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# Nutrient Stormwater Monitoring Results: WY 2012 and WY 2013

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# Nutrient Stormwater Monitoring

WY 2012 and WY 2013

Final

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## Acknowledgements

This work was funded by the San Francisco Bay Regional Monitoring Program. We are grateful to the Bay Area Stormwater Management Agencies Association (BASMAA) for their cooperation in this effort, and to Chris Sommers (BASMAA) for originally suggesting the piggybacking approach. Thanks to the field teams – SFEI staff and several external groups – who set up sites, organized the program, and collected samples wet conditions and at unpredictable and odd hours. Thanks also to Caltest Anaytical Laboratory (Napa, CA) for their cooperation on this effort and their willingness to establish and test lab methods with detection limits more appropriate for stormwater samples, and for their expert analysis of those samples.

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Background

San Francisco Bay has long been recognized as a nutrient-enriched estuary, but one that has exhibited resistance to some of the classic symptoms of nutrient overenrichment, such as high phytoplankton biomass and low dissolved oxygen. However, recent observations indicate that the Bay's resistance to high nutrient loads is weakening, leading regulators and stakeholders to collaboratively develop the San Francisco Bay Nutrient Strategy (SFBRWQCB, 2012). The Nutrient Strategy lays out an approach for building the scientific foundation to inform the upcoming nutrient management decisions.

Among its recommendations, the Nutrient Strategy calls for quantifying nutrient loads to San Francisco Bay from external sources. A recent study found that estimated nutrient loads exhibit considerable seasonal and spatial variability in their magnitudes (kg/d N and P), form of N, and major source(s) (SFEI #704, 2014). Bay-wide, the largest nutrient sources were publicly owned wastewater treatment works (POTWs). Only rough stormwater load estimates were possible because of data and model limitations. The best readily available tool for estimating stormwater loads (the Regional Watershed Spreadsheet Model,Mckee and Lent 2011) has not been calibrated or validated for nutrients, or for monthly-scale load estimates. Moreover, there is currently limited data from Bay Area watersheds to calibrate N and P loads using that or other models. Although in most cases estimated stormwater nutrient loads appeared small relative to other sources (POTW loads, loads entering from the Delta), those estimates were considered highly uncertain (SFEI 2014). In addition, because loads were compared at the subembayment scale, the potential importance of stormwater-derived loads at smaller spatial scales could not be assessed (e.g., contribution to Bay margin habitats, such as sloughs or wetlands)

Developing accurate estimates for nutrient loads entering SFB from regional watersheds will require both robust models and empirical data to calibrate those models. To address the empirical data gaps, the Regional Monitoring Program (RMP), in partnership with the Bay Area Stormwater Management Agencies Association (BASMAA), began measuring nutrient concentrations in stormwater samples being collected as part of a multi-year, multi-contaminant stormwater monitoring effort. Nitrate ($NO_3^-$), ortho-phosphate (o-$PO_4$) and total phosphorous (TP) were part of the original study design; for a modest additional cost, the RMP was able to capitalize on the sampling effort and add additional nutrient measurements to round out the suite of analytes (ammonium ($NH_4^+$), nitrate ($NO_2^-$) and total kjeldahl nitrogen (TKN)). This short report aims to

- Document nutrient concentrations measured in the six monitoring watersheds during Water Year (WY) 2012 and WY2013; and

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- Characterize variability of nutrient concentrations within storms, between storms and between sites to inform potential next steps with nutrient-related monitoring;

# 1. Water Year 2012 and 2013 Data

## 2.1 Sampling locations and climate

Four watersheds in the San Francisco Bay region were sampled in WY2012 and two additional watersheds were added in WY 2013 (Figure 1Figure 1; Table 1). These watersheds were also monitored in WY2014, but that data was not available at the time of this report's completion. The watersheds represent a range of land use and land cover characteristics (Table 1), and were selected and monitored as part of a larger effort to satisfy monitoring requirements for other pollutants of the concern under the Municipal Regional Permit (MRP). Although nutrients were not the main focus of this multi-year monitoring project, three nutrient parameters were included as part of the MRP-required effort ($NO_3^-$, o-$PO_4$ and TP), and the RMP funded three additional non-MRP nutrients ($NH_4^+$, $NO_2^-$ and TKN). The combined suite of nutrient analytes matches the type of information being collected in the United States Geological Survey (USGS) monthly Bay surveys, as well as data that may be collected in the near future at some regional POTWs. Both WY 2012 and 2013 were dry years relative to average annual conditions. Mean annual precipitation and flow across all locations/water years were 68% and 61%, respectively, of long-term average conditions and not higher than 89% or 82% at any single site (Table 2, for sites where long-term data were available), despite a notable storm series that occurred during late November and December of WY 2013. In that sense, the results may not reflect what might be measured during wetter years.

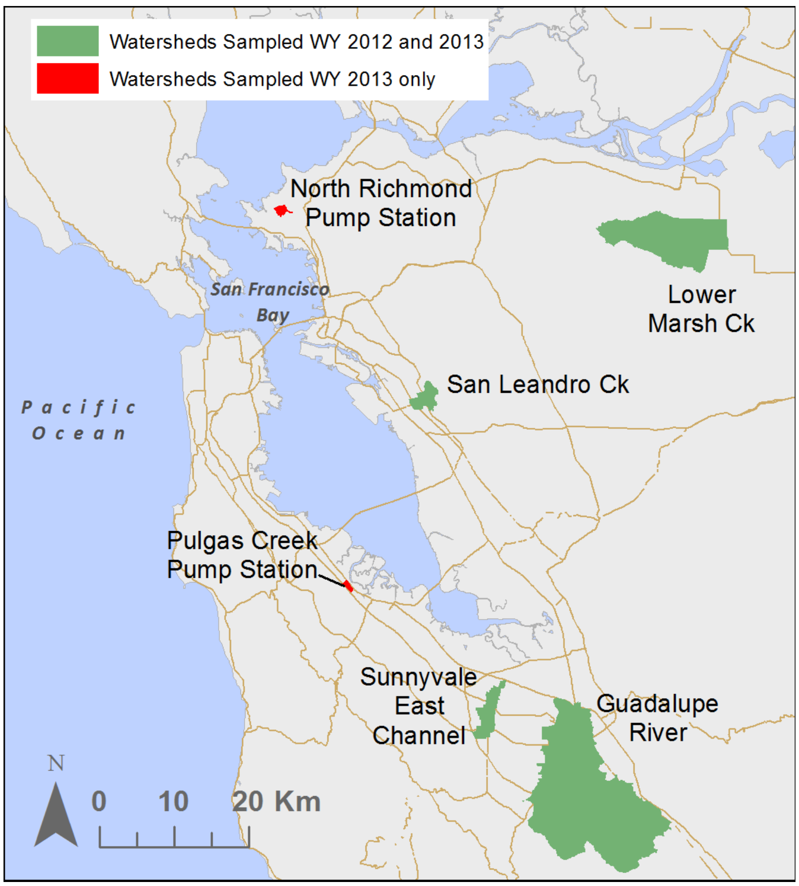


Figure 1. Water year 2012 and 2013 sampling watersheds

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**Table 1. Sampling locations and land uses at each site**

