landing), Tuolumne (Maze) and Stanislaus (Vernalis) Rivers, and a large increase at SJR Patterson due to a large input of soluble-reactive PO_4 from the Harding Drain (Fig. 4 & 5). Median TP concentrations in the Harding Drain were about 1.6 mg L^{-1}, which was nearly 10 times greater than the SJR at its confluence. Higher median TP and SRP values were also found in Los Banos Creek (wetland drainage) and TID Laterals 6/7 (unknown sources). Median TP concentrations in the three east-side tributaries (Merced, Tuolumne and Stanislaus) were very low (0.04 to 0.07 mg P L^{-1}). Because of the low TP concentrations and the relative large river discharges associated with these tributaries, they have a significant dilution capacity below their confluences with the SJR. The San Luis Drain was characterized by having low median TP concentration (0.07 mg P L^{-1}) and SRP concentrations that were generally less than detection limits (<0.005 mg P L^{-1}). The origin of the majority of the water in the San Luis Drain as tile drainage results in sorption of PO_4 by soils during leaching through the vadose zone. The SRP concentrations in the San Luis Drain are generally below concentrations reported to limit algae growth (~0.01 mg P L^{-1}). Of all the sites monitored, the end of the San Luis Drain is possibly the only site where algae standing crop is nutrient limited.

Nutrient Loads along the SJR mainstem and inputs from tributaries and drains

A summary of the overall nutrient loads for the seven mainstem and 17 tributaries and drains is shown in Table 3. The sampling period generally represents weekly to biweekly sampling for the time period March 2005 to December 2007 (n=50-101). A few sampling sites, TID Laterals 6/7, Ramona Lake, and Hospital Creek, were added later in the monitoring program and therefore have a lower number of samples (n=17-35).

The distribution of nutrient loads for the entire study period along with the distribution of longitudinal cumulative loads from measured tributaries and drains are shown in Figures 6-10. The cumulative load lines were drawn by summing the mean daily loads of nitrogen and phosphorus species from the tributaries/drains upstream of the mainstem sites. This analysis provides an assessment of the major nutrient sources and a relative evaluation of potential sources (from mass balance approach) that were not measured for the tributary and drain loads above a given sampling site.

A load assessment based on total N and NO_3-N reveal similar conclusions (Figures 6 and 7). The primary nitrogen sources as a percentage of the total loads measured at Vernalis originate from the SJR above Lander (TN=11.6%, NO_3-N=5.4%), the three east-side tributaries (Merced TN=19.2%, NO_3-N=20.0%; Tuolumne TN=25.1%, NO_3-N=21.4%; Stanislaus TN=7.9%, NO_3-N=5.2%), Salt Slough (TN=9.7%, NO_3-N=10.7%), San Luis Drain (TN=9.2%, NO_3-N=13.7%), Harding Drain (TN=7.1%, NO_3-N=10.5%), Westport Drain (TN=6.3%, NO_3-N=9.0%), and TID Laterals 6/7 (TN=5.4%, NO_3-N=8.0%) (Table

4). The remaining measured sources each generally contributed less than 1% of the TN and NO_3-N loads measured at Vernalis. While the three major east-side tributaries had among the lowest TN and NO_3-N concentrations, the higher flows associated with these tributaries resulted in appreciable TN (52.2% of Vernalis load) and NO_3-N (46.6% of Vernalis load) loads to the SJR. In sum, the measured mean TN and NO_3-N loads from tributaries and drains accounted for about ~111% of the Vernalis nitrogen loads, which suggests that the tributaries and drains measured in this study represent the major nitrogen sources. The cumulative mean values summing to greater than 100% may further suggest that denitrification of nitrate or sedimentation of particulate nitrogen may result in the loss of about 11% of the total nitrogen load during downstream transport.

A similar load assessment for total P and SRP indicates that the primary phosphorus sources as a percentage of the total loads measured at Vernalis originate from the SJR above Lander (TP=8.0%, SRP=5.9%), the three east-side tributaries (Merced TP=17.3%, SRP=17.7%; Tuolumne TP=21.8%, SRP=17.7%; Stanislaus TP=10.1%, SRP=11.5%), Salt Slough (TP=12.3%, SRP=11.0%), and the Harding Drain (TP=9.5%, SRP=16.7%) (Figures 9 and 10; Table 4). The remaining measured sources generally each contributed less than 1% of the TP and SRP loads measured at Vernalis. As with nitrogen, the three major east-side tributaries had very low TP and SRP concentrations, but higher flows that resulted in appreciable TP (42.0% of Vernalis load) and SRP (36.5% of Vernalis load) loads. In sum, the measured loads from tributaries and drains accounted for 89 to 92% of the Vernalis P loads, which leaves 8 to 11% unaccounted for. Because SRP can be transformed by biological (algae uptake) and physical (PO_4 sorption/desorption) processes during downstream transport, it appears best to use TP for cumulative longitudinal load assessments. Given the potential errors in accounting for TP and SRP loads in the complex SJR system, coming within 10% of the mass balance amount measured at Vernalis appears very acceptable.

Temporal patterns in nutrients

Nutrient concentrations in the San Joaquin River demonstrate considerable variability at the diel, seasonal, annual and decade time steps. At the diel scale, nitrate concentrations are inversely related to algae concentrations due to algal uptake of nitrogen during growth. Stoichiometric uptake of N according to the Redfield C:N for algae is on the order of 6.6:1. This can lead to diel fluctuation of NO_3-N on the order of 0.5 mg N L^{-1} associated with peak algae growth rates during the summer months. A strong seasonal pattern in NO_3-N concentrations occurs due to patterns in irrigation, winter storm events, spring snowmelt runoff, and fish augmentation flows. The overall NO_3-N concentration pattern varies from year-to-year, but is generally lowest in the April to early June period associated with snowmelt runoff and spring-fish attracting flow augmentations. Maximum concentrations occur during the late-summer to fall when irrigation return flows are highest and flows from the east-side tributaries are at their annual minimum. Nitrate concentrations were especially low during the very high flows associated with the spring runoff in 2006.

The long-term NO_3-N record for Vernalis consists of data from 1908, 1930, and consistent data since 1950 (Figure 11). Prior to 1950, NO_3-N concentrations ranged from nil to about 0.5 mg N L^{-1}. Concentrations increased progressively from 1950 to about the 1990s when the concentrations appear to level out. The large increase beginning in the

1950s has been largely attributed to the increased use of nitrogen fertilizer and increased numbers of animal husbandry, primarily dairies (Kratzer and Shelton, 1998). While NO_3-N concentrations have not fallen off in recent years, there does appear to be a leveling off in NO_3-N concentrations during the past 20 years.

During the 2005-07 monitoring period, TN and NO_3-N concentrations in the SJR mainstem sites displayed a strong seasonal pattern which grow more prominent at downstream sites (Figures 12-17). The highest concentrations occurred from July to December and concentrations were generally decreased during the winter and spring due to dilution from snowmelt runoff and storm events from the Sierra Nevada. Minimum concentrations were generally associated with fish augmentation flows during the May to early June period. Exceptionally high spring runoff in 2006 resulted in very low concentrations of TN and NO_3-N. TN and NO_3-N concentrations in many of the tributaries and drains demonstrated much greater scatter and weaker seasonal patterns. In particular, the Harding Drain did not show appreciable seasonal patterns; however, there was a wide range of scatter among data.

Seasonal patterns in TP and SRP were evident for the SJR mainstem sites, but they were weaker than for TN and NO_3-N concentrations (Figures 18-23). The timing of maximum and minimum concentrations was comparable between nitrogen and phosphorus concentrations. As with the nitrogen concentrations, seasonal patterns in TP and SRP were less evident and displayed appreciably greater scatter in the temporal record.

Conclusions

- Nutrient concentrations demonstrate appreciable temporal variability at the diel, seasonal and inter-annual time scales. This temporal variability has great ramifications for designing an appropriate monitoring program and for assessing the appropriateness of published data for answering questions concerning nutrient loads.
- The major sources of nitrogen and phosphorus loads were identified: SJR above Lander, Stanislaus, Tuolumne, Merced, San Luis Drain (N source), Salt Slough, Harding Drain, TID Laterals 6/7, and Westport Drain. Contributions from the other tributaries and drains combined accounted for less than 10% of the total load as measured at Vernalis.
- The measured tributary/drain sources and cumulative longitudinal loads calculated for SJR mainstem sites were within 11% of the expected Vernalis loads for total N and total P indicating that the monitoring program identified the majority of the major nutrient sources contributing to total nutrient loads in the SJR.
- Because the three major east-side tributaries (Merced, Tuolumne, Stanislaus) are significant sources of nutrients, a longitudinal assessment along each river reach should be conducted to determine the longitudinal accretion rate of nutrient within these watersheds. Previous studies indicated that nutrient loads from above Highway 99 are minimal and that the primary nutrient accretion occurs in the lower reaches of these tributaries.
- To determine the sensitivity of algae growth to SRP concentrations, P addition experiments should be conducted within the San Luis Drain, the only site within the

SJR watershed that appears to have nutrient-limited (SRP <0.005 mg P L^{-1}) algae growth. Spiking the San Luis Drain with SRP and determining the effect on downstream algae growth could provide evidence for the feasibility of P reductions to limit algae standing biomass in other portions of the SJR watershed.

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Table 1: Summary of nutrient concentrations for the 7 mainstem sites along the San Joaquin River and the 17 tributaries and drains monitored in this study for the period March 2005 to December 2007. The mean (X), standard deviation (SD), minimum (min), maximum (max), and number of samples (n) are listed for each site.

	River mile	Total N (mg/L)			NH_4-N (mg/L)			NO_3-N (mg/L)			Total P (mg/L)			SRP (mg/L)		
		X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n
SJR-Mossdale	56.2	1.75 (0.66)	0.32 2.76	64	0.03 (0.02)	<0.01 0.10	65	1.24 (0.61)	0.08 2.45	65	0.176 (0.064)	0.060 0.380	64	0.095 (0.041)	0.005 0.194	65
SJR- Vernalis	72.2	1.79 (0.70)	0.31 2.94	70	0.04 (0.03)	0.01 0.14	72	1.32 (0.65)	0.07 2.78	72	0.172 (0.084)	0.060 0.640	70	0.086 (0.034)	0.005 0.200	72
SJR – Maze	77.4	2.52 (1.13)	0.35 4.10	68	0.04 (0.04)	0.01 0.17	69	1.94 (1.00)	0.06 3.72	69	0.211 (0.073)	0.050 0.410	68	0.114 (0.035)	0.050 0.201	69
SJR – Laird Park	91.0	2.74 (1.46)	0.57 8.06	22	0.08 (0.10)	<0.01 0.39	22	2.05 (1.31)	0.16 6.64	22	0.240 (0.071)	0.147 0.377	22	0.125 (0.064)	<0.005 0.260	22
SJR – Patterson	99.4	3.26 (1.49)	0.49 6.02	72	0.05 (0.06)	<0.01 0.45	74	2.55 (1.40)	0.08 5.91	74	0.326 (0.134)	0.090 0.798	72	0.205 (0.091)	0.045 0.450	74
SJR – Crows Landing	108.6	2.94 (1.31)	0.44 6.45	78	0.04 (0.03)	0.01 0.21	80	2.24 (1.25)	0.08 6.11	80	0.192 (0.064)	0.067 0.381	78	0.084 (0.030)	0.032 0.210	80
SJR - Lander	131.9	2.41 (1.84)	0.30 9.58	81	0.05 (0.07)	0.01 0.52	83	1.38 (1.54)	0.01 6.65	83	0.233 (0.089)	0.060 0.502	81	0.084 (0.056)	0.005 0.350	83
Stanislaus	74.9	0.43 (0.17)	0.10 0.98	65	0.04 (0.05)	<0.01 0.40	67	0.23 (0.13)	0.03 0.74	67	0.060 (0.043)	0.010 0.320	65	0.040 (0.035)	0.005 0.210	67
Tuolumne	83.8	1.41 (0.78)	0.19 3.00	66	0.03 (0.03)	<0.01 0.15	68	1.10 (0.75)	0.02 2.42	68	0.092 (0.071)	0.007 0.394	66	0.062 (0.050)	<0.005 0.173	68
Merced	118.2	1.81 (1.34)	0.20 4.83	65	0.05 (0.03)	0.01 0.14	67	1.50 (1.28)	0.04 4.27	67	0.051 (0.054)	0.007 0.401	65	0.023 (0.017)	<0.005 0.142	67
Salt Slough	129	2.03 (1.06)	0.58 5.32	101	0.10 (0.13)	0.01 1.25	103	1.28 (0.96)	0.01 4.31	103	0.348 (0.125)	0.137 0.753	101	0.145 (0.093)	0.020 0.680	103
San Luis Drain	-	13.99 (5.44)	3.76 28.63	72	0.07 (0.11)	<0.01 0.58	73	13.05 (5.85)	2.82 30.29	73	0.075 (0.035)	0.020 0.220	72	0.007 (0.017)	<0.005 0.110	73
Mud Slough	122.7	6.04 (3.30)	1.51 15.96	74	0.11 (0.14)	0.01 1.09	76	4.83 (3.28)	0.14 14.96	76	0.221 (0.114)	0.038 0.563	74	0.073 (0.086)	<0.005 0.320	76

Table 1: (continued)	River mile	Total N (mg/L)			NH_4-N (mg/L)			NO_3-N (mg/L)			Total P (mg/L)			SRP (mg/L)		
		X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n
Los Banos	121.0	2.17 (1.07)	0.56 5.94	65	0.23 (0.43)	0.01 3.22	66	0.62 (0.53)	0.01 2.09	66	0.623 (0.290)	0.197 1.460	65	0.325 (0.212)	0.071 1.026	66
TID Lat. 6/7	110.9	16.39 (5.39)	6.41 40.06	35	0.13 (0.20)	0.02 0.91	35	14.95 (5.15)	5.66 36.46	35	0.593 (0.2157)	0.290 1.225	35	0.525 (0.184)	0.290 1.173	35
Orestimba Crk	109.3	4.69 (3.20)	0.45 13.01	57	0.21 (0.77)	0.01 5.76	58	3.84 (2.97)	0.05 12.05	58	0.285 (0.158)	0.050 0.760	57	0.110 (0.066)	0.005 0.311	58
Ramona Lake	108	4.10 (0.89)	2.81 5.67	28	0.31 (0.35)	0.01 1.38	28	2.05 (1.03)	0.09 4.02	28	0.418 (0.175)	0.153 0.848	28	0.100 (0.095)	<0.005 0.418	28
Harding Drain	101	10.69 (4.05)	4.56 23.30	64	0.28 (0.44)	0.02 2.67	65	9.56 (3.84)	4.21 22.39	65	2.009 (1.283)	0.120 5.197	64	1.793 (1.208)	0.060 4.740	65
Del Puerto Crk	93.3	5.75 (3.46)	0.22 19.56	57	0.46 (0.85)	<0.01 4.93	58	4.04 (2.15)	0.01 10.71	58	0.342 (0.201)	0.046 0.923	57	0.205 (0.141)	0.020 0.711	58
Westport Drain	93	13.53 (6.15)	2.21 30.53	50	0.11 (0.22)	0.02 1.45	50	11.95 (6.06)	0.62 29.83	50	0.285 (0.201)	0.040 0.980	50	0.231 (0.188)	0.010 0.870	50
MID Lat. 5 - Tuol.	83	1.85 (3.56)	0.08 18.35	29	0.14 (0.25)	<0.01 1.16	29	1.32 (3.36)	<0.01 17.97	29	0.152 (0.299)	0.010 1.431	29	0.100 (0.216)	<0.005 1.053	29
Ingram Crk	82.8	7.36 (4.30)	1.64 16.94	44	0.49 (0.72)	0.02 2.85	44	5.74 (3.57)	0.61 16.53	44	0.399 (0.273)	0.040 1.493	44	0.161 (0.069)	0.020 0.333	44
Hospital Crk	82.8	2.70 (1.51)	0.83 5.65	17	0.15 (0.21)	0.02 0.77	17	1.28 (0.97)	0.35 3.72	17	0.517 (0.360)	0.100 1.441	17	0.264 (0.223)	0.040 0.740	17
MID Main – Stan.	76.0	3.43 (4.61)	0.59 30.79	40	0.72 (3.44)	0.01 21.76	40	1.73 (1.31)	<0.01 3.45	40	0.549 (0.997)	0.040 6.340	40	0.401 (0.852)	0.014 5.310	40

