



RMP
REGIONAL MONITORING
PROGRAM FOR WATER QUALITY
IN SAN FRANCISCO BAY

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Regional Monitoring Program Status and Trends Wet Season Water Monitoring Pilot Study; Water Years 2022-2024

Martin Trinh, Amy Kleckner, Jay Davis, Alicia
Gilbreath, Don Yee, Miguel Mendez, Ezra Miller,
Rebecca Sutton, Jennifer Dougherty

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Executive Summary

The Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) has conducted long-term contaminant monitoring in San Francisco Bay waters since 1993 through its Status and Trends (S&T) program. Following a 2020 program review and growing concern that urban stormwater delivers contaminants of emerging concern (CECs) to the Bay, the RMP launched a pilot in 2021 to resume wet-season monitoring, which had not been conducted since 2010, at both near-field stations close to stormwater discharge points and open Bay stations along the main channel. The pilot targeted per- and polyfluoroalkyl substances (PFAS), bisphenols, and organophosphate esters (OPEs).

Across three wet seasons (fall 2021–spring 2024), PFAS were widely detected throughout the Bay. Near-field concentrations were consistently higher than open Bay concentrations, roughly double on a wet-season median basis, with a statistically significant spatial gradient toward the South and Lower South Bay. A small number of compounds (PFHxA, PFOS, and PFOA) dominated PFAS profiles at both open Bay and near-field sites, and near-field sites had a broader range of detectable PFAS overall, consistent with their proximity to watershed discharge points. Limited dry-season sampling suggested near-field PFAS inputs persist outside the wet season, potentially reflecting a wastewater contribution in addition to stormwater.

PFAS concentrations at near-field sites were inversely related to salinity, reflecting the varying mix of stormwater and Bay water sampled at each site; the sampling design partially achieved its target mixing ratios, though one site (Stevens Creek) consistently fell short of the target range, meaning some site differences may reflect mixing rather than loading.

OPEs and bisphenols could not be evaluated in this study; quality assurance data indicated methodological contamination, and no usable results were generated for either compound class.

A concurrent special study sampled tire- and vehicle derived contaminants using the same collection effort. It found that 6PPD-quinone, a chemical linked to salmonid toxicity, reached concentrations in Bay water that may be of concern for sensitive species, though most other measured contaminants remained below available toxicity thresholds (Miller et al. 2025).

Given the strong stormwater influence on near-field PFAS concentrations, continued seasonal monitoring is recommended. Additional sampling could generate data for OPEs and bisphenols and would improve understanding of spatial and temporal trends, provide additional data for future CECs modeling efforts, and provide data to assess broader ecological exposure. Future efforts should also aim to improve sampling designs to better control for mixing effects, potentially leveraging salinity-based modeling approaches.

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1. Introduction

In 1993, the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) began monitoring spatial patterns and long-term trends in contaminants in water, as part of its Status and Trends (S&T) program. Currently, surface water monitoring in the dry season occurs on a two-year cycle at five targeted historic stations and 17 random stations in the open Bay. The samples are analyzed for copper, cyanide, per- and polyfluorinated alkyl substances (PFAS), bisphenols, organophosphate esters (OPEs), and ancillary parameters such as particulate and dissolved organic carbon, suspended sediment concentration, and chlorophyll.

Wet season water sampling had not been conducted by the RMP since 2010 and sampling locations were previously limited to open Bay stations far from stormwater inputs. In 2020, the RMP reviewed the S&T Program and added a pilot effort to quantify contaminants of emerging concern (CECs) in Bay water in areas near (“near-field” of) expected loading pathways during or shortly after storm events and during the dry season. Stormwater monitoring conducted by the RMP and others has shown that stormwater is a major pathway for CECs in the Bay, including bisphenols, OPEs, and PFAS (Houtz and Sedlak 2012; Sutton et al. 2019; Peter et al. 2024).