| County program | Watershed name | Water years sampled | Watershed area ($km^2$) | City | Agriculture | Commercial | Industrial | Open | Residential | Transportation | Water or Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contra Costa | Marsh Creek (LMarCr) | 2012 and 2013 | 99 | Brentwood | 4 | 3 | 0 | 73 | 14 | 6 | 0 |
| Contra Costa | North Richmond Pump Station (Rich) | 2013 | 2.0 | Richmond | 0 | 8 | 33 | 6 | 27 | 25 | 1 |
| Alameda | San Leandro Creek (SLeaCr) | 2012 and 2013 | 8.9 | San Leandro | 0 | 6 | 0 | 27 | 48 | 19 | 0 |
| Santa Clara | Guadalupe River (GR) | 2012 and 2013 | 236 | San Jose | 1 | 11 | 3 | 26 | 39 | 19 | 0 |
| Santa Clara | Sunnyvale East Channel (SunCh) | 2012 and 2013 | 14.8 | Sunnyvale | 0 | 19 | 3 | 3 | 51 | 23 | 0 |
| San Mateo | Pulgas Creek Pump Station (PulCr) | 2013 | 0.6 | San Carlos | 0 | 57 | 23 | 3 | 2 | 16 | 0 |

## 2.2 Data Collection and Quality Assurance

The six watersheds were monitored between October 1 and April 30 of each water year, a period when the majority of rainfall and pollutant transport through stormwater runoff occurs in the Bay Area. Nutrients were measured in discrete samples collected over the rising, peak, and falling stages of the hydrograph. Field crews aimed to collect 16 samples per water year covering a variety of storm types but this goal was not always fulfilled due to the relatively dry conditions during the years sampled. A detailed description of field sampling, sample analysis, and quality assurance methods are provided in Gilbreath et al., (2014). Several forms of N and P were determined, either by direct measurement or calculation as described in Table 3.

## Table 2. Climate and flow in WY 2012 and 2013 at each sampling location.

| | | Marsh Creek[2] | North Richmond Pump Station[3] | San Leandro Creek[4] | Guadalupe River[5] | Sunnyvale East Channel[6] | Pulgas Creek Pump Station[7] |
|---|---|---|---|---|---|---|---|
| Rainfall (mm) (% mean annual) | WY 2012 | 321 (70%) | No data | 486 (75%) | 179 (47%) | 224 (58%) | No data |
| | WY 2013 | 278 (61%) | 508 (89%) | 342* (52%) | 223 (59%) | 259* (67%) | 378* (78%) |
| | Mean Annual | 457 | 570 | 652 | 378 | 387 | 488 |
| Runoff ($Mm^3$) (% mean annual) | WY 2012 | 1.87 (22%) | No data | 5.47 | 38.0 (68%) | 1.07 | No data |
| | WY 2013 | 6.23 (73%) | 0.76 | 8.81 | 45.45 (82%) | 1.79 | 0.21 |
| | Mean Annual | 8.51 | No data | No data | 55.6 | No data | No data |

[1] Unless otherwise stated, averages are for the period Climate Year (CY) (Jul-Jun) (rainfall) or Water Year (WY) (Oct-Sep) (runoff) 1971-2010.
[2] Rainfall gauge: Concord Wastewater treatment plant (NOAA gauge number 041967) (CY 1991-2013); Runoff gauge: Marsh Creek at Brentwood (gauge number 11337600) (WY 2001-2013).
[3] Rainfall gauge: This study with mean annual from modeled PRISM data; Runoff gauge: This study.
[4] Rainfall gauge: Upper San Leandro Filter (gauge number 049185); Runoff gauge: This study.
[5] Rainfall gauge: San Jose (NOAA gauge number 047821); Runoff gauge: Guadalupe River at San Jose (gauge number 11169000) and at Hwy 101 (gauge number 11169025).
[6] Rainfall gauge: Palo Alto (NOAA gauge number 046646); Runoff gauge: This study
[7] Rainfall gauge: Redwood City NCDC (gauge number 047339-4); Runoff gauge: This study.
* indices data missing for the latter few months of the season

## Table 3. Measured and calculated forms of N and P

| Nitrogen Species | | Phosphorous Species | |
|---|---|---|---|
| **Chemical Formula** | **Notes** | **Chemical Formula** | **Notes** |
| Nitrate $NO_3^-$ | Directly measured. Typically most abundant oxidized form of dissolved inorganic nitrogen | Orthophosphate o-$PO_4$ | Directly measured. Also referred to as soluble reactive phosphorous |
| Nitrite $NO_2^-$ | Directly measured. Typically a minor oxidized form of dissolved inorganic nitrogen | Total P TP | Directly measured, includes o-$PO_4$ and other P forms |
| Ammonium $NH_4^+$ | Directly measured. Reduced form of dissolved inorganic nitrogen | Total particulate P TPP | Calculated. Includes organic P and inorganic P associated with particles TPP = TP - o-$PO_4$ |
| Total Kjeldhal Nitrogen TKN | Directly measured. Includes both organic N forms and $NH_4^+$ | | |
| Organic N orgN | Calculated orgN = TKN – $NH_4^+$ | | |
| Total Nitrogen TN | Calculated TN = TKN + $NO_3^-$ | | |