Table 2: **Median concentrations for total N (TN) and total P (TP) concentrations for 7 mainstem sites along the San Joaquin River and 17 tributaries and drains for the monitoring period March 2005 to December 2007. The distribution of the median total N and P is shown for the various nutrient forms.**

	River mile	**Median TN mg/L**	**Organic %**	**NH_4 %**	**NO_3 %**	**Median TP mg/L**	**Particulate + Organic %**	**Soluble-reactive P %**
SJR-Mossdale	56.2	1.83	27.0	1.9	71.1	0.17	46.0	54.0
SJR- Vernalis	72.2	1.95	24.1	2.0	73.9	0.16	50.0	50.0
SJR – Maze	77.4	2.73	21.4	1.6	77.0	0.22	46.0	54.0
SJR – Laird Park	91.0	2.65	22.4	2.8	74.8	0.23	47.9	52.1
SJR – Patterson	99.4	3.26	20.4	1.4	78.2	0.31	37.1	62.9
SJR – Crows Landing	108.6	2.84	22.5	1.3	76.2	0.18	56.3	43.8
SJR - Lander	131.9	2.02	40.7	2.1	57.2	0.22	52.4	36.1
Stanislaus	74.9	0.42	37.8	8.6	53.6	0.05	67.0	33.0
Tuolumne	83.8	1.51	19.9	2.3	77.8	0.07	32.6	67.4
Merced	118.2	1.24	14.3	2.3	83.4	0.04	53.6	46.4
Salt Slough	129	1.86	32.1	5.1	62.8	0.32	58.3	41.7
San Luis Drain	-	13.63	6.2	0.5	93.3	0.07	90.7	9.3
Mud Slough	122.7	6.04	18.3	1.8	79.9	0.20	67.0	33.0
Los Banos	121.0	1.93	60.5	10.7	28.8	0.57	47.8	52.2
TID Lat. 6/7	110.9	15.65	7.9	0.8	91.3	0.57	11.5	88.5
Orestimba Crk	109.3	4.09	13.6	4.5	81.9	0.25	61.4	38.6
Ramona Lake	108	3.89	42.4	7.5	50.1	0.42	76.1	23.9
Harding Drain	101	9.81	8.0	2.6	89.4	1.63	10.8	89.2
Del Puerto Crk	93.3	5.62	21.8	8.0	70.2	0.29	40.1	59.9
Westport Drain	93	12.27	10.9	0.8	88.3	0.25	18.9	81.1
MID Lat. 5 - Tuol.	83	0.59	21.7	7.7	70.6	0.06	34.2	65.8
Ingram Crk	82.8	6.51	15.4	6.7	77.9	0.36	59.6	40.4
Hospital Crk	82.8	2.88	47.2	5.5	47.3	0.43	48.9	51.1
MID Main – Stan.	76.0	2.87	28.6	21.0	50.4	0.55	27.0	73.0

Table 3: Summary of nutrient loads for the 7 mainstem sites along the San Joaquin River and the 17 tributaries and drains monitored in this study for the period March 2005 to December 2007. The mean (X), standard deviation (SD), minimum (min), maximum (max), and number of samples (n) are listed for each site.

	River mile	Total N (Mg/d)			NH_4-N (Mg/d)			NO_3-N (Mg/d)			Total P (Mg/d)			SRP (Mg/d)		
		X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n
SJR-Mossdale	56.2	13.30 (8.44)	2.88 52.80	64	0.48 (0.74)	<0.01 4.01	64	8.29 (4.25)	1.81 16.57	64	1.77 (2.32)	0.20 15.90	64	1.00 (1.13)	0.01 (5.63)	64
SJR- Vernalis	72.2	13.44 (9.00)	4.25 64.70	70	0.56 (0.99)	0.02 5.66	70	8.30 (3.39)	3.39 16.97	70	1.79 (2.70)	0.32 20.57	70	0.96 (1.33)	0.01 7.43	70
SJR – Maze	77.4	12.19 (9.20)	3.47 67.21	66	0.53 (1.01)	0.01 6.09	66	7.50 (3.15)	2.68 15.37	66	1.63 (2.67)	0.24 18.79	66	0.92 (1.38)	0.09 6.77	66
SJR – Laird Park	91.0	10.57 (4.20)	3.30 18.94	22	0.44 (0.59)	0.01 2.05	22	7.17 (2.59)	1.81 12.60	22	1.18 (0.97)	0.27 4.59	22	0.53 (0.38)	<0.01 1.32	22
SJR – Patterson	99.4	8.64 (6.93)	1.54 41.09	72	0.29 (0.58)	0.01 3.14	72	5.26 (2.39)	1.24 13.64	72	1.17 (1.63)	0.14 10.41	72	0.68 (0.85)	0.11 4.34	72
SJR – Crows Landing	108.6	7.54 (5.35)	2.03 41.45	78	0.19 (0.39)	0.01 2.83	78	4.98 (2.17)	0.09 11.73	78	0.73 (1.29)	0.11 10.79	78	0.32 (0.52)	0.05 3.45	78
SJR - Lander	131.9	1.56 (3.63)	0.01 23.99	79	0.09 (0.27)	<0.01 1.52	79	0.45 (0.81)	<0.01 4.81	79	0.31 (0.90)	<0.01 6.02	79	0.17 (0.51)	<0.01 3.13	79
Stanislaus	74.9	1.06 (1.47)	0.20 10.88	65	0.09 (0.19)	<0.01 1.31	65	0.43 (0.37)	0.12 2.21	65	0.18 (0.50)	0.02 4.05	65	0.11 (0.32)	<0.01 2.58	65
Tuolumne	83.8	3.38 (5.27)	0.94 38.84	66	0.16 (0.33)	<0.01 2.40	66	1.78 (0.96)	0.40 4.53	66	0.39 (1.18)	0.01 7.67	66	0.17 (0.41)	<0.01 3.37	66
Merced	118.2	2.58 (2.63)	0.50 17.46	62	0.15 (0.25)	0.01 1.67	62	1.66 (1.58)	0.26 8.88	62	0.18 (0.61)	0.01 4.81	62	0.07 (0.22)	<0.01 1.70	62
Salt Slough	129	1.31 (1.71)	0.11 11.77	101	0.06 (0.09)	0.01 0.49	101	0.89 (1.36)	<0.01 9.76	101	0.22 (0.29)	0.03 2.03	101	0.11 (0.23)	0.01 1.82	101
San Luis Drain	-	1.23 (0.64)	0.21 3.34	62	<0.01 (0.01)	<0.01 0.03	62	1.14 (0.63)	0.14 3.23	62	0.01 (0.01)	<0.01 0.02	62	<0.01 (<0.01)	<0.01 0.01	62
Mud Slough	122.7	1.55 (1.71)	0.02 11.00	74	0.03 (0.03)	<0.01 0.13	74	1.19 (1.51)	0.01 9.69	74	0.08 (0.10)	<0.01 0.55	74	0.03 (0.05)	<0.01 0.21	74

Table 3: (continued)	River mile	Total N (Mg/d)			NH_4-N (Mg/d)			NO_3-N (Mg/d)			Total P (Mg/d)			SRP (Mg/d)		
		X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n	X± SD	Min Max	n
Los Banos	121.0	0.12 (0.09)	0.01 0.41	56	0.01 (0.01)	<0.01 0.06	56	0.03 (0.03)	<0.01 0.14	56	0.04 (0.03)	<0.01 0.14	56	0.02 (0.02)	<0.01 0.08	56
TID Lat. 6/7	110.9	0.73 (0.54)	0.04 2.32	34	0.01 (0.01)	<0.01 0.06	34	0.66 (0.50)	0.04 2.01	34	0.03 (0.02)	<0.01 0.07	34	0.02 (0.02)	<0.01 0.07	34
Orestimba Crk	109.3	0.14 (0.13)	0.01 0.90	58	0.01 (0.02)	<0.01 0.08	58	0.12 (0.16)	<0.01 1.16	58	0.01 (0.03)	<0.01 0.24	58	<0.01 (0.01)	<0.01 0.06	58
Ramona Lake	108	0.14 (0.09)	0.01 0.28	26	0.01 (0.02)	<0.01 0.05	26	0.07 (0.05)	<0.01 0.18	26	0.01 (<0.01)	0.01 0.03	26	<0.01 (<0.01)	<0.01 0.01	26
Harding Drain	101	0.95 (0.42)	<0.01 1.85	65	0.03 (0.04)	<0.01 0.21	65	0.87 (0.38)	<0.01 1.80	65	0.17 (0.11)	<0.01 0.53	65	0.16 (0.11)	<0.01 0.53	65
Del Puerto Crk	93.3	0.16 (0.13)	<0.01 0.52	42	0.01 (0.03)	<0.01 0.17	42	0.11 (0.08)	<0.01 0.32	42	0.01 (0.01)	<0.01 0.04	42	0.01 (0.01)	<0.01 0.03	42
Westport Drain	93	0.84 (0.44)	0.12 2.24	50	0.01 (0.01)	<0.01 0.07	50	0.75 (0.44)	0.04 2.19	50	0.02 (0.01)	<0.01 0.07	50	0.01 (0.01)	<0.01 0.06	50
MID Lat. 5 - Tuol.	83	0.05 (0.05)	<0.01 0.24	29	0.01 (0.01)	<0.01 0.06	29	0.03 (0.04)	<0.01 0.14	29	<0.01 (0.01)	<0.01 0.04	29	<0.01 (0.01)	<0.01 0.03	29
Ingram Crk	82.8	0.18 (0.19)	0.01 0.68	44	0.02 (0.03)	<0.01 0.11	44	0.13 (0.13)	0.01 0.45	44	0.01 (0.02)	<0.01 0.07	44	<0.01 (<0.01)	<0.01 0.01	44
Hospital Crk	82.8	0.03 (0.03)	<0.01 0.09	17	<0.01 (<0.01)	<0.01 0.01	17	0.02 (0.02)	<0.01 0.06	17	0.01 (0.01)	<0.01 0.02	17	<0.01 (<0.01)	<0.01 0.01	17
MID Main – Stan.	76.0	0.09 (0.16)	<0.01 0.87	36	0.03 (0.11)	<0.01 0.61	36	0.04 (0.05)	<0.01 0.19	36	0.02 (0.04)	<0.01 0.18	36	0.01 (0.03)	<0.01 0.15	36

Table 4: The percentage of nutrient concentrations originating from the various tributaries and drains compared to the mean load measured at the San Joaquin River at Vernalis.

	TN %	NO_3-N %	TP %	SRP %
San Joaquin River – Lander Avenue	11.6	5.4	17.3	17.7
Stanislaus	7.9	5.2	10.1	11.5
Tuolumne	25.1	21.4	21.8	17.7
Merced	19.2	20.0	10.1	7.3
Salt Slough	9.7	10.7	12.3	11.0
San Luis Drain	9.2	13.7	<0.1	<0.1
Mud Slough above San Luis Drain	2.4	0.6	3.9	3.0
Los Banos	0.9	0.4	2.2	2.1
TID Lat. 6/7	5.4	8.0	1.7	2.1
Orestimba Creek	1.0	1.4	<0.1	<0.1
Ramona Lake	1.0	0.8	<0.1	<0.1
Harding Drain	7.1	10.5	9.5	16.7
Del Puerto Creek	1.2	1.3	<0.1	1.0
Westport Drain	6.3	9.0	0.1	1.0
MID Lat. 5 – Tuol.	0.4	0.4	<0.1	<0.1
Ingram Creek	1.3	1.6	<0.1	<0.1
Hospital Creek	0.2	0.2	<0.1	<0.1
MID Main – Stan.	0.7	0.5	0.1	1.0
Sum	**110.6**	**111.1**	**89.1**	**92.1**

Figure 1: Distribution of total nitrogen concentrations for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom). The median (line), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed.

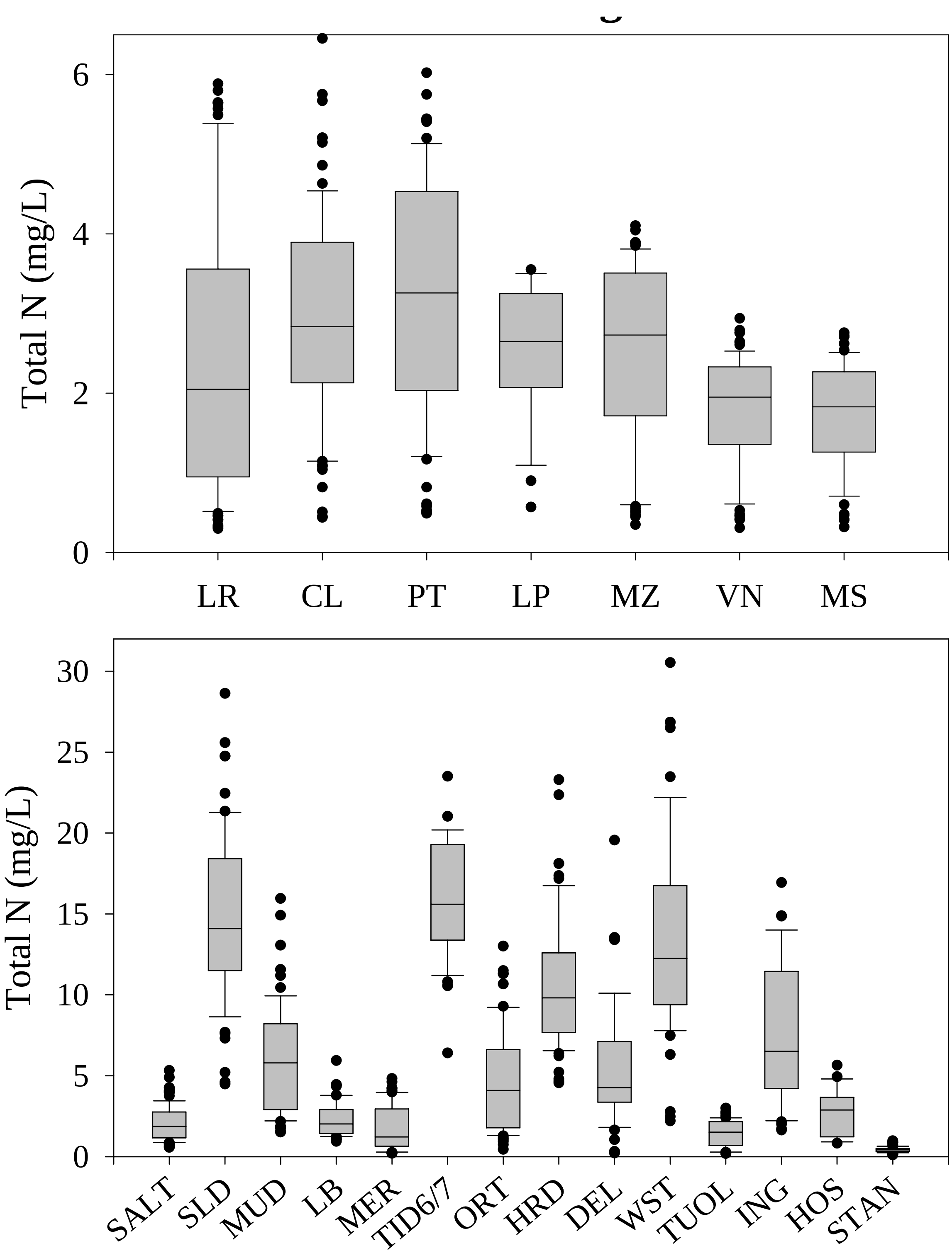


Figure 2: Distribution of ammonium concentrations for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom). The median (line), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed.