Pilot monitoring for CECs in Bay water during the wet season commenced in October 2021. Samples were collected following one storm event from three near-field stations near where stormwater enters the Bay from Redwood Creek, Stevens Creek, and Damon Slough in San Leandro Bay. In subsequent years, the RMP added a fourth near-field station in Palo Alto to characterize an area receiving both stormwater and municipal wastewater effluent. Samples were also collected at four open Bay stations adjacent to the near-field stations along the main channel of the Bay during monthly U.S. Geological Survey (USGS) nutrient monitoring cruises. The sampling design included near-field sample collection shortly after two storm events and once in the dry season, and open Bay sample collection within a three week window after storm events and once in the dry season. Dry-season sampling was included to enable comparison of CEC concentrations between wet and dry seasons. The goals of this study were to characterize the concentrations of CECs in Bay waters during the wet season, understand how long CECs are present in the Bay, determine if they reach levels of concern, improve understanding of stormwater as a pathway for CECs into the Bay, and initiate status and trends monitoring for CECs in areas expected to have high CEC concentrations.

The RMP’s CEC strategy describes the classes of CECs selected for S&T water monitoring: PFAS, OPEs, and bisphenols (Sutton et al., 2024b). PFAS, a family of thousands of synthetic, fluorine-rich compounds commonly referred to as “forever chemicals,” are known for their thermal stability, non-reactivity, and surfactant properties. All PFAS are highly persistent or, in the case of precursors, degrade to substances that are highly persistent. Some PFAS, particularly the long-chain compounds, bioaccumulate and are associated with a wide variety of toxic effects in wildlife and humans. These unique compounds have many uses across consumer, commercial, and industrial products, resulting in widespread occurrence

in the environment and wildlife across the globe. Perfluoroalkyl acids (PFAAs) are the most well-known group and do not break down in the environment. The two major subclasses of PFAAs, perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs), can be divided into long-chain and short-chain groups to differentiate environmental fate properties. Long-chain compounds are PFCAs with eight or more carbons, like perfluorooctanoic acid (PFOA), and PFSAs with six or more carbons, such as perfluorooctane sulfonic acid (PFOS). Short-chain compounds refer to PFCAs with seven or fewer carbons, such as perfluorobutanoic acid (PFBA), and PFSAs with five or fewer carbons, such as perfluorobutane sulfonic acid (PFBS).

OPEs and bisphenols are classes of mobile, endocrine-disrupting chemicals found widely in the environment. Predominantly used as plastic and polymer additives, these compounds are manufactured and used at high volumes globally (USEPA, 2016). OPEs have also emerged as a new generation of flame retardants due to the phase-out of polybrominated diphenyl ethers (PBDEs). OPEs and bisphenols enter surface waters through both wastewater effluent and urban stormwater runoff (Peter et al., Mendez et al., 2022, Sutton et al., 2019). The two classes share key chemical properties, including high mobility in the environment. OPEs have been linked to endocrine disrupting effects, neurotoxicity, adverse fertility effects, and cancer, with three OPEs (TCEP, TDBPP, TDCIPP) listed as carcinogens on California's Proposition 65 List (OEHHA [Office of Environmental Health Hazard Assessment], 2019; Wei et al., 2015). Bisphenol A (BPA), the best studied of the bisphenols, has been shown to cause adverse estrogenic effects and is listed on California's Proposition 65 List for developmental toxicity and female reproductive toxicity (Bjornsdotter, 2017, OEHHA, 2019).

This report summarizes the results of the three-year pilot wet season Bay water monitoring of CECs. In addition to PFAS, OPEs, and bisphenols, a separate study focused on tire- and vehicle-derived contaminants was conducted concurrently, leveraging the same sampling effort. Results of the special study are detailed elsewhere (Miller et al., 2025), but are mentioned here for completeness.

2. METHODS

2.1. Sample Collection

Over three wet seasons (fall 2021 - spring 2024), near-field and open Bay water was collected after storms at several stations in the Central, South, and Lower South Bays (Figure 1). Within two tidal cycles after a storm event, near-field samples were collected at three to four stations, which were selected based on their high urban watershed land use and accessibility for sampling (a total of 27 samples). In addition, four open Bay stations, selected from existing stations sampled independently by the USGS with the closest proximity to near-field stations, were sampled within three weeks after a storm event ($n = 24$). Further sampling information is provided in the 2023 and 2024 Near-field Water Sampling and Analysis Plans (Dougherty et al., 2024; Kleckner et al., 2023).