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# 2. Results and Discussion

## 2.1 Overview of concentration data: all sites, all storms

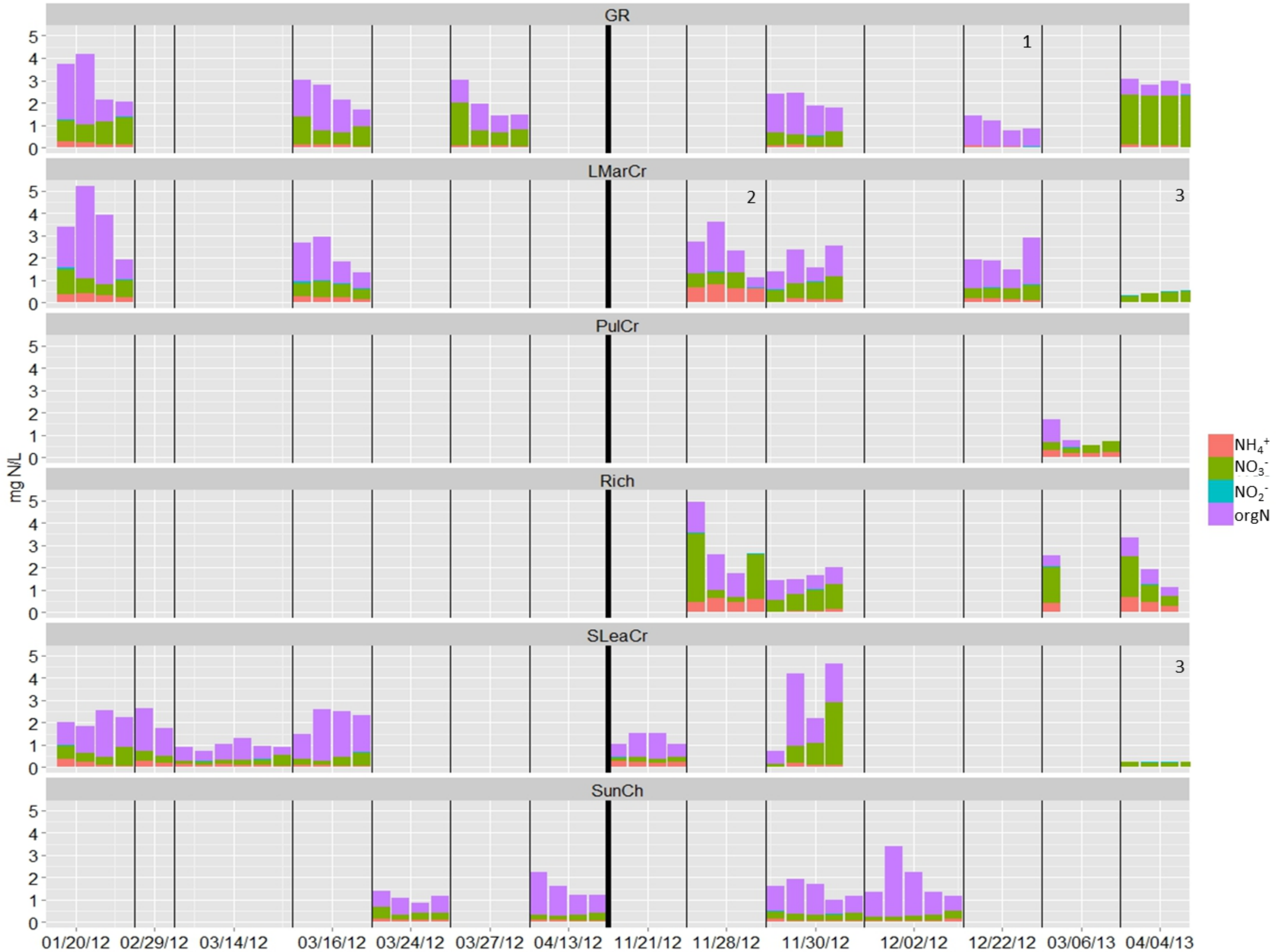
Figure 2A and 2B summarize N and P concentrations observed across all sites and all storms during WY2012 and WY2013. The storms sampled differed among sites, and, in total, 28 individual site-storm combinations were monitored, with samples collected at 111 time points. For the vast majority of time points, data for the full suite of nutrient forms was obtained, except for the 7 cases noted.

Both total N (TN) and the relative abundances of N species exhibited substantial variability between sites, between storms at a given site, and among time points within individual storms (Figure 2A). In general, $NO_3$- and orgN were the dominant N forms, with non-trivial levels of $NH_4^+$ occasionally observed. As expected, $NO_2^-$ was always the least abundant form of N.

Similar to TN, total P (TP) and the proportions present as o-$PO_4$ and total particulate phosphorous (TPP) exhibited substantial variability between sites, storms, and time points (Figure 2B). TPP typically comprised more than 50% of TP, and frequently accounted for most of TP.

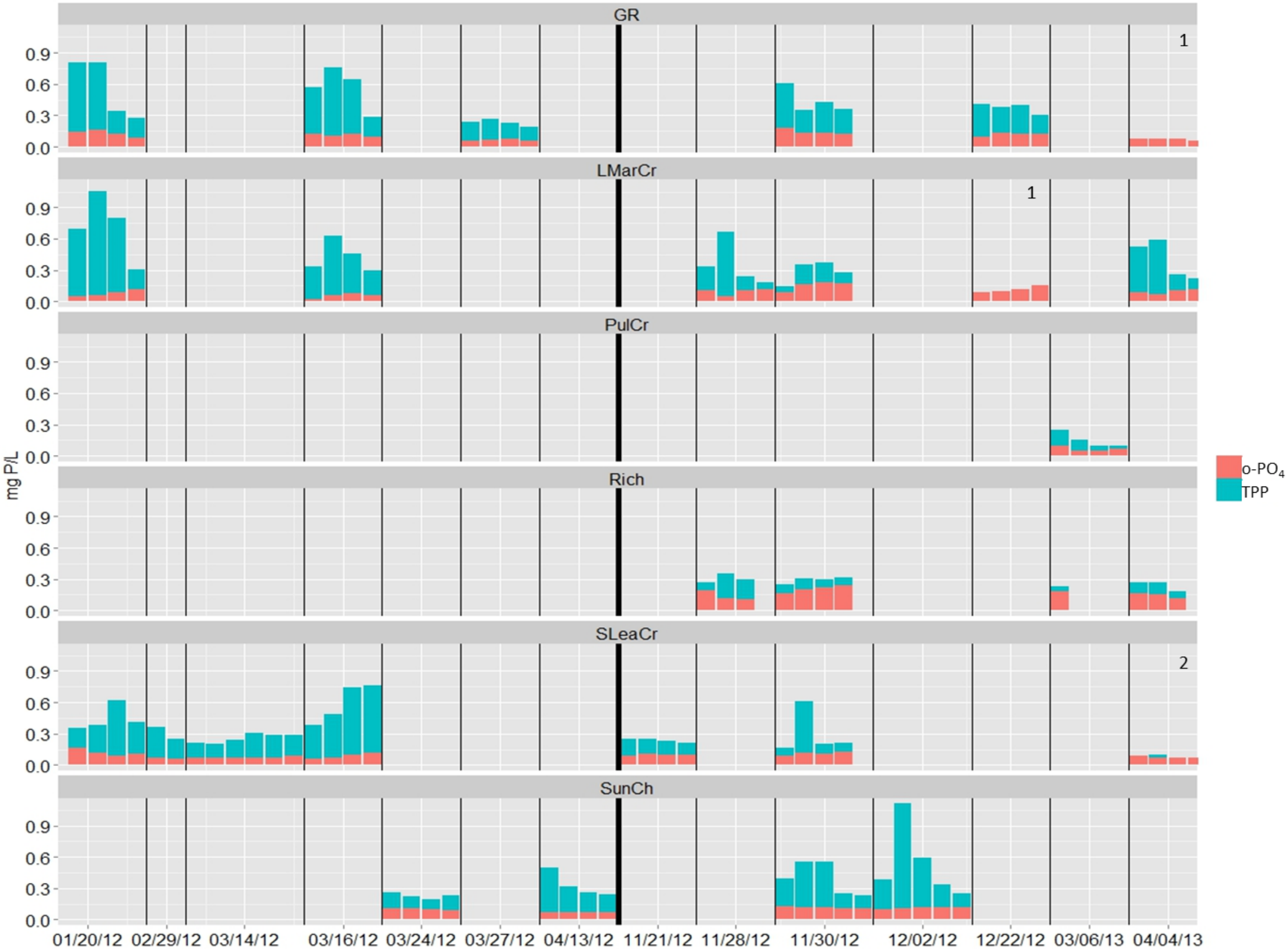
Although variation in TN and TP concentrations and speciation across sites was observed (Figure 2), some broad patterns do emerge. Figure 3 and Table 4 summarize concentration data, pooled by sites. Mean TN concentrations for individual sites fell within a fairly narrow range of 1.6-2.4 mg N/L (Table 4; except at Pulgas, where only one storm was monitored), and interquartile range fell between 1 and 3 mg N/L at most sites (Figure 3). orgN interquartile ranges showed considerable overlap across sites, with the majority of values falling between 0.5-1.5 mg N/L. Although the central tendencies of $NO_3^-$ concentrations differed by as much as 3-fold between some sites, three of the six sites had narrow $NO_3^-$ interquartile ranges (SunCh, SLeaCr, LMarCr). Most of the o-$PO_4$ concentrations were in the range of 0.06-0.13 mg P/L, with Richmond's concentration range standing apart from other sites. Most TPP and TP concentrations fell within the range 0.1-0.6 mg P/L and TP 0.3-0.7 mg P/L, respectively.