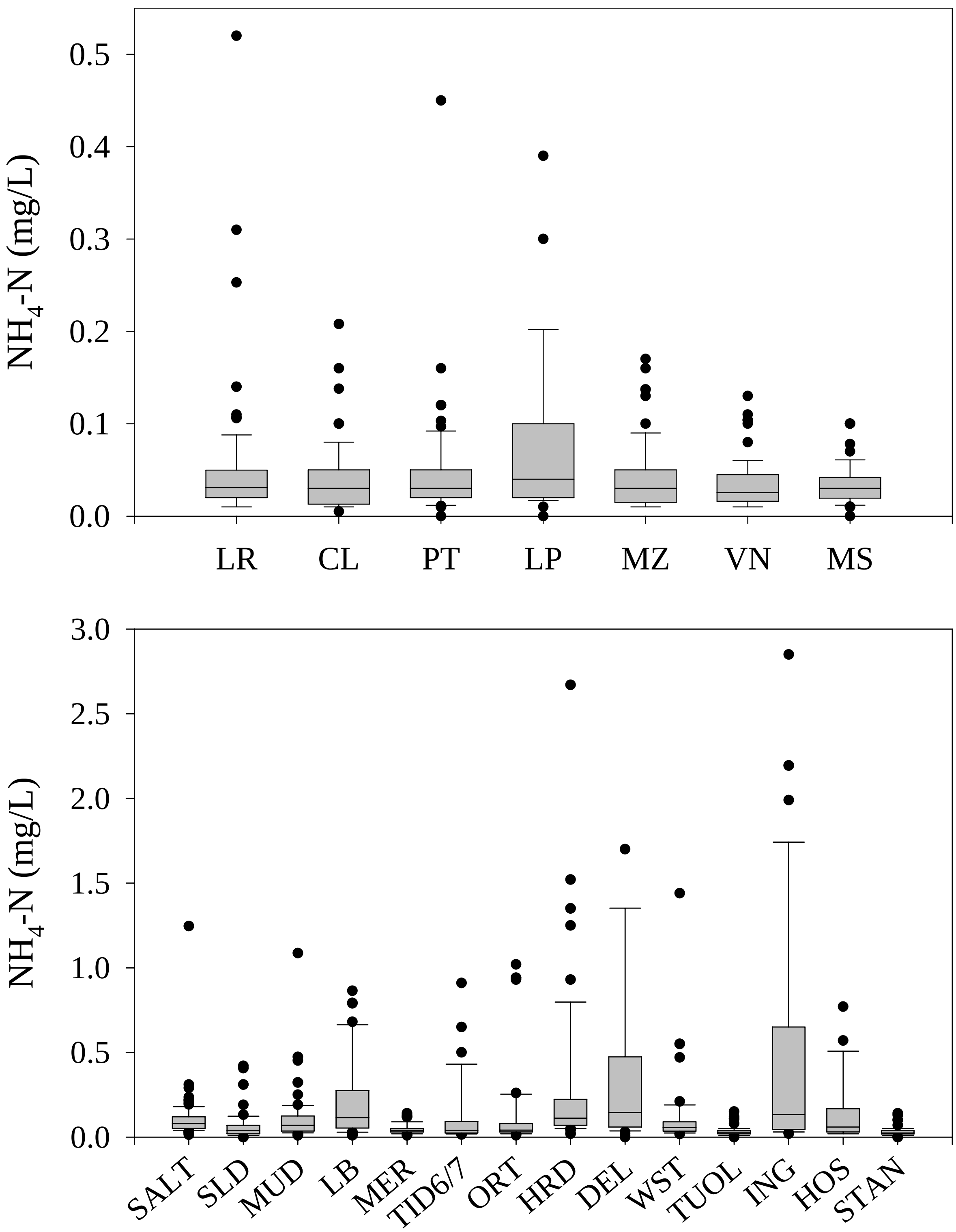


Figure 3: Distribution of nitrate concentrations for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom). The median (line), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed.

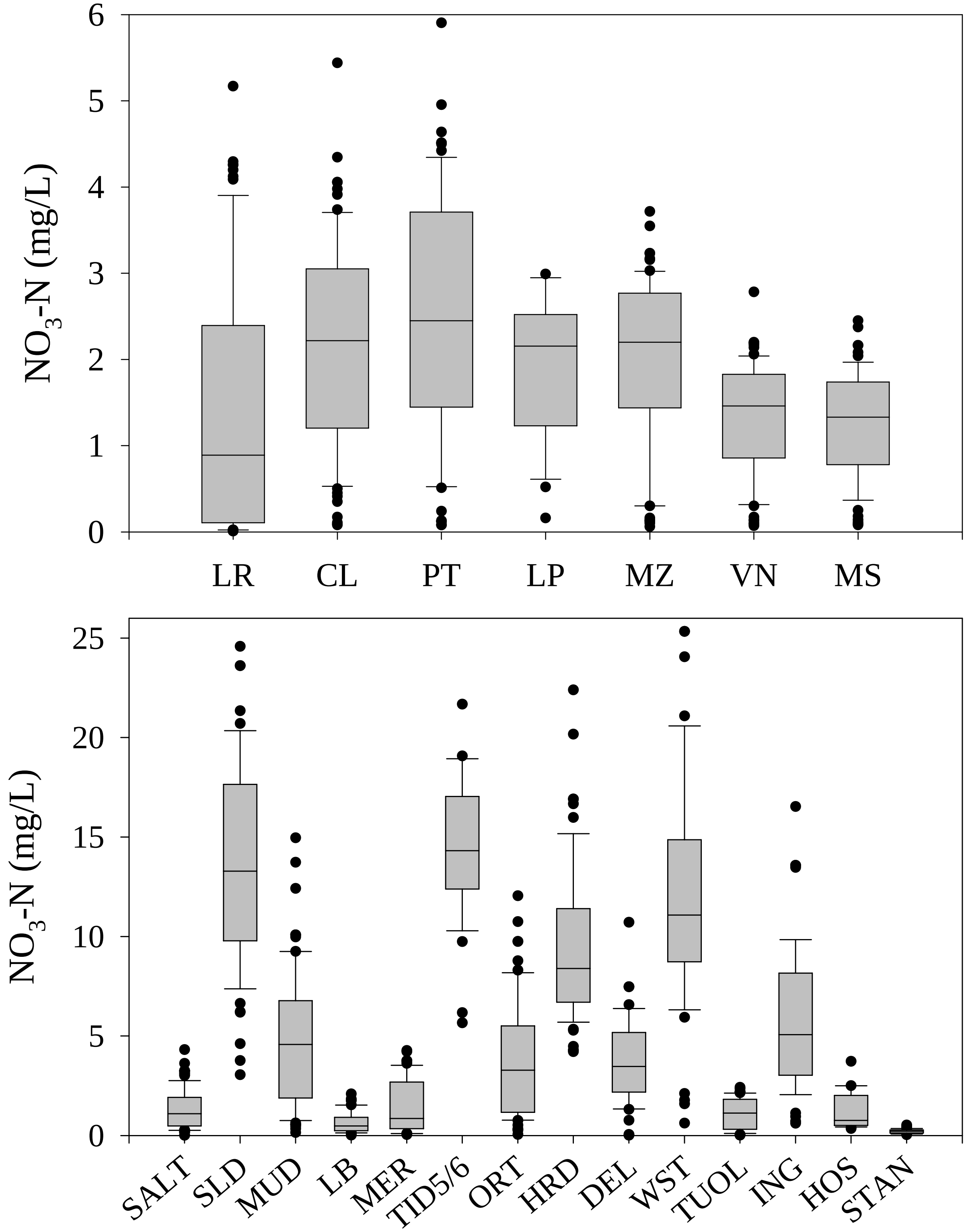


Figure 4: Distribution of total phosphorus concentrations for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom). The median (line), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed.

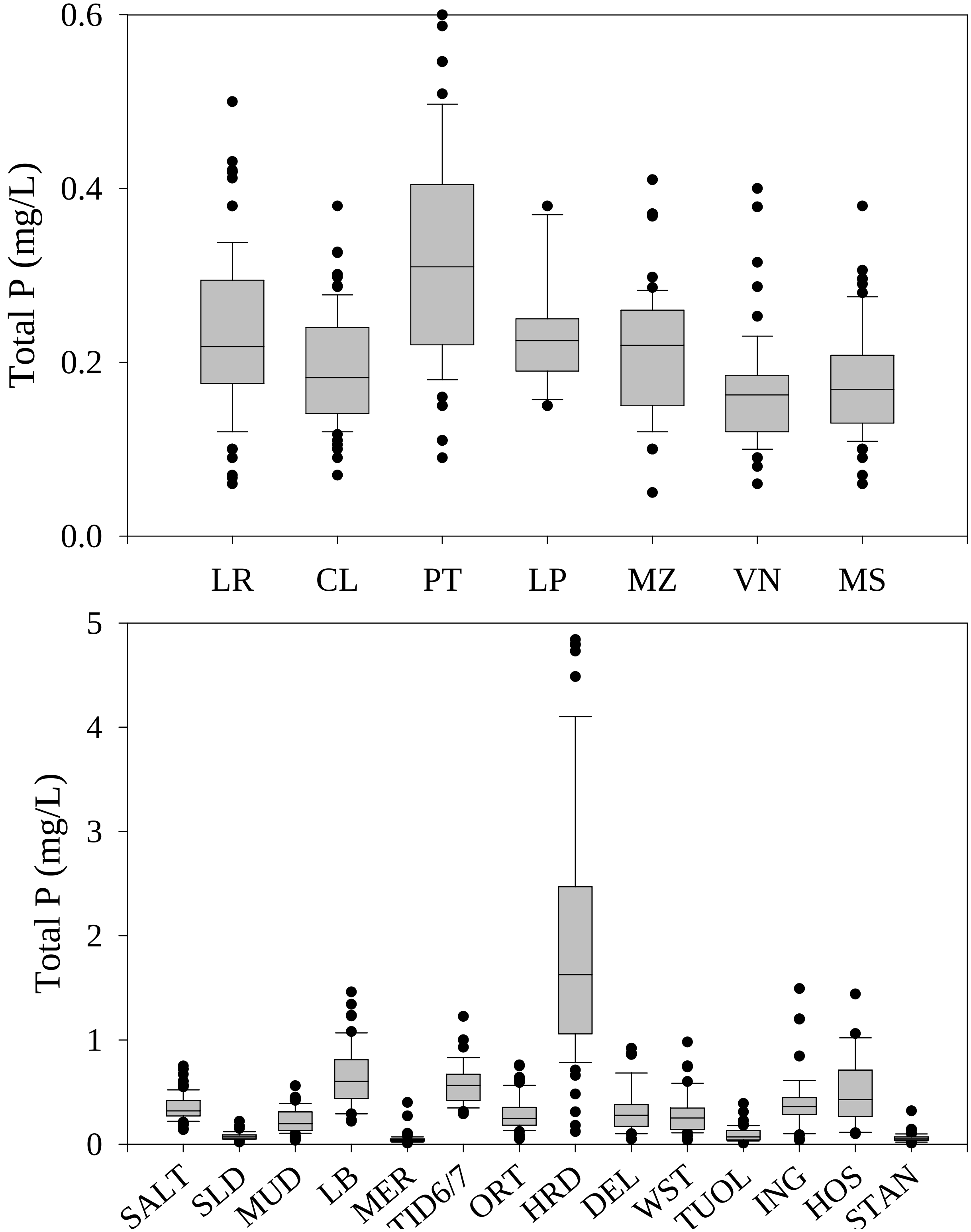


Figure 5: Distribution of soluble-reactive phosphate concentrations for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom). The median (line), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed.

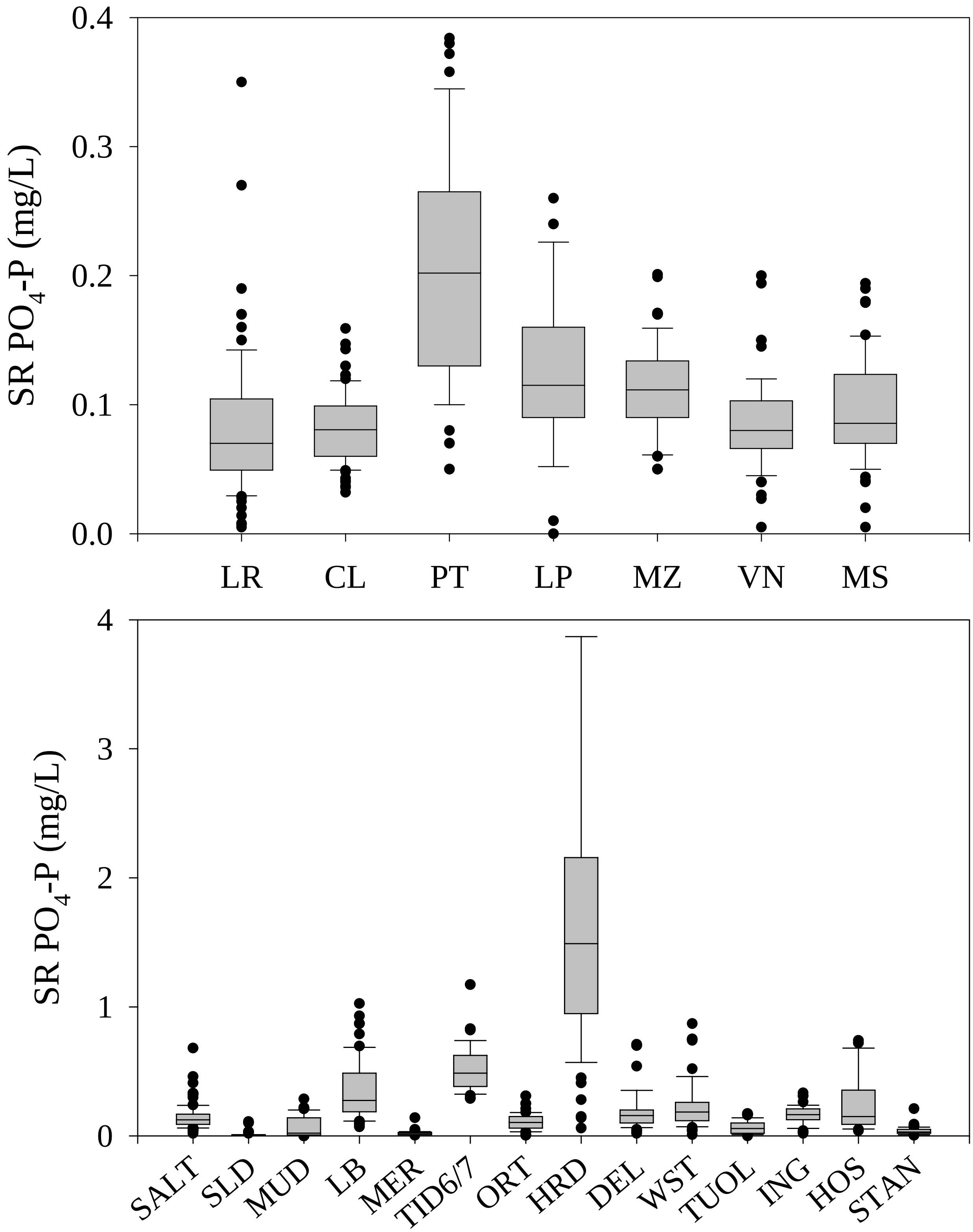


Figure 6: Distribution of total nitrogen loads for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom) for the study period (March 2005 to December 2007). The median (line), mean (dashed), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed. The line represents the cumulative loads based on the mean daily loads from tributaries and drains located above each mainstem site.