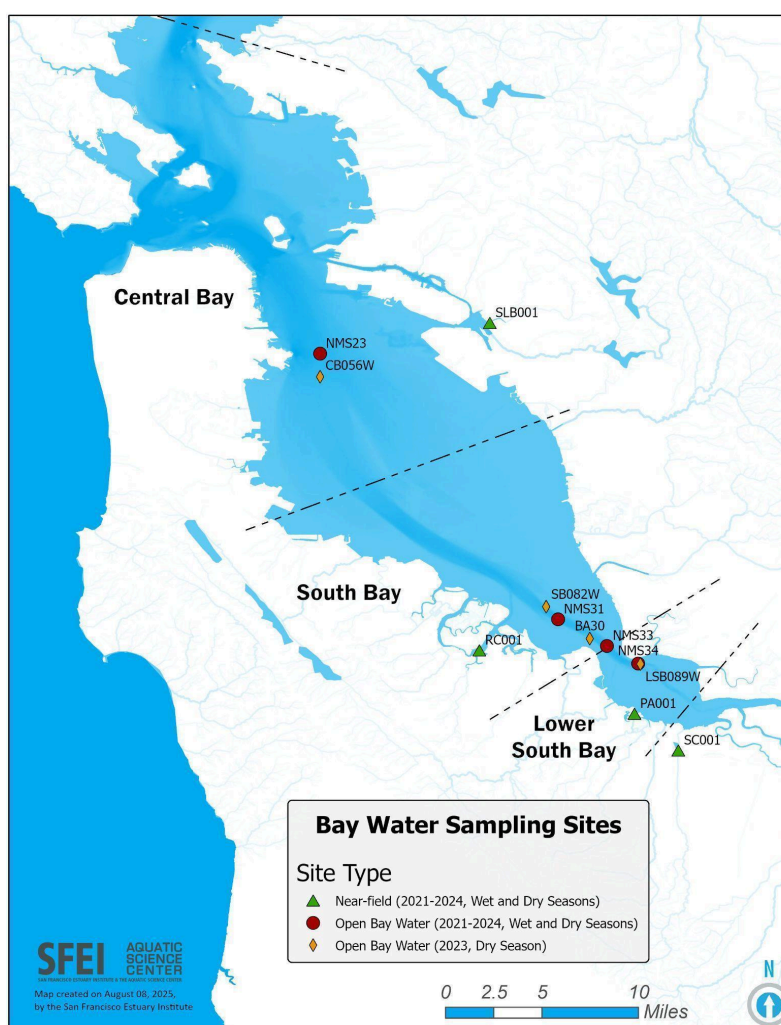


Figure 1. Bay water stations sampled across dry and wet seasons for CEC analysis as part of pilot S&T wet-season monitoring since fall 2021.

Samples were collected by deploying a stainless steel bailer via a cotton rope and filling pre-cleaned sample containers with Bay water from the surface to approximately one foot below the surface. Samples were stored on wet ice in coolers (1 to 5°C) and frozen at the end of each sampling day. Samples were shipped overnight on ice to the analytical laboratory, SGS AXYS, and stored frozen until analysis. All samples were analyzed within the recommended hold time of 90 days. Including quality assurance and control (QA/QC) samples, a total of 65 samples for each chemical class were collected in this study for targeted analysis.

Quality control samples collected include field duplicates, field blanks, and samples for matrix spikes and matrix spike duplicates. Field blanks were collected by opening a sample bottle pre-filled with contaminant-free water while the field sample was collected. Further information on the QA/QC sample collection methods is provided in the Near-field Water Sampling and Analysis Plans (Dougherty et al., 2024; Kleckner et al., 2023).