Given limited data and the lack of striking patterns based on Figure 2A and 2B, we decided to not pursue a detailed analysis of changes in concentrations within or between storms at this time, although such an analysis may be warranted as more data becomes available. Summary plots of concentrations for each station, pooled by storm, are however included in Appendix 1.




1. All $NO_3^-$ samples were non-detect
2. The $NO_3^-$ samples during the fourth sampling point was a non-detect
3. All $NH_4^+$ and TKN samples were not yet reported by the lab at the time of this report, so $NH_4^+$ and orgN could not be reported

**Figure 2A Results of stormwater monitoring for nitrogen species from WY 2012 and 2013, by site and storm. orgN was calculated as TKN (not shown) – $NH_4^+$. Unless otherwise noted, all species were reported but may be of such small magnitude that they are difficult to see.**




1. Total phosphorous data was not yet reported by the lab at the time of this report, therefore TPP could not be reported
2. Total phosphorous data for the 1st, 3rd and 4th sampling points was not yet reported by the lab at the time of this report, therefore TPP could not be calculated

**Figure 2A Results of stormwater monitoring for phosphorous species from WY 2012 and 2013, by site and storm. TPP was calculated as TP (not shown) – o-$PO_4$. Unless otherwise noted, all species were reported but may be of such small magnitude that they are difficult to see.**

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## 2.2 WY2012-WY2013 vs compared to other data: Uncertainty and Implications for future monitoring

The WY2012 and WY2013 monitoring effort substantially increased the amount of stormwater nutrient speciation and concentration data for Bay Area watersheds. Overall, mean $NO_3^-$ concentrations from the 6 WY2012-2013 watersheds were of a similar order of magnitude as previously reported mean concentrations for urban and non-urban watersheds in the Bay Area (Table 3). The relative variability in $NH_4^+$ concentrations was greater than that for $NO_3^-$ across all sites. However, $NH_4^+$ tended to be present at the lowest concentrations of the three major N forms (i.e., orgN, $NO_3^-$, $NH_4^+$), and so that variability/uncertainty is less quantitatively important than other uncertainties in terms of labile N and P loads to SFB. orgN and TPP (and therefore TN and TP) concentrations at WY2012-2013 sites (except Pulgas) were substantially greater than previously reported in the urban Z4LA and non-urban Sonoma Ck and Napa River watersheds. (TN and TP were not measured in the other prior monitoring efforts reported in Table 3). Considering that Sonoma Creek and Napa River watersheds have a higher proportion of agriculture-intensive land uses, the observation of higher nutrient concentrations at the six WY2012-2013 sampling sites than past Sonoma and Napa sites was initially somewhat surprising. However, nutrient sampling in Sonoma and Napa were conducted in dry weather, not during storm events, which may partially explain their lower concentration. A limited survey of stormwater nitrogen concentrations for agricultural land uses in CA suggests they can be much higher than observed in the six WY2012-2013 watersheds ($NH_{4\ ,avg}^+$= 1.3 mg N/L from Ackermann and Schiff (2003) and Willardson (2008); $NO_{3\ ,avg,}^-$= 8.9 mg N/L from Davis et al. (2000), Ackermann and Schiff (2003) and Willardson (2008); TN = 4.7-6.0 mg N/L, Cox from et al. (2012) and 2.6-25.5 mg N/L from Ramos and Martinez-Casasnovas (2006), in vineyards). If better estimates of nutrient loads from agricultural watersheds are needed, future monitoring efforts should include stormwater monitoring in agriculture dominated watersheds.

The nutrient load estimates in SFEI (#704, 2014), which suggested that stormwater loads are, in general, a minor contributor to overall loads, had two major caveats: i. Stormwater loads were recognized to be highly uncertain both because of limitations of the model and insufficient data to calibrate the model; and ii. While stormwater loads may be minor at the subembayments scale, greater importance in shallow habitats could not be ruled out. The body of data (Figures 2-3 and Table 4) indicates that there is considerable variability in the forms and concentrations of N and P in stormwater, which directly translates to uncertainty when used to estimate loads in the sampled watersheds and when extrapolated to other watersheds. The stormwater load estimates in SFEI (#704, 2014) only included inorganic forms of N and P. WY2012-2013 data

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suggest that only using inorganic N and P forms could result in stormwater loads being underestimated by a factor of 2 or more. On the whole, orgN and TPP will be less bioavailable than inorganic N and P species, but orgN and TPP bioavailability depends heavily on their forms and sources and is itself another source of uncertainty (e.g., N and P in ‘old’ organic matter from soils will have low bioavailability, while ‘fresh’ organic matter from decomposing algae, terrestrial plants, or animal waste will be more labile). Focused modeling efforts would be useful for obtaining an improved quantitative understanding of stormwater N and P loads, especially a modeling approach that explicitly explores uncertainty through multiple simulations having different combinations of variable flows and variable concentrations (e.g., Monte Carlo simulations). The WY2012-2013 data provides a much better basis for estimating the uncertainties in N and P concentrations and forms. Additional monitoring would also be helpful, especially if new sampling captured larger events and watersheds having landuses that are underrepresented in the current dataset. SFEI and BASMAA are going to continue watershed monitoring in WY2015, but will collect composite samples over the course of a storm (rather than 4 discrete sampling points per storm), allowing them to sample more watersheds that in previous years. In general, the WY2012-2013 data suggest that between-storm and between-site variability in nutrient concentrations are at least as large or larger than within-storm variability (Figures 2A and 2B). Therefore, it could be argued that the composite approach in WY2015 will provide valuable information. It may therefore again be worthwhile to piggyback nutrient measurements on the BASMAA-RMP effort.