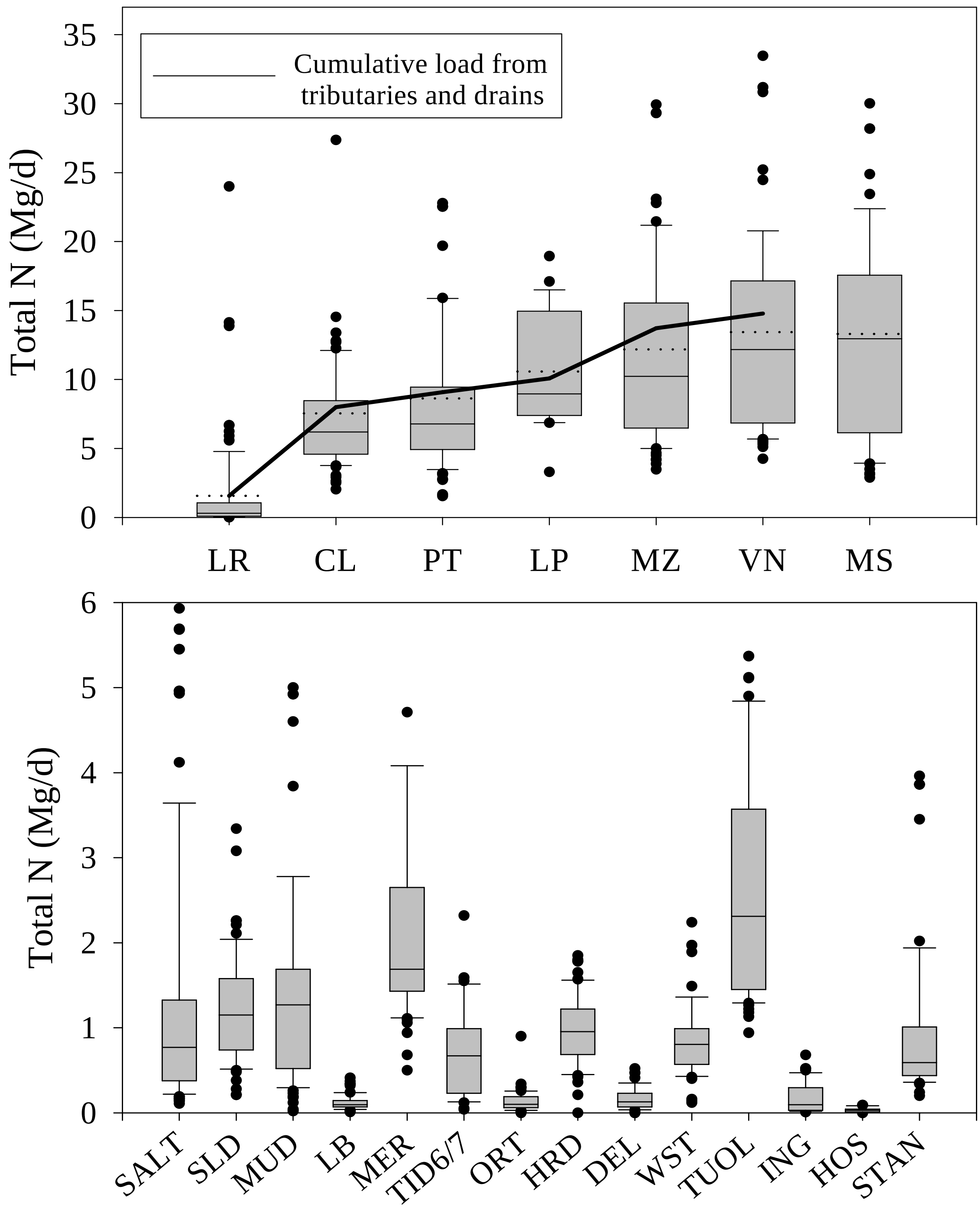


Figure 7: Distribution of nitrate-N loads for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom) for the study period (March 2005 to December 2007). The median (line), mean (dashed), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed. The line represents the cumulative loads based on the mean daily loads from tributaries and drains located above each mainstem site.

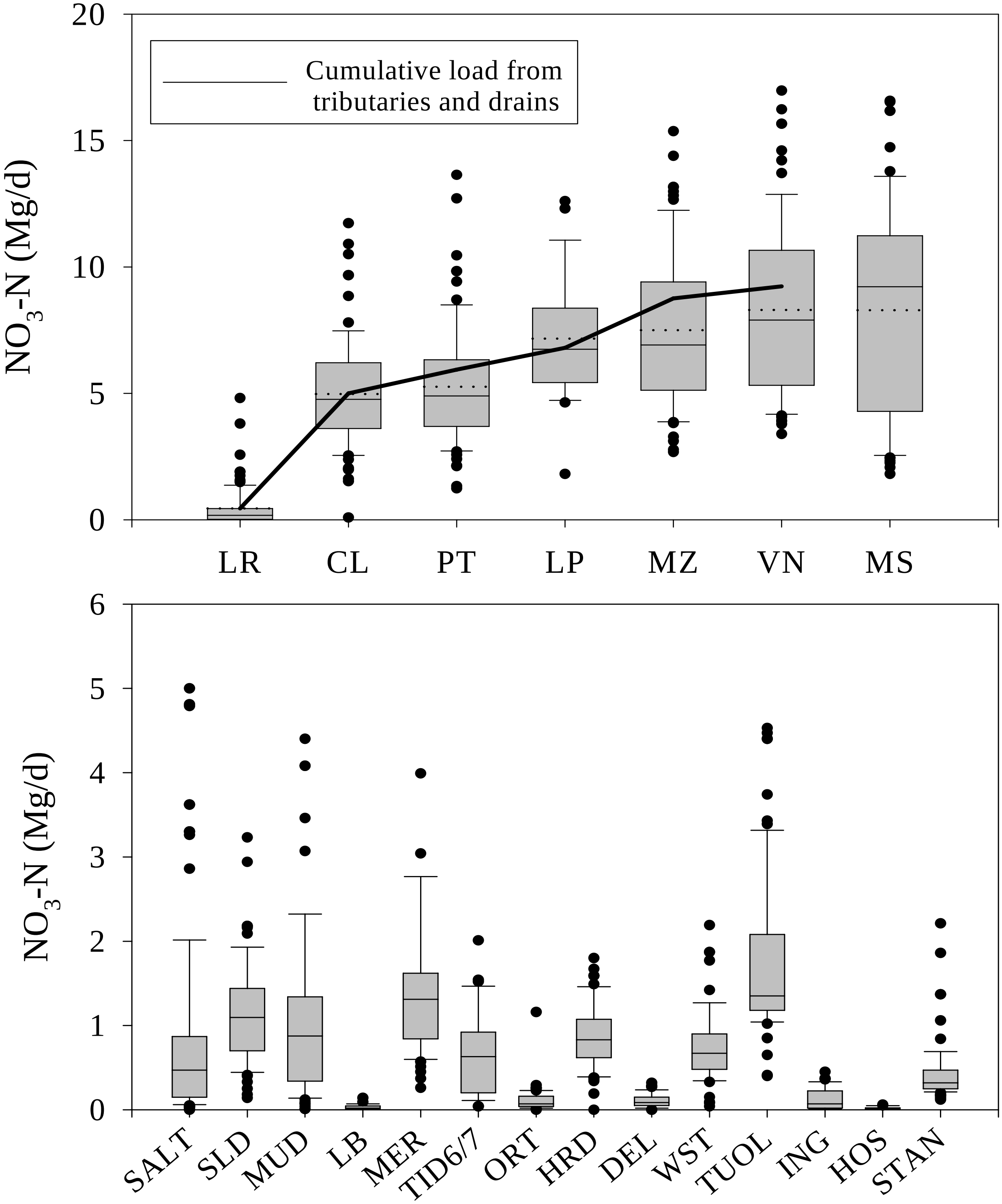


Figure 8: Distribution of ammonium-N loads for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom) for the study period (March 2005 to December 2007). The median (line), mean (dashed), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed. The line represents the cumulative loads based on the mean daily loads from tributaries and drains located above each mainstem site.

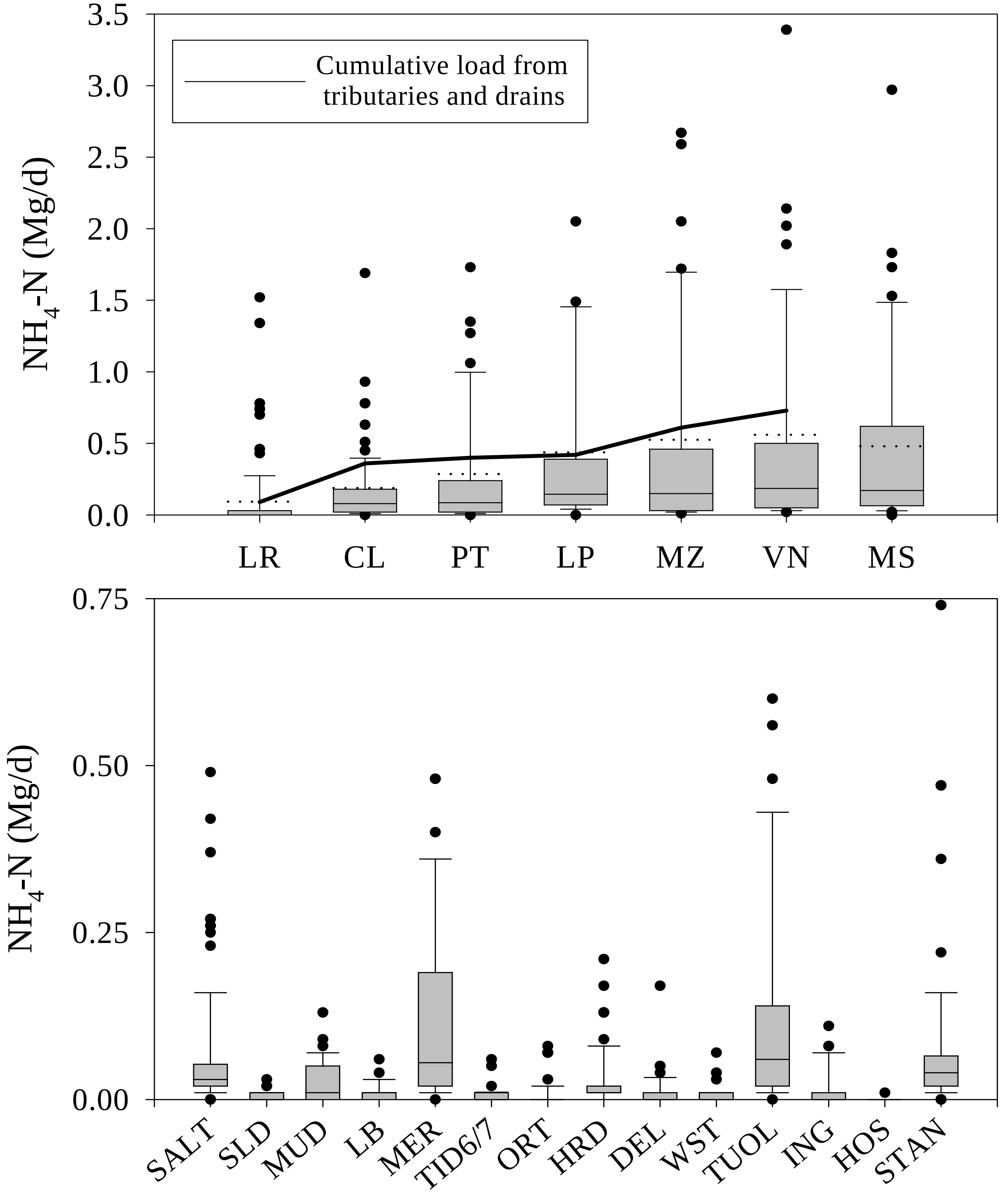


Figure 9: Distribution of total phosphorus loads for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom) for the study period (March 2005 to December 2007). The median (line), mean (dashed), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed. The line represents the cumulative loads based on the mean daily loads from tributaries and drains located above each mainstem site.