2.2. Laboratory Analysis

Samples were analyzed for target PFAS using EPA Method 1633, also referred to as SGS AXYS Method MLA-110. Briefly, samples were spiked with isotope-labeled surrogate standards and then extracted and cleaned through solid phase extraction (SPE). Sample extracts were analyzed by liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS), and reported sample concentrations were determined by isotope-dilution/internal-standard quantification. The method quantifies 40 target analytes, which include PFCAs, PFSAAs, fluorotelomer sulfonates, fluorotelomer carboxylates, perfluorooctane sulfonamides, perfluorooctane sulfonamidoacetic acids, perfluorooctane sulfonamide ethanols, per- and polyfluoroether carboxylates, and ether sulfonates.

Samples for OPEs were analyzed for target OPEs using SGS AXYS Method MLA-098. The method quantifies 13 OPEs, which include TEP, TCEP, TPrP, TCPP, V6, TDCPP, TPP, TDBPP, TBP, TBEP, TCrP, EHDPP, and TEHP. Aqueous samples are spiked with isotopically labeled surrogate standards and liquid-liquid extracted with dichloromethane. Typical reporting limits (RLs) are in the range of 0.1 – 1.2 ng/L for a 0.5L aqueous samples. For TBP and TBEP, quantification limits are elevated by laboratory background levels.

Samples for bisphenols were analyzed for target bisphenols using SGS AXYS Method MLA-113. The method quantifies six target analytes, including bisphenols A, AF, B, E, F, and S. Aqueous samples are pH-adjusted to 1.5-2, spiked with labeled quantification standards, and extracted by solid-phase extraction (SPE) and analyzed by ultra-high-pressure liquid chromatography-tandem mass spectrometry (UPLCMS/MS)..

Table 1. Compounds analyzed for this study, including acronyms.

Analyte Name	Acronym	Median Water MDL (ng/L)	Median Water RL (ng/L)
PFAS			
Perfluorobutanoate	PFBA	2.0	7.9
Perfluoropentanoate	PFPeA	1.0	4.0
Perfluorohexanoate	PFHxA	0.50	2.0
Perfluoroheptanoate	PFHpA	0.50	2.0
Perfluorooctanoate	PFOA	0.50	2.0
Perfluorononanoate	PFNA	0.50	2.0
Perfluorodecanoate	PFDA	0.50	2.0
Perfluoroundecanoate	PFUnA	0.50	2.0
Perfluorododecanoate	PFDoA	0.50	2.0
Perfluorotridecanoate	PFTTrDA	0.50	2.0
Perfluorotetradecanoate	PFTeDA	0.50	2.0
Perfluorobutanesulfonate	PFBS	0.50	2.0
Perfluoropentanesulfonate	PFPeS	0.50	2.0
Perfluorohexanesulfonate	PFHxS	0.50	2.0
Perfluoroheptanesulfonate	PFHpS	0.50	2.0
Perfluorooctanesulfonate	PFOS	0.50	2.0
Perfluorononanesulfonate	PFNS	0.50	2.0
Perfluorodecanesulfonate	PFDS	0.50	2.0
Perfluorododecanesulfonate	PFDoS	0.50	2.0
Fluorotelomer Sulfonate, 4:2-	4:2 FTS	2.0	7.9
Fluorotelomer Sulfonate, 6:2-	6:2 FTS	1.8	24.8
Fluorotelomer Sulfonate, 8:2-	8:2 FTS	1.7	7.9
Fluorotelomer Carboxylic Acid, 3:3-	3:3 FTCA	2.0	7.9
Fluorotelomer Carboxylic Acid, 5:3-	5:3 FTCA	12.4	49.5
Fluorotelomer Carboxylic Acid, 7:3-	7:3 FTCA	12.4	49.5
Perfluorooctanesulfonamide	PFOSA	0.50	2.0
Methyl-perfluorooctanesulfonamide, N-	N-MeFOSA	0.50	2.3
Ethyl-perfluorooctanesulfonamide, N-	N-EtFOSA	1.3	5.0
Methyl Perfluorooctane Sulfonamido Acetic Acid, N-	N-MeFOSAA	0.50	2.0
Ethyl Perfluorooctane Sulfonamido Acetic Acid, N-	N-EtFOSAA	0.50	2.0
Methyl-perfluorooctanesulfonamidoethanol, N-	N-MeFOSE	4.9	19.8
Ethyl-perfluorooctanesulfonamidoethanol, N-	N-EtFOSE	4.8	14.8
Perfluoro-2-Propoxypropanoic Acid	HFPO-DA	2.0	7.5