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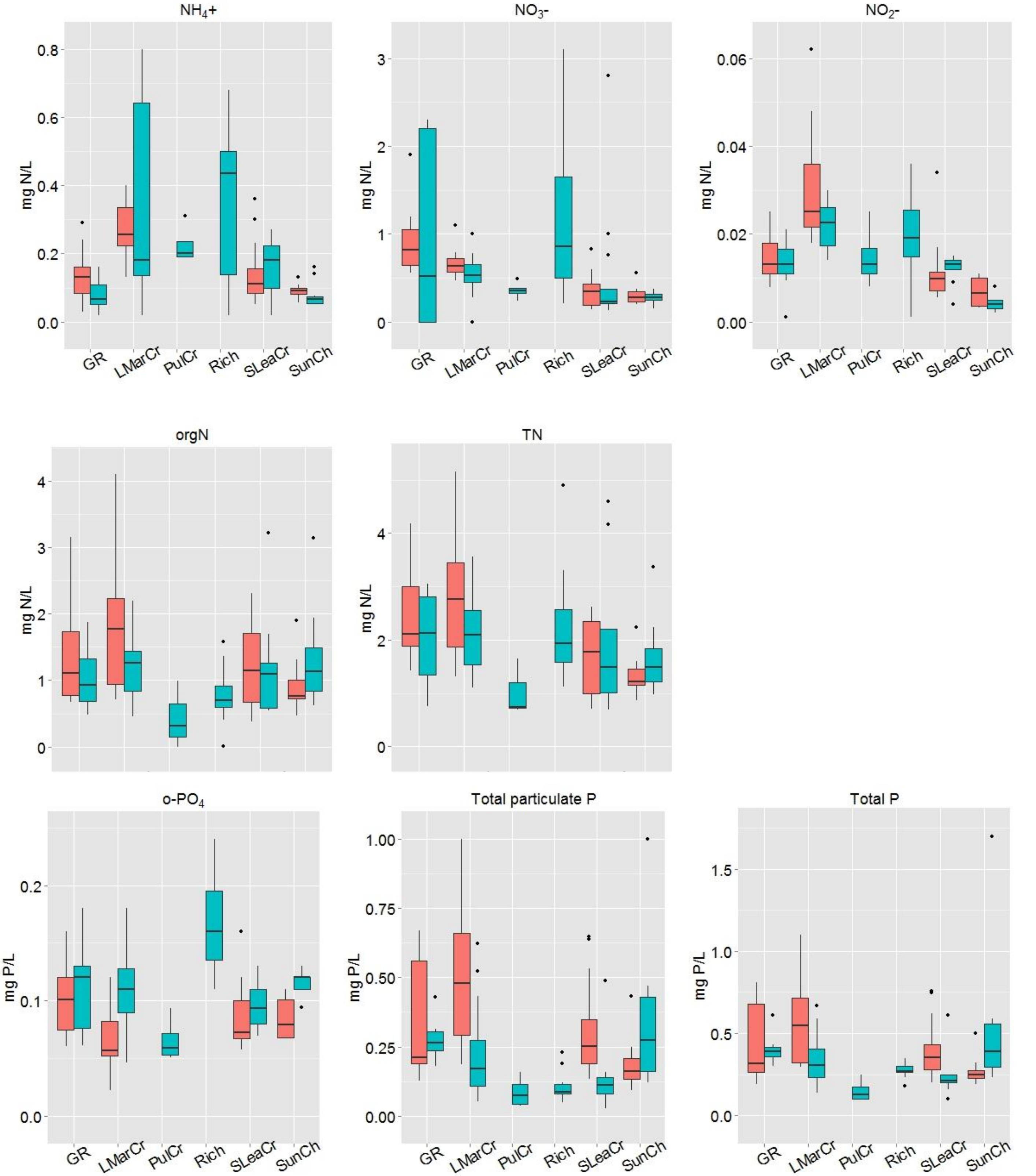


Figure 3. Concentrations of N and P species at each sampling location, with WYs separated. Box plots include median, 25th and 75th percentiles. Note: Pulgas Creek and Richmond Pump Station were only

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**Table 4. Mean concentrations ± 1 s.d. for nutrient forms and ratios by site, in mg/L N or mg/L P. Means from previously monitored watersheds within the region (watershed name shown with brown background) included for comparison.**

| Analyte Name | Marsh Creek | North Richmond Pump Station | San Leandro Creek | Guadalupe River | Sunnyvale East Channel | Pulgas Creek Pump Station[a] | Zone 4 Line A (urban) | El Cerrito (urban) | Ettie Street (urban) | Sonoma Ck[b] (non-urban) | Napa River[b] (non-urban) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $NH_4$+ | 0.30 ± 0.22 | 0.35 ± 0.23 | 0.15 ± 0.09 | 0.11 ± 0.07 | 0.08 ± 0.03 | 0.23 ± 0.06 | 0.10 | 0.44 | 0.86 | 0.03 | 0.03 |
| $NO_3$- | 0.58 ± 0.22 | 1.13 ± 0.85 | 0.43 ± 0.51 | 0.92 ± 0.73 | 0.29 ± 0.09 | 0.36 ± 0.10 | 0.19 | 1.1 | 0.91 | 0.73 | 0.60 |
| $NO_2$- | 0.02 ± 0.01 | 0.02 ± 0.01 | 0.01 ± 0.01 | 0.01 ± 0.01 | 0.01 ± <0.01 | 0.01 ± 0.01 | 0.01 | | | 0.01 | 0.01 |
| orgN | 1.5 ± 0.89 | 0.77 ± 0.42 | 1.2 ± 0.70 | 1.2 ± 0.67 | 1.2 ± 0.65 | 0.43 ± 0.51 | 0.35 | | | 0.32 | 0.33 |
| TN | 2.4 ± 1.1 | 2.3 ± 1.0 | 1.8 ± 1.0 | 2.2 ± 0.87 | 1.5 ± 0.60 | 1.0 ± 0.54 | 0.66 | | | 1.1 | 1.0 |
| o-$PO_4$ | 0.10 ± 0.04 | 0.17 ± 0.04 | 0.09 ± 0.02 | 0.11 ± 0.03 | 0.10 ± 0.02 | 0.07 ± 0.02 | 0.09 | 0.04 | 0.07 | 0.08 | 0.07 |
| TPP | 0.34 ± 0.26 | 0.11 ± 0.06 | 0.25 ± 0.17 | 0.32 ± 0.18 | 0.28 ± 0.22 | 0.08 ± 0.06 | 0.01 | | | 0.00 | 0.00 |
| TP | 0.44 ± 0.24 | 0.28 ± 0.04 | 0.34 ± 0.18 | 0.43 ± 0.20 | 0.42 ± 0.34 | 0.15 ± 0.07 | 0.10 | | | 0.08 | 0.07 |
| TN:TP | 5.5 | 8.2 | 5.3 | 5.1 | 3.6 | 6.7 | 7.0 | | | 14 | 14 |
| DIN:TN | 0.38 | 0.65 | 0.33 | 0.47 | 0.25 | 0.60 | 0.43 | | | 0.70 | 0.66 |
| o-$PO_4$:TP | 0.23 | 0.61 | 0.26 | 0.26 | 0.24 | 0.47 | 0.92 | | | 0.99 | 1.0 |

[a] Sample n <10.