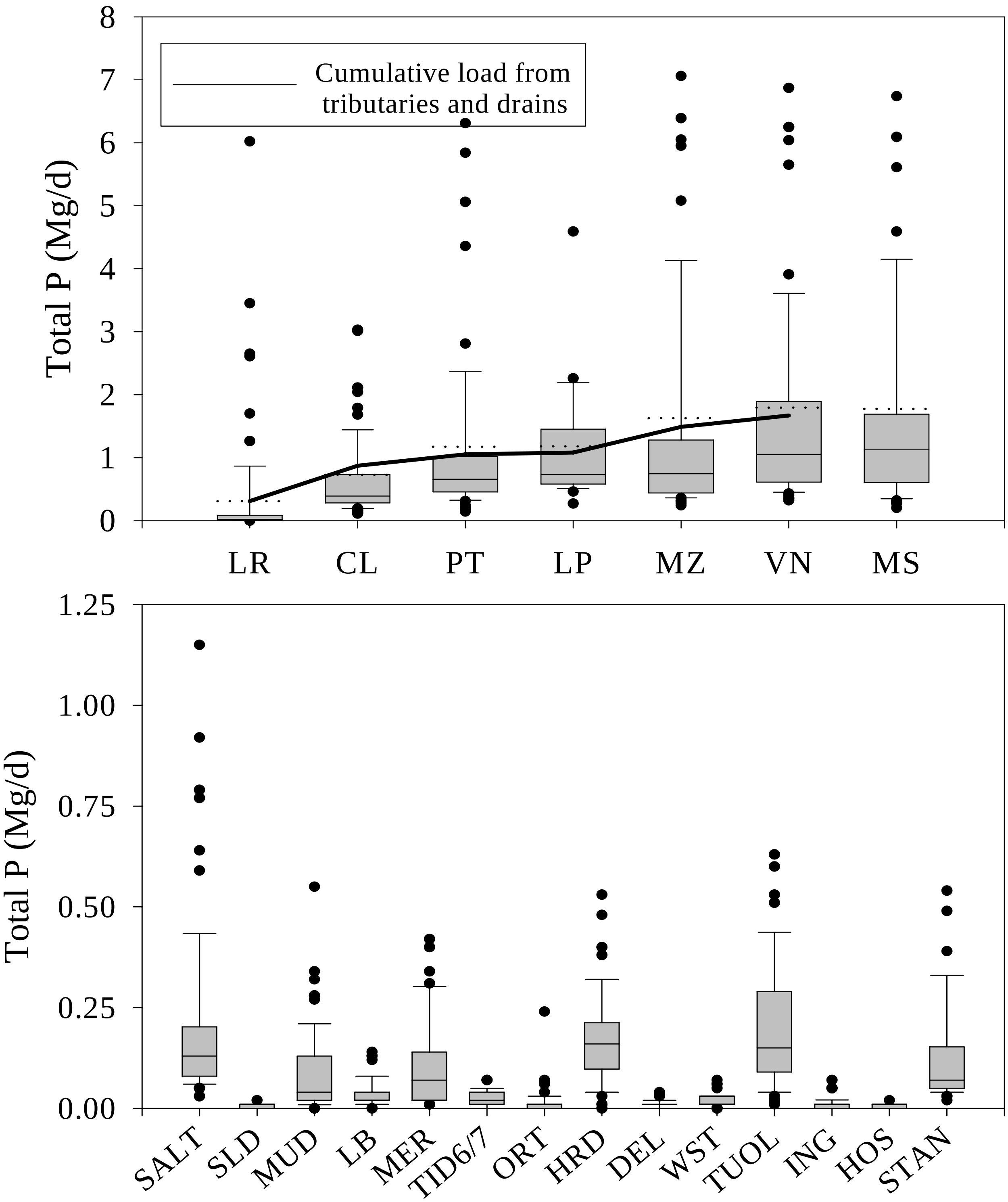


Figure 10: Distribution of soluble-reactive phosphate loads for San Joaquin River mainstem sites (top) and major tributaries and drains (bottom) for the study period (March 2005 to December 2007). The median (line), mean (dashed), 25th and 75th percentile (box), 10th and 90th percentile (whisker), and outlier points (points) are displayed. The line represents the cumulative loads based on the mean daily loads from tributaries and drains located above each mainstem site.

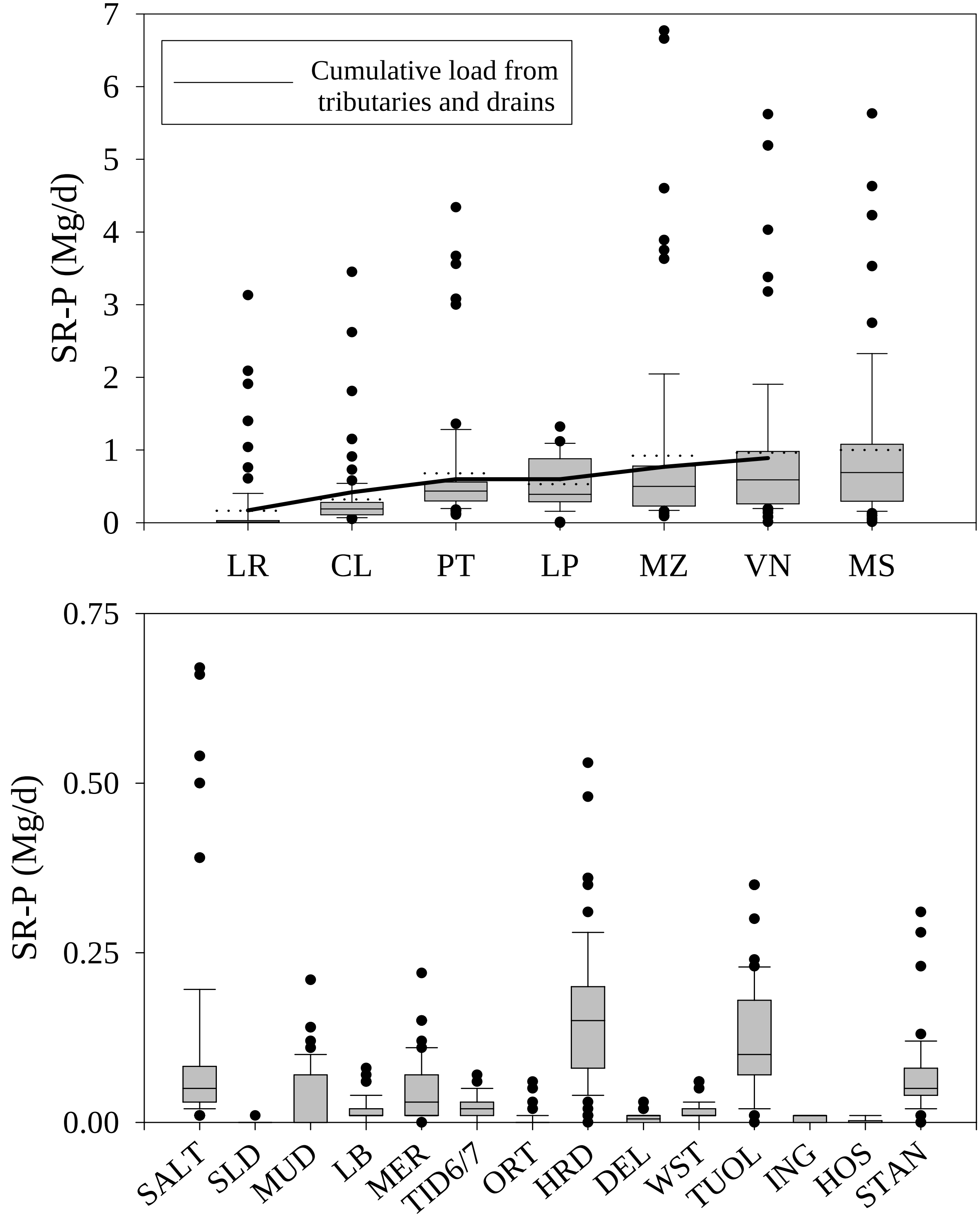


Figure 11: Long-term nitrate-N concentrations for the San Joaquin River at Vernalis.

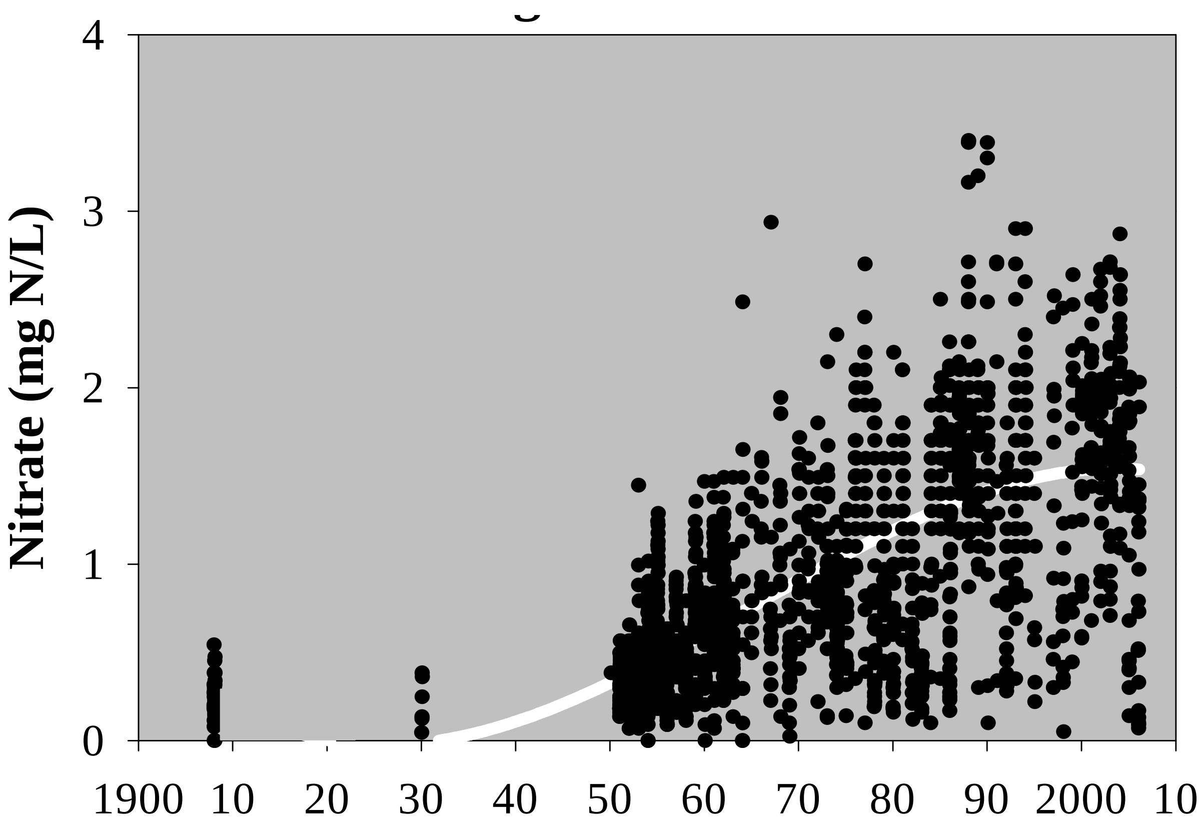


Figure 12: Temporal variability in total N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

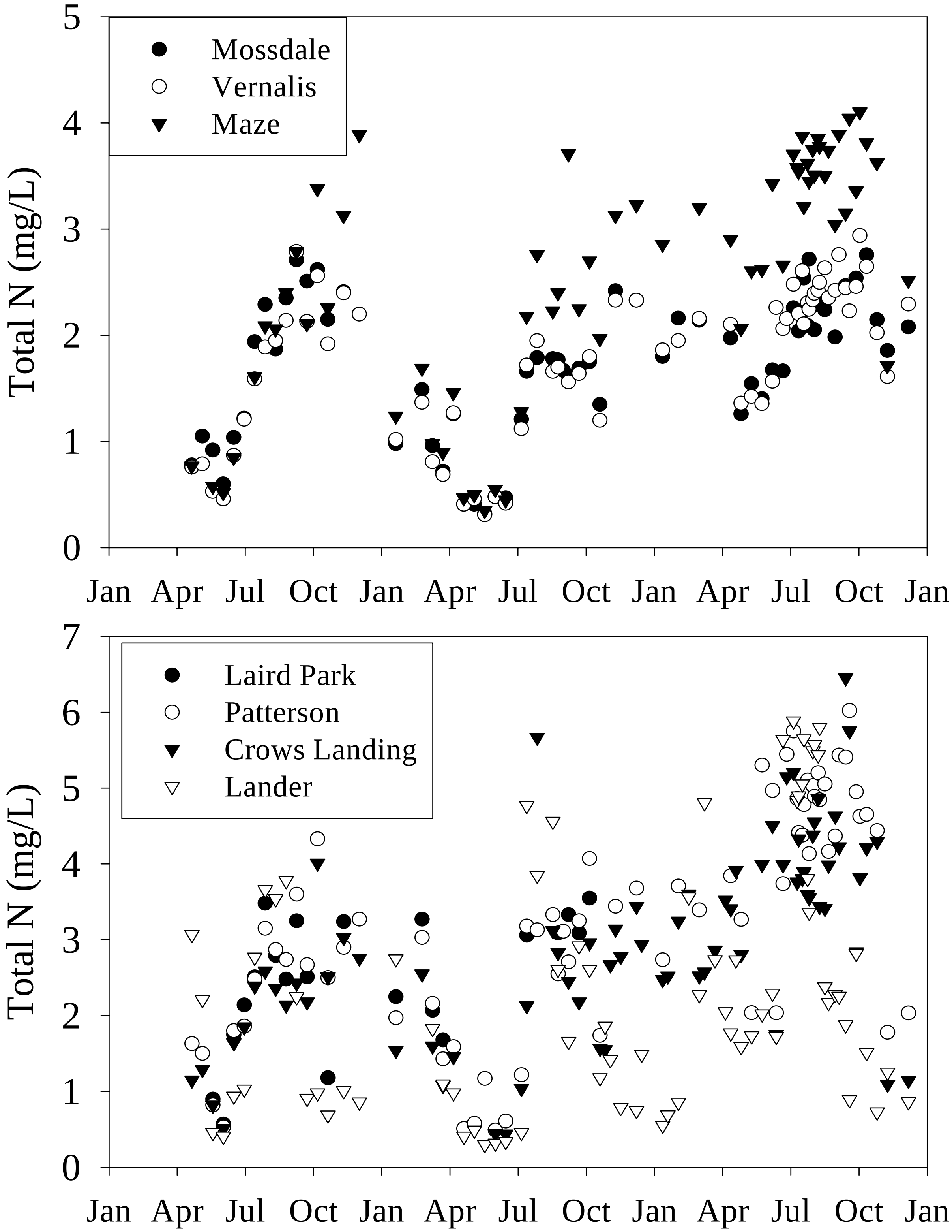


Figure 13: Temporal variability in total N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

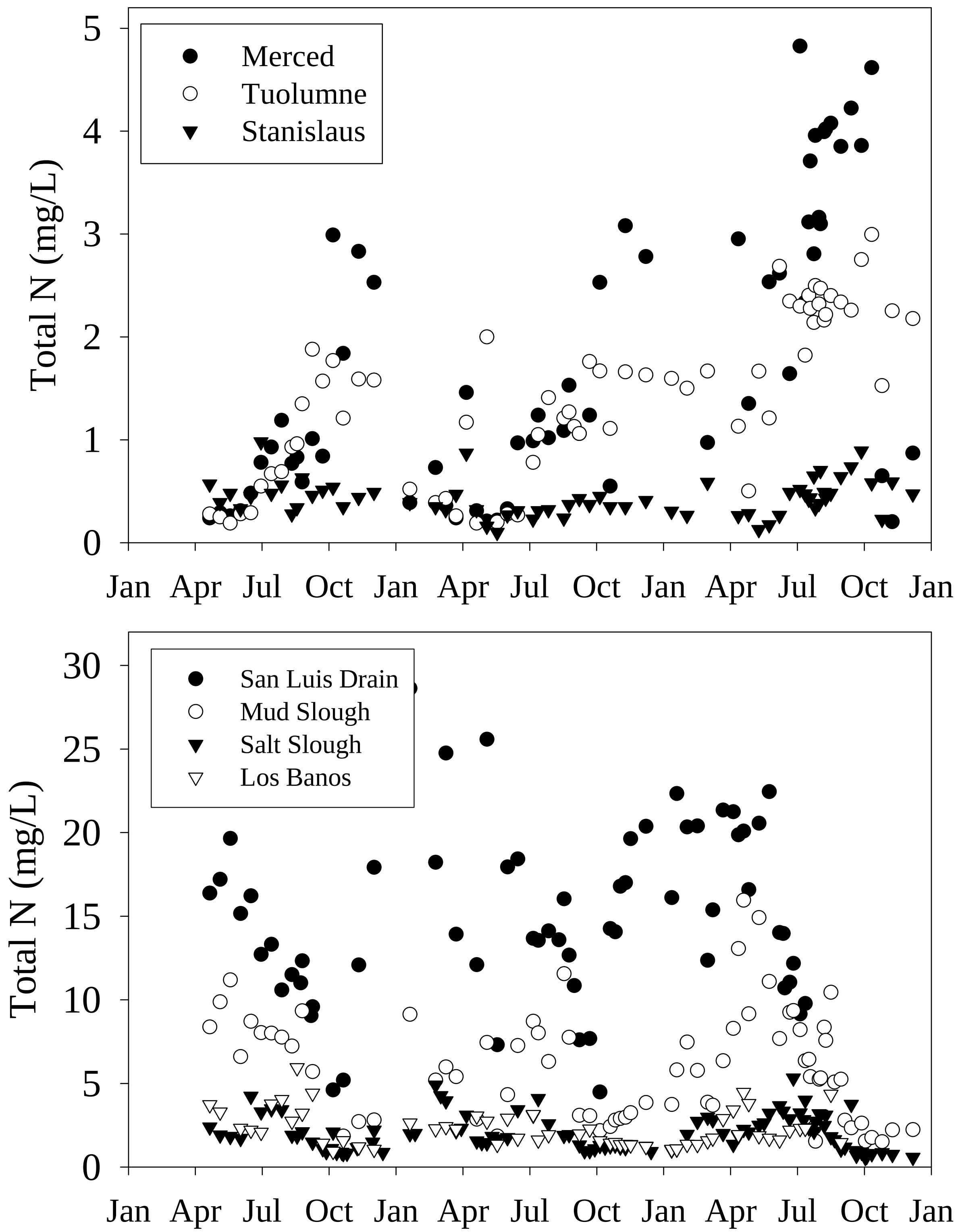


Figure 14: Temporal variability in total N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