Analyte Name	Acronym	Median Water MDL (ng/L)	Median Water RL (ng/L)
Dioxa-3H-Perfluorononanoate Acid, 4,8-	ADONA	2.0	7.9
Perfluoro-3,6-dioxaheptanoate	NFDHA	1.0	4.0
Perfluoro-4-methoxybutanoate	PFMBA	0.50	2.0
Perfluoro-3-methoxypropanoate	PFMPA	1.0	4.0
Chlorohexadecafluoro-3-Oxanonane-1-Sulfonic Acid, 9-	9CI-PF3ONS	2.0	7.9
Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid, 11-	11CI-PF3OUdS	2.0	7.9
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	0.5	2.0
Organophosphate Esters			
Triethyl phosphate	TEP	0.1	
Tris(2-chloroethyl) phosphate	TCEP	1	
Tripentyl phosphate	TPrP	0.1	
Tris(2-chloroisopropyl) phosphate	TCPP	0.5	
Tetrakis(2-chloroethyl)dichloroisopentyldiphosphate	V6	0.5	
Tris(1,3-dichloro-2-propyl) phosphate	TDCPP	5	
Triphenyl phosphate	TPP	0.5	
Tris(2,3-dibromopropyl) phosphate	TDBPP	3	
Tributyl phosphate	TBP	Up to 24	
Tris(2-butoxyethyl) phosphate	TBEP	Up to 360	
Tricresyl phosphate	TCrP	0.2	
2-Ethylhexyl-diphenyl phosphate	EHDPP	5	
Tris(2-ethylhexyl) phosphate	TEHP	0.2	
Bisphenols			
Bisphenol A	BPA	2	
Bisphenol AF	BPAF	2	
Bisphenol B	BPB	2	
Bisphenol E	BPE	5	
Bisphenol F	BPF	5	
Bisphenol S	BPS	2.5	

2.3. Quality Control

SFEI staff performed a quality assurance review of each dataset for completeness, accuracy, precision, and lack of contamination following methods described in the RMP Quality Assurance Project Plan (Yee et al., 2024). Data were flagged with a qualifying code if accuracy and precision did not meet RMP criteria. This was done by independently calculating reported precision (as relative percent difference, RPD, or relative standard deviation, RSD) for lab and field replicates and percent recovery for samples of a known concentration (i.e., surrogate and matrix spiked samples). In some cases, records were already flagged by the laboratory. Qualifiers added by SFEI or the laboratory indicate that there has been a deviation from the project's quality criteria, and certain records may be inaccurate or imprecise. Summary statistics were calculated excluding the results of field duplicates, as duplicates are quality assurance samples intended to evaluate the accuracy of the field samples. Overall, there were no significant issues with the accuracy or precision of the sampling methods.

To verify that contamination of samples had not occurred in sampling or lab analysis, we compared the results for blank samples (field and lab blanks) to method detection limits (MDLs) and reporting limits (RLs). In cases where an analyte was detected in a blank, we compared the measured concentration in the blank sample to concentrations measured in field samples; RMP criteria specify censoring field sample measurements that are within three times the blank level (for each sample in a batch for method blank detections and each sample in a particular study for field blank detections). Additional information on specific samples and analytes impacted by blanks is included in Tables 1 and 2.

There were several contamination concerns in field and lab blanks in this study. Three field blanks from the analysis of near-field and open Bay sites during the wet season in 2022 contained 6:2 FTS (range: 2.0 – 2.3 ng/L). All of the sample results for this analyte from 2022 were censored. In 2023, two lab blanks also contained detectable 6:2 FTS (1.5, 2.1 ng/L) with only two samples censored. Additionally, in the 2024 wet season, a lab blank contained PFOS (0.76 ng/L) and PFOSA (0.53 ng/L). PFOSA results in two open Bay samples and seven near-field samples were affected. However, all the samples had PFOS concentrations well above those found in the blank.