[b] Data reported for these watersheds is a synthesis of multiple studies at multiple locations within each watershed. Source: Water Board, 2013.

Other sources: Zone 4 Line A data from Gilbreath et al., 2012; El Cerrito and Ettie Street data from McKee and Gluchowski, 2011, reporting data provided by Francois Rodigari at EBMUD.

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# Appendix 1

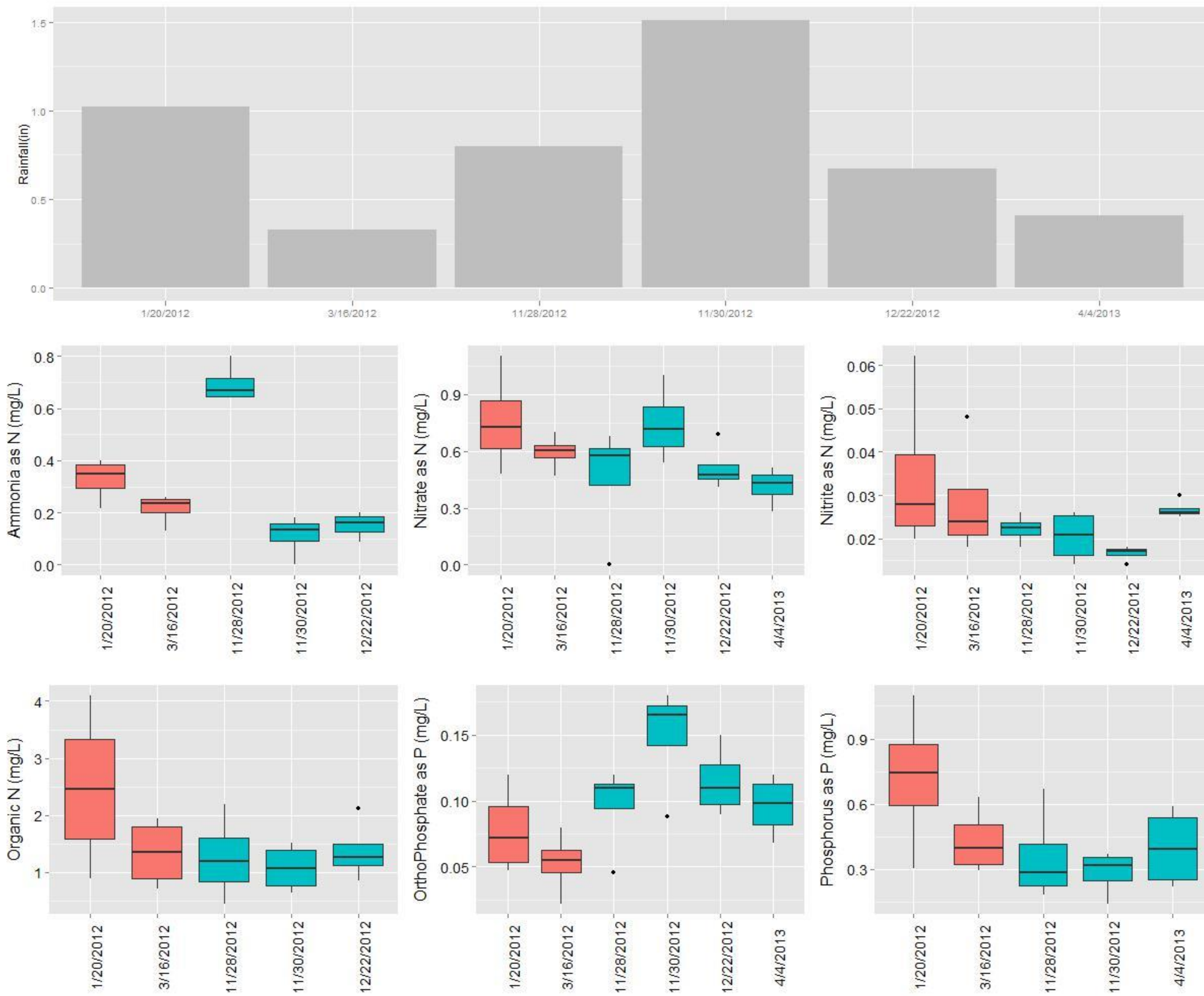


**Figure A1. Nutrient concentrations for each sampling storm at Lower Marsh Creek watershed, with WYs separated. Box plots include median, 25th and 75th percentiles. Top plot shows total rainfall for each storm.**

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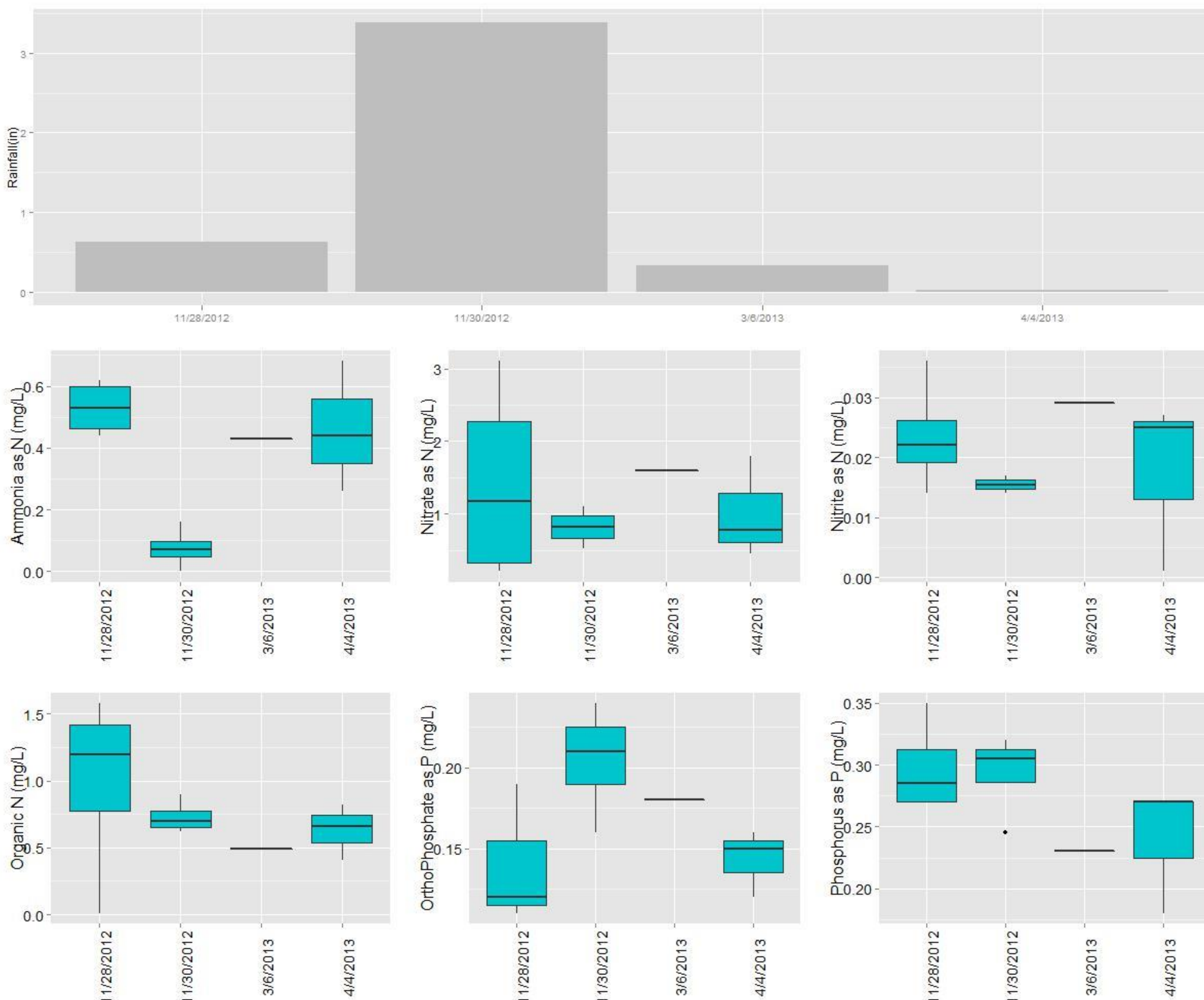