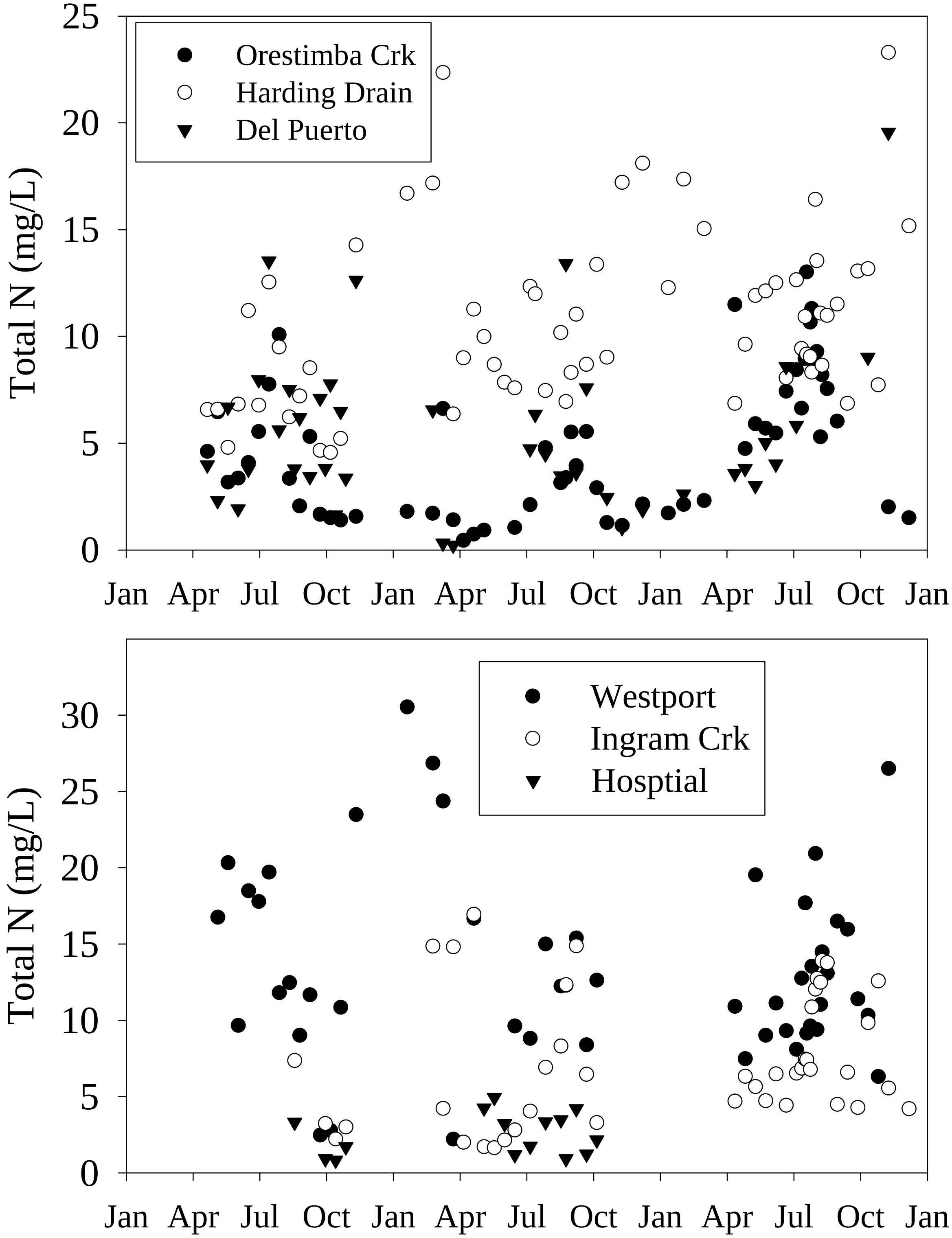


Figure 15: Temporal variability in nitrate-N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

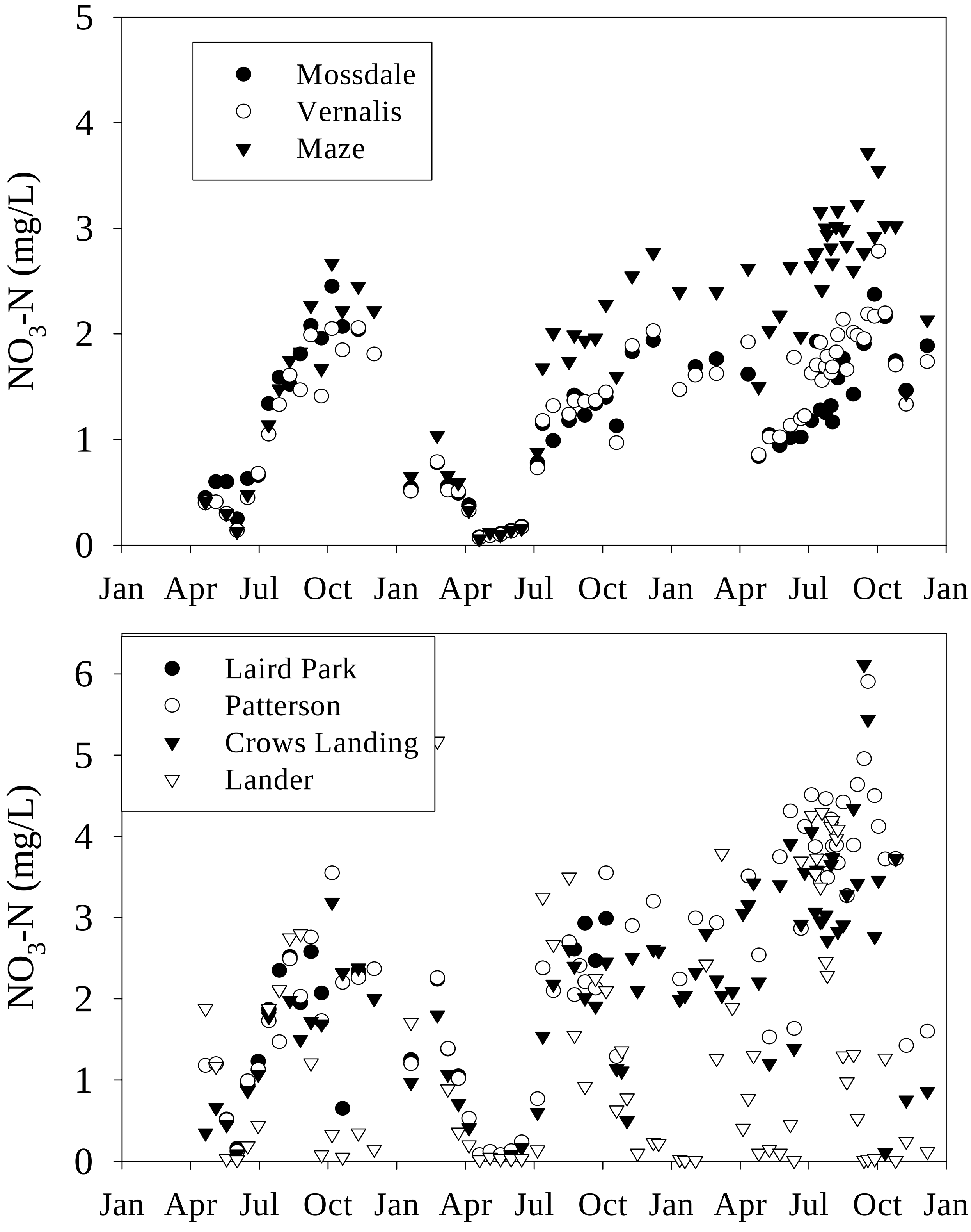
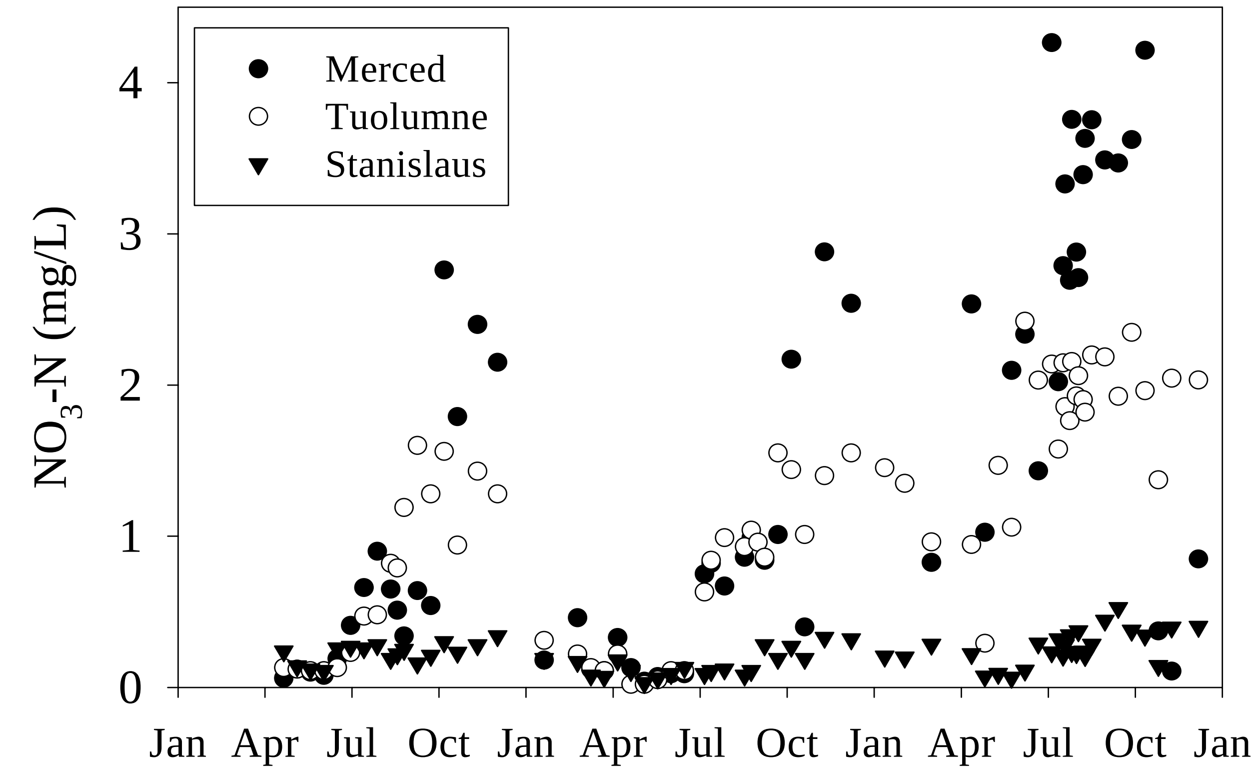


Figure 16: Temporal variability in nitrate-N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.



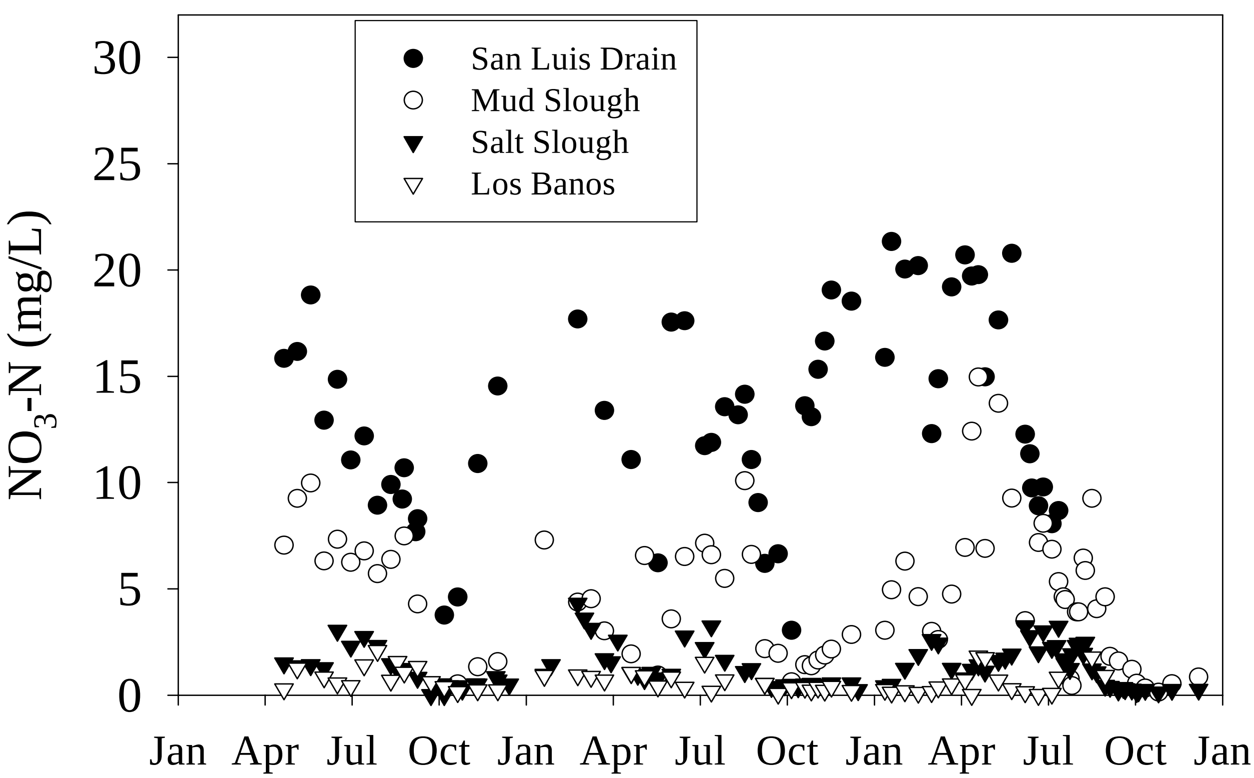


Figure 17: Temporal variability in nitrate-N concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