**Figure A2. Nutrient concentrations for each sampling storm at Richmond Pump Station (only monitored in WY2013). Box plots include median, 25th and 75th percentiles. Top plot shows total rainfall for each storm.**

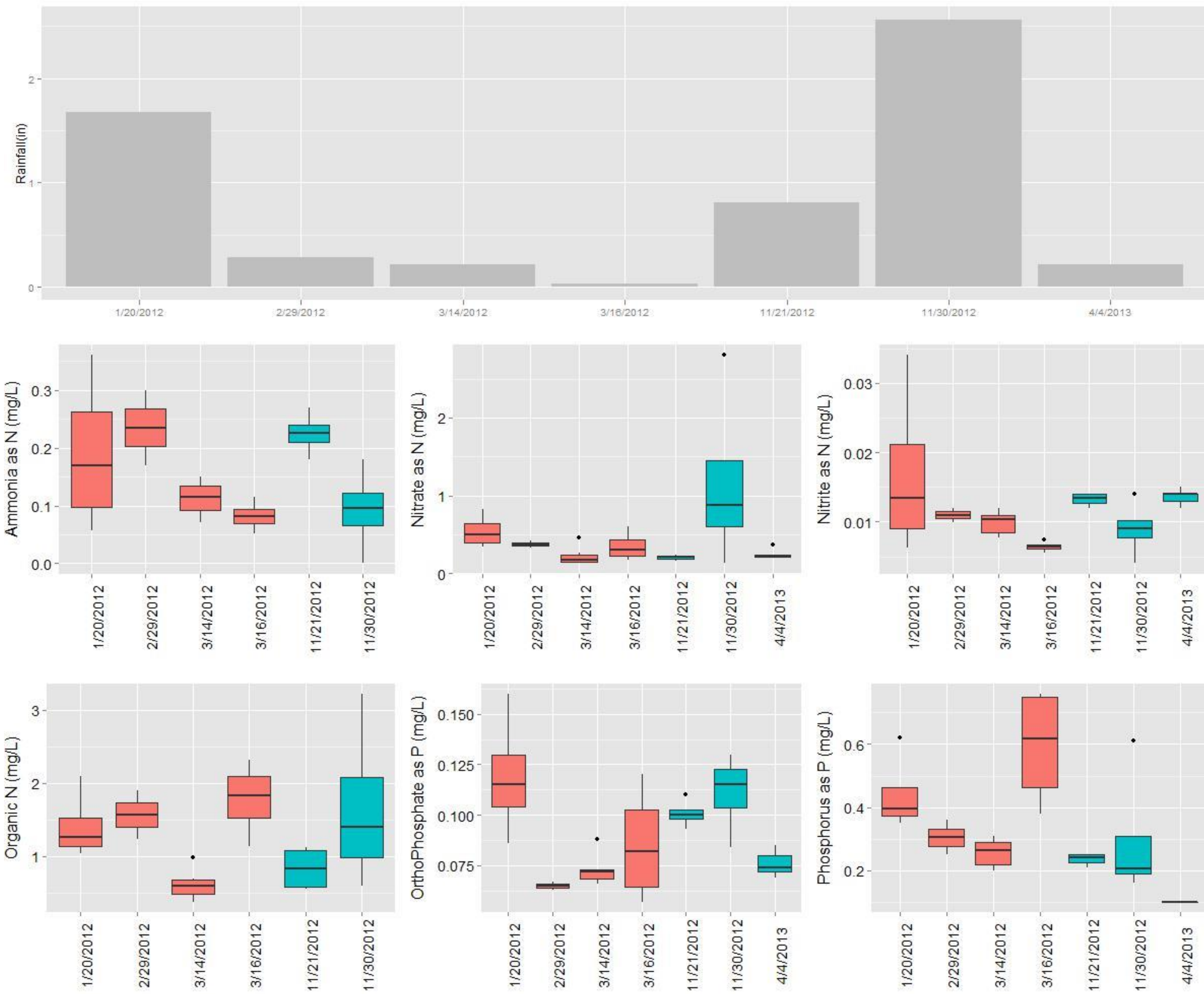


**Figure A3. Nutrient concentrations for each sampling storm at San Leandro Creek, with WYs separated. Box plots include median, 25th and 75th percentiles. Top plot shows total rainfall for each storm.**