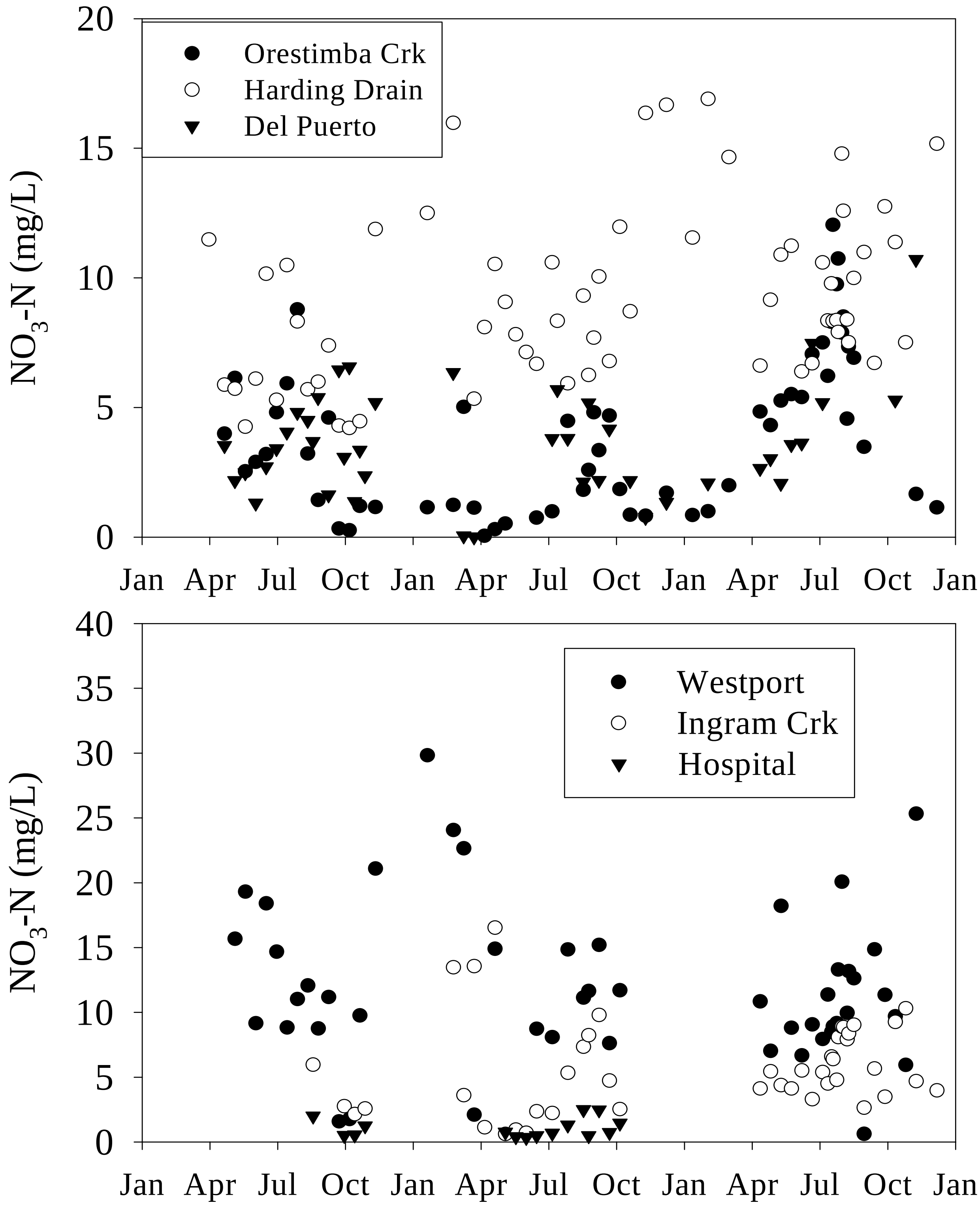
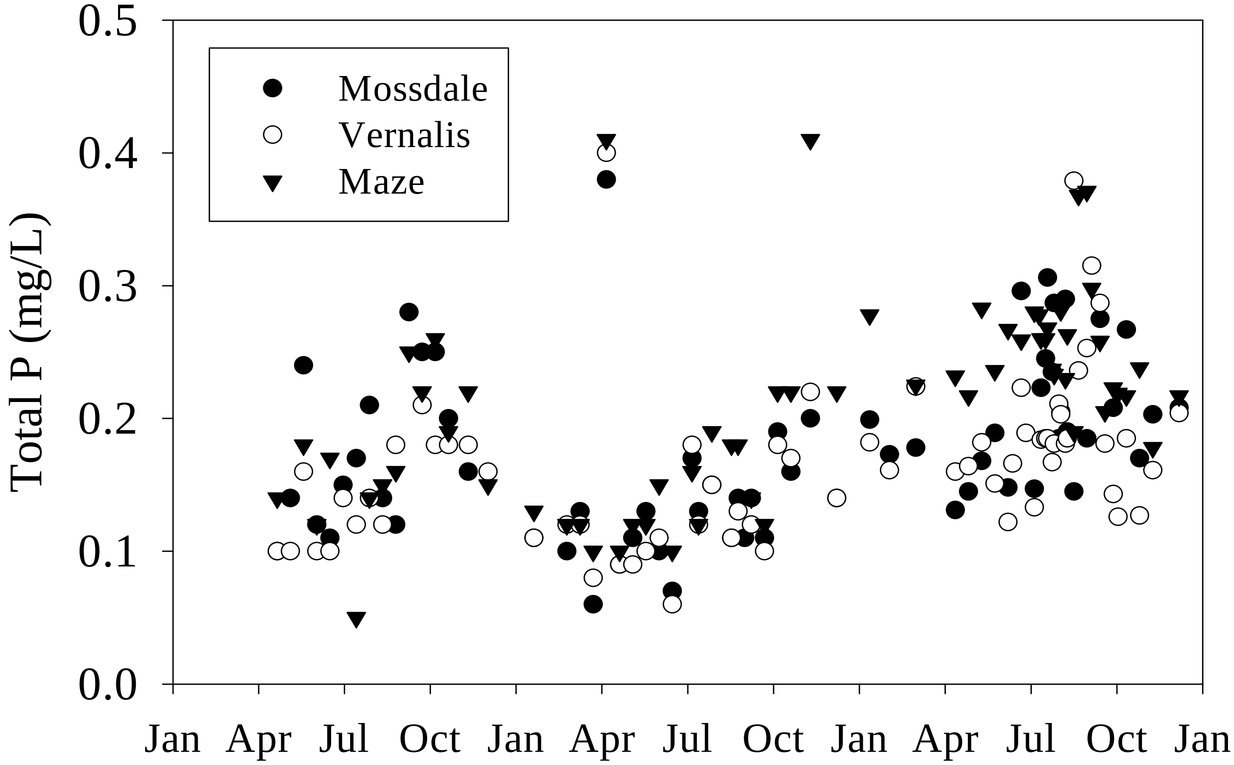


Figure 18: Temporal variability in total phosphorus concentrations for selected sites in the San Joaquin River watershed during 2005-2007.



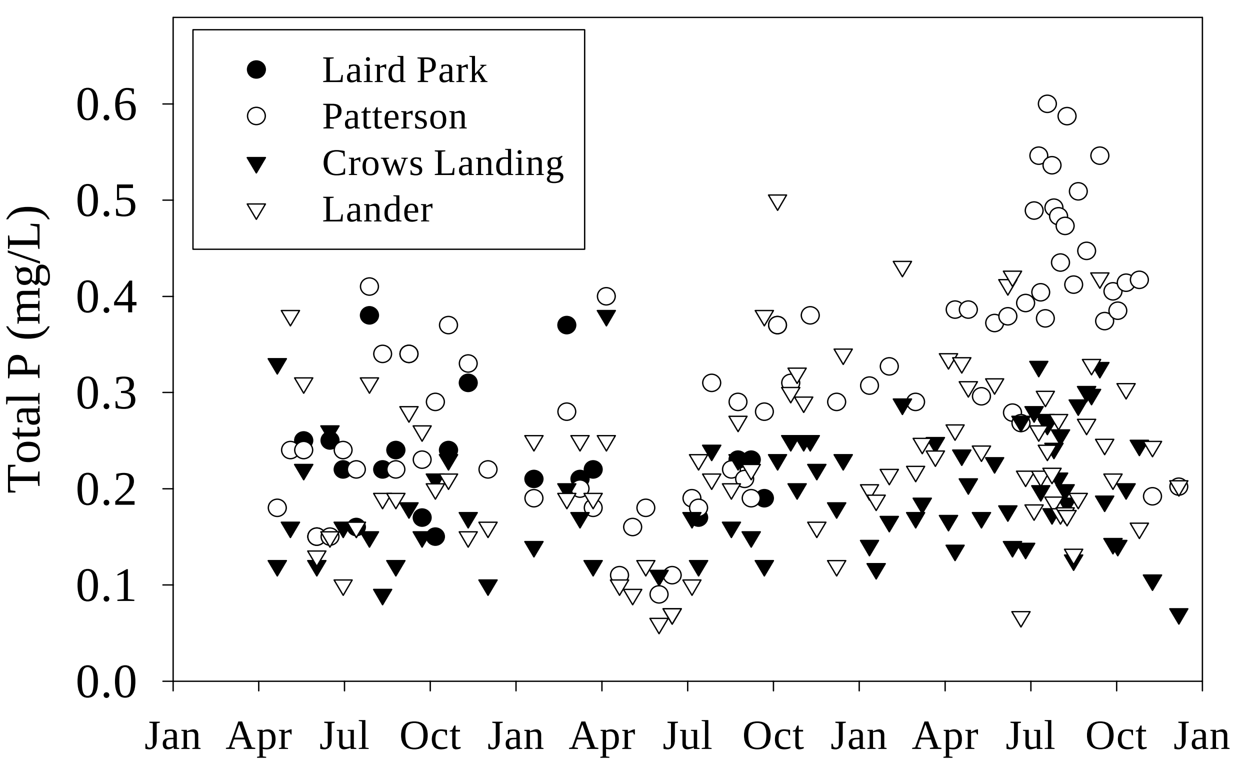


Figure 19: Temporal variability in total phosphorus concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

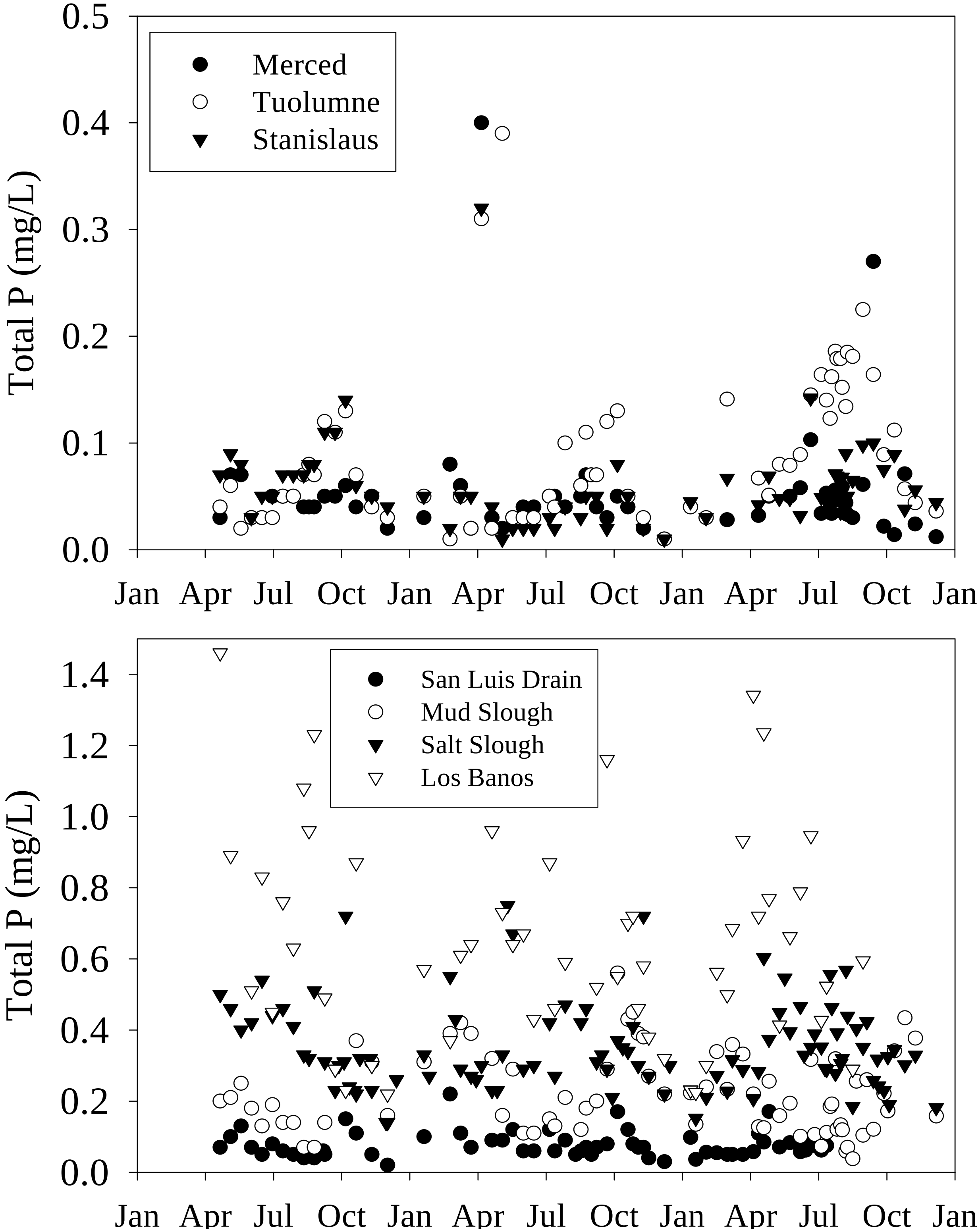


Figure 20: Temporal variability in total phosphorus concentrations for selected sites in the San Joaquin River watershed during 2005-2007.

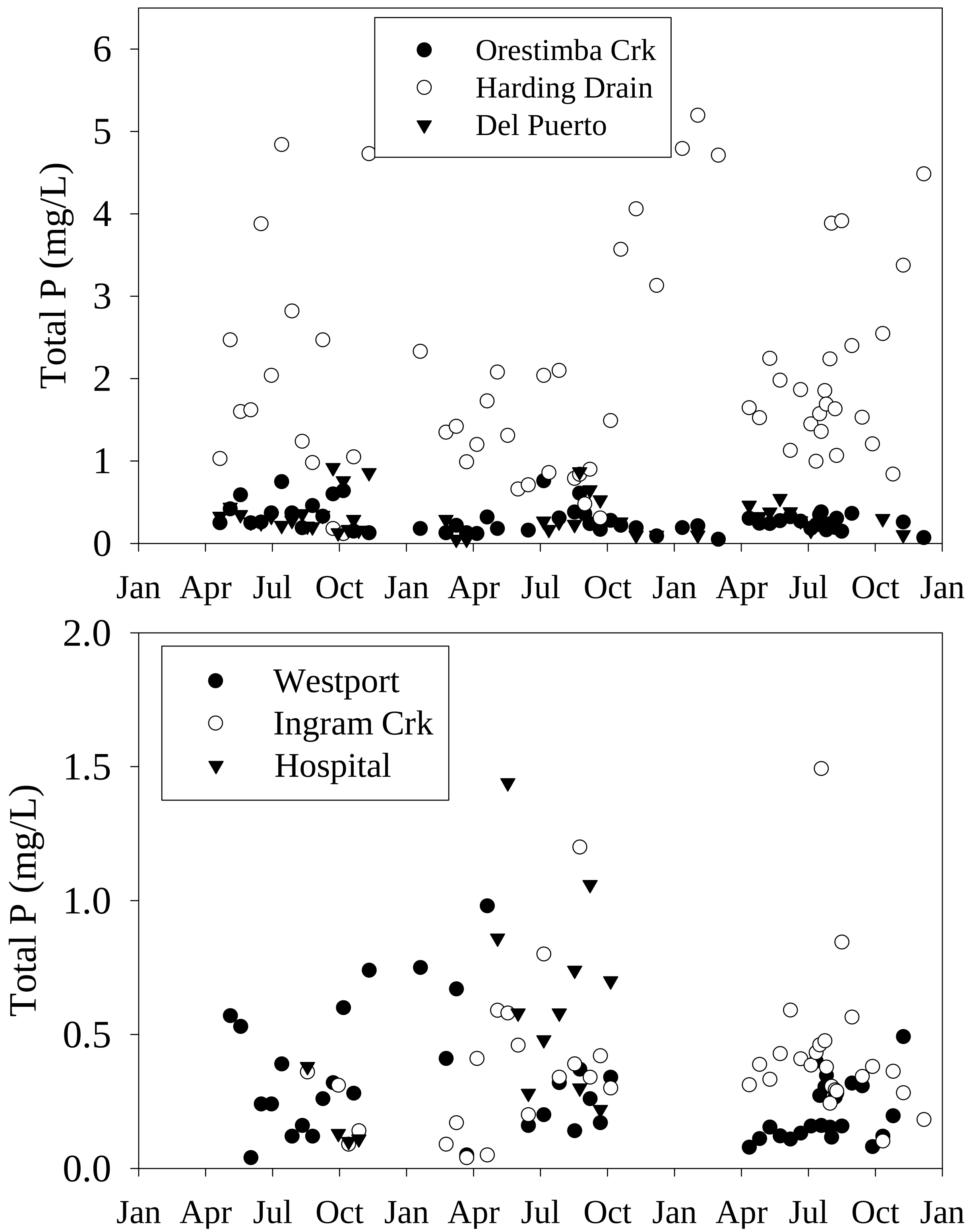
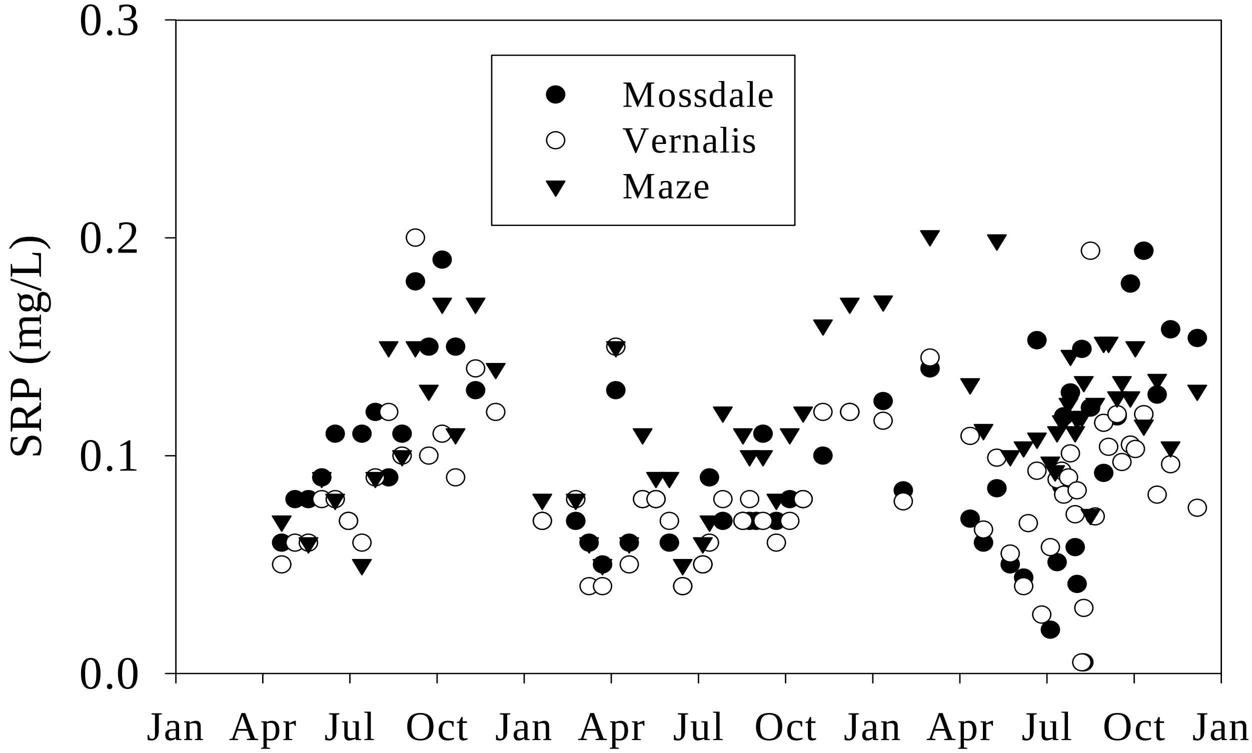


Figure 21: Temporal variability in soluble-reactive phosphate concentrations for selected sites in the San Joaquin River watershed during 2005-2007.



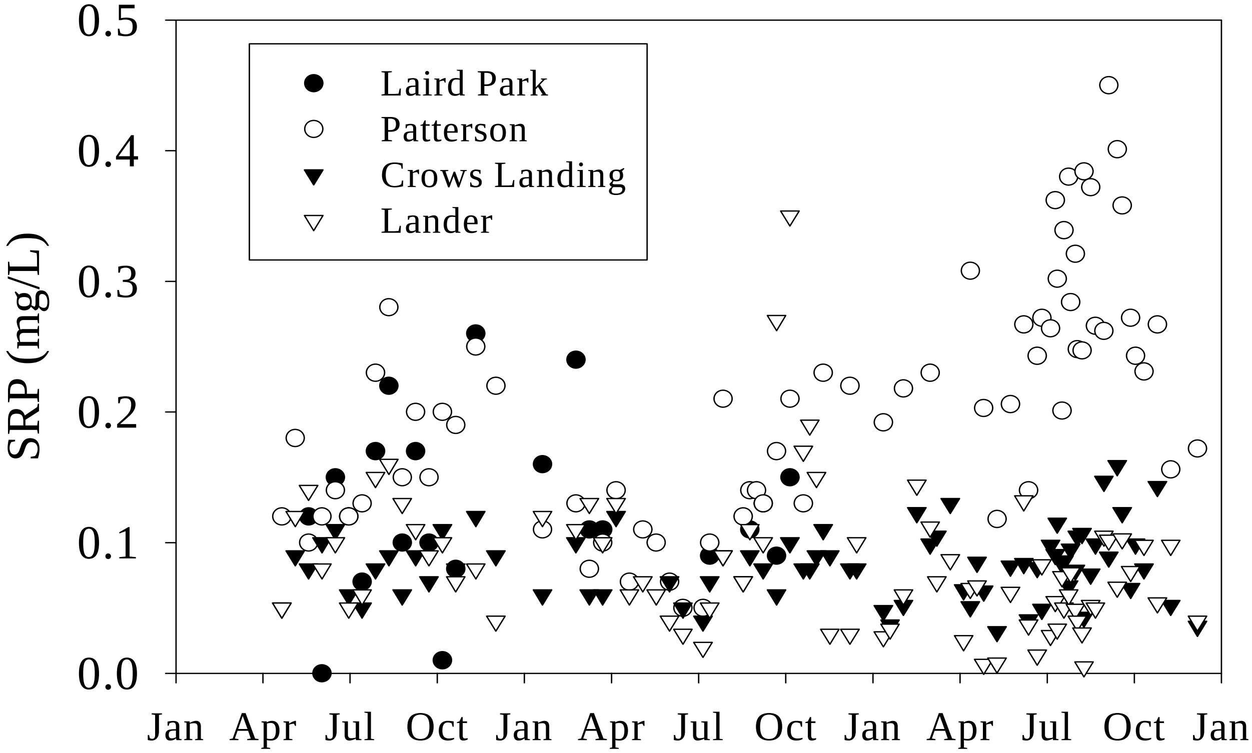
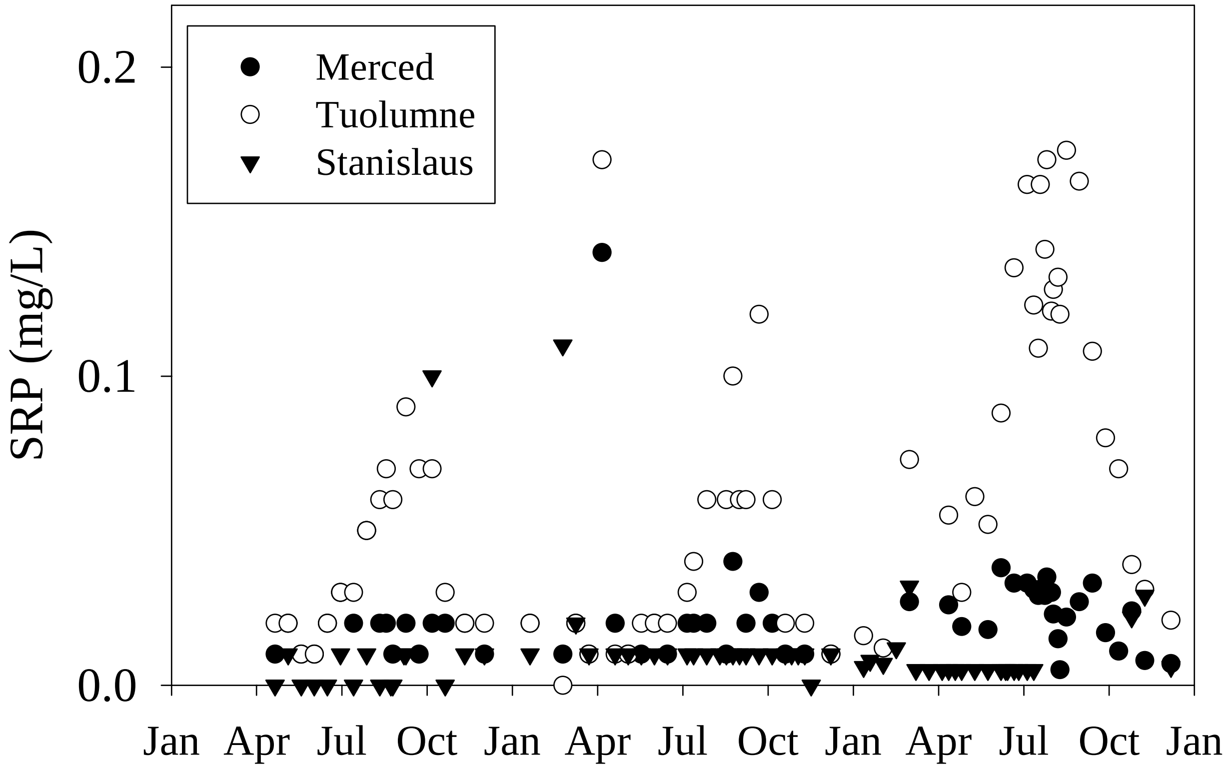


Figure 22: Temporal variability in soluble-reactive phosphate concentrations for selected sites in the San Joaquin River watershed during 2005-2007.



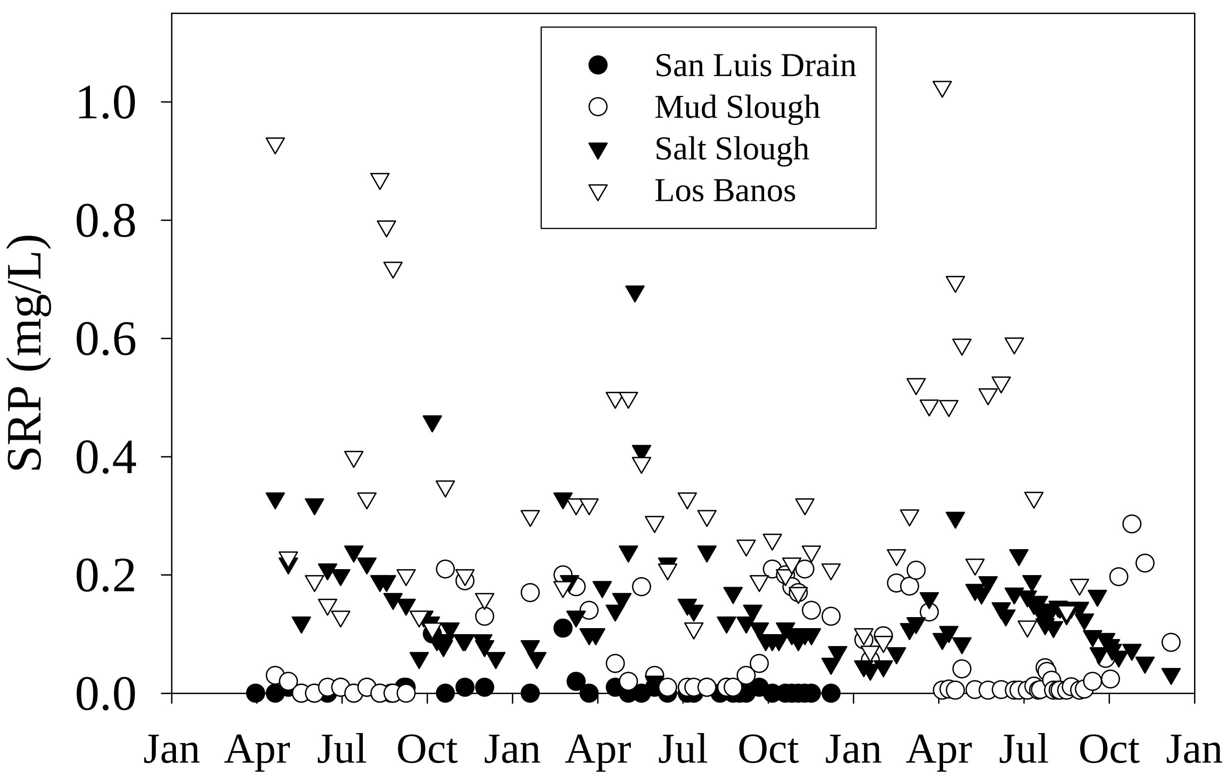


Figure 23: Temporal variability in soluble-reactive phosphate concentrations for selected sites in the San Joaquin River watershed during 2005-2007.