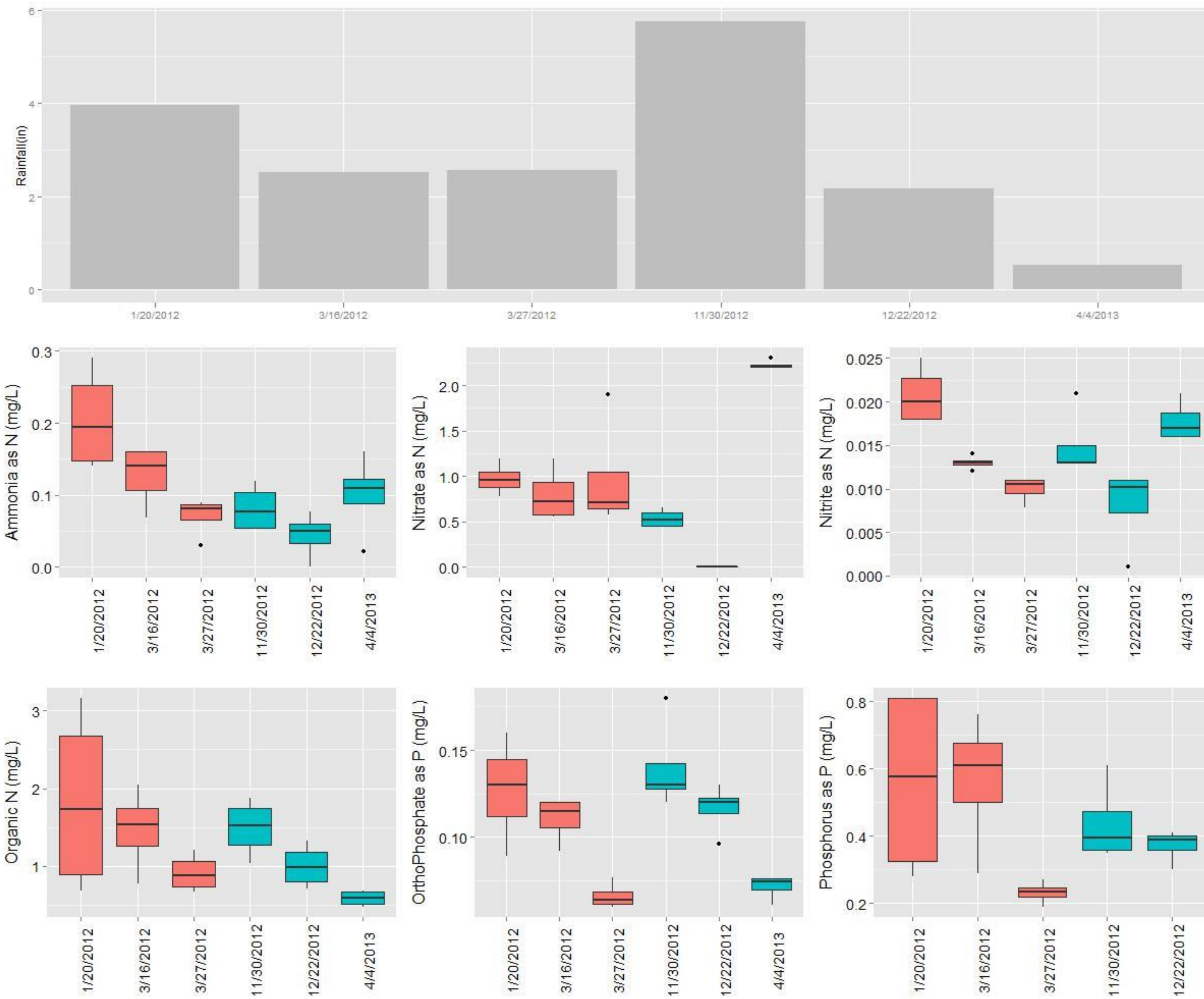


**Figure A4. Nutrient concentrations for each sampling storm at Guadalupe River, with WYs separated. Box plots include median, 25th and 75th percentiles. Top plot shows total rainfall for each storm.**

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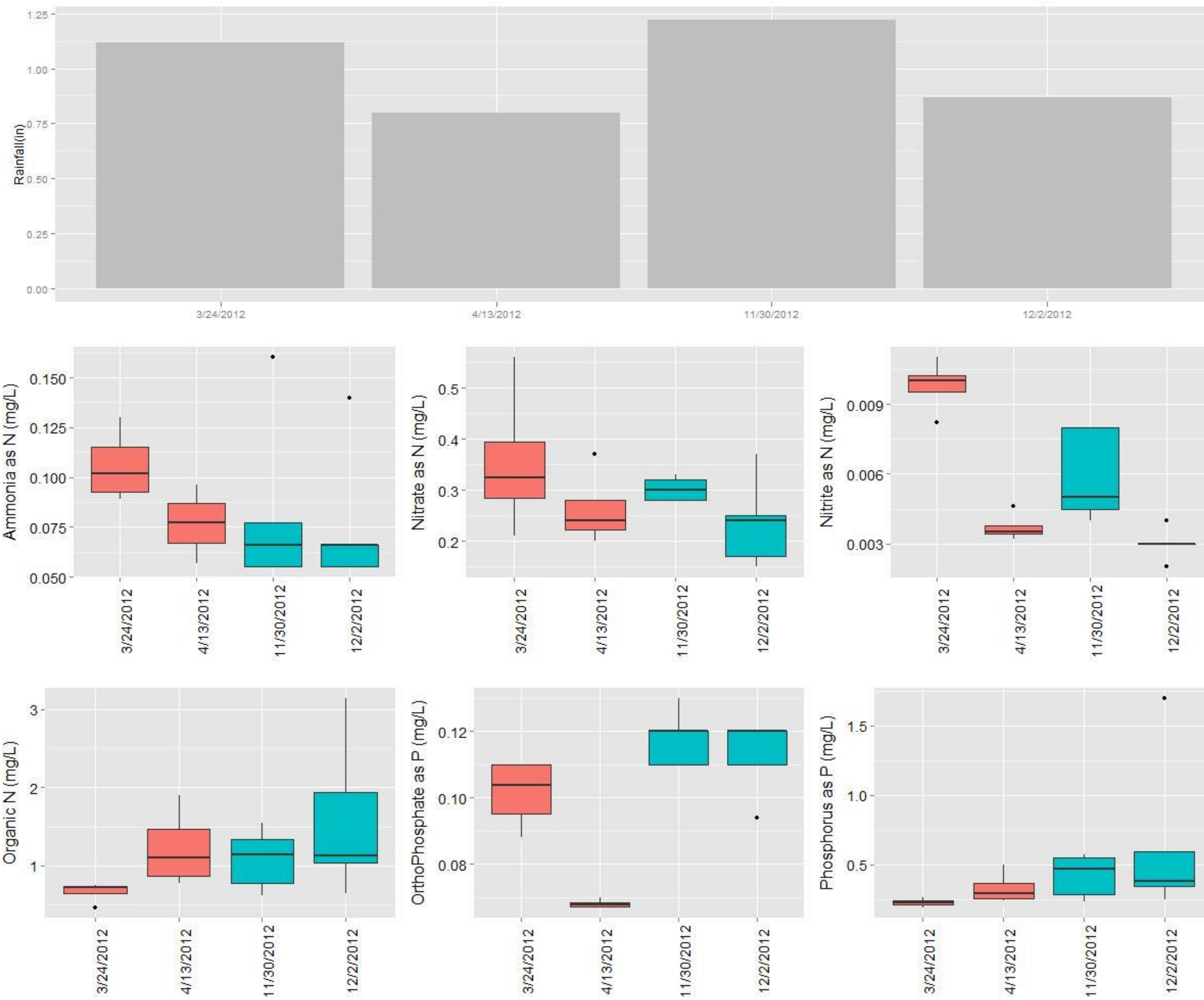


**Figure A5. Nutrient concentrations for each sampling storm at Sunnyvale Channel, with WYs separated. Box plots include median, 25th and 75th percentiles. Top plot shows total rainfall for each storm.**