SGS AXYS provided measurements that included values above standard reporting limits (RLs), as well as values above lower method detection limits (MDLs). Values between the RL and the MDL have greater uncertainty and may be considered semi-quantitative, flagged with a “J” to indicate they are estimated values. In this report, we have generally used all reported values, including those with a “J” flag, in our analyses, with appropriate caveats.

For OPEs, field blanks produced inconsistent yet frequent contamination hits, with concentrations occasionally exceeding those found in actual field samples. In 2021, blank samples of TEP had up to >600 ng/L and TBEP averaged ~250 ng/L in two field blanks. In 2023, TDCIPP and BPA were found at over 1000 ng/L in one field blank each.

There were also discrepancies in reported bisphenol levels. Data collected in the 2023 dry season showed unexpectedly low detection frequencies for BPA and BPS, despite earlier data from 2021 indicating consistent detection of this compound. This inconsistency could be related to BPA's presence in both particle-associated and dissolved forms, as particle-associated BPA may not be fully extracted via the SGS AXYS total water method. Prior monitoring in 2017 by an academic partner characterized dissolved and particulate phases independently, with dissolved-phase analysis showing lower levels of BPA (Shimabuku et al., 2020).

2.4. Statistical Analysis

Summary statistics were calculated to summarize the distribution of measured PFAS concentrations in field samples, with any non-detects (NDs) for analytes detected in more than 60% of samples replaced with half the MDL. Data were evaluated for normality using the Shapiro-Wilks test. To test for statistically significant differences, an analysis of variance (ANOVA) was used with the Tukey HSD/Kramer and Nemenyi tests used for multiple pairwise comparisons. The alpha level for statistical significance was set to 0.05 for all tests. All statistical analyses were performed in Excel.

3. RESULTS AND DISCUSSION

3.1. PFAS

3.1.1. *Wet Season Monitoring (Near-field and Open Bay Water): PFAS Occurrence and Comparison to Dry Season*

In the wet seasons between fall 2021 and spring 2024, a range of PFAS were detected in surface water samples.

Near-Field

Near-field samples, collected within two tidal cycles following storm events and in close proximity to stormwater runoff and wastewater inputs to the Bay, exhibited a broader range and higher concentrations of PFAS compared to open Bay samples.

A total of 16 PFAS were detected in the near-field, with nine measured in over 60% of samples (Table 2, Figure 2). PFHxA, PFOS, PFOA, and PFPeA, were found in 100% of near-field samples, with median concentrations higher than those observed in open Bay samples (5.3, 4.6, 4.5, and 3.7 ng/L, respectively). PFHpA, PFBS, and PFHxS were also frequently detected, with detection frequencies above 90% and median concentrations ranging from 1.6–1.9 ng/L. PFBA was present in 78% of samples and, when detected, exhibited a relatively high median concentration of 3.3 ng/L. PFDA was found in 63% of samples, though at generally lower concentrations (median: 0.63 ng/L). Additional PFAS, including long-chain PFCAs (PFNA, PFUnDA, and PFDA), the short-chain PFSA PFPeS, and two precursor compounds—PFOSA and N-EtFOSAA—were detected sporadically at concentrations below 0.87 ng/L. An exception was observed at one site where PFNA reached 4.2 ng/L during a sampling event characterized by elevated concentrations of multiple analytes. In addition, the precursor 6:2 FTS was detected in a single sample at a relatively high concentration of 8.9 ng/L.

Redwood Creek in the South Bay exhibited the lowest median sum of PFAS concentrations (sumPFAS) (median: 19 ng/L), while higher concentrations were observed at the Palo Alto station in the Lower South Bay (median: 24 ng/L). The San Leandro Bay station had the second highest median concentration (64 ng/L). Stevens Creek, located in the Lower South Bay, consistently exhibited the highest PFAS concentrations, with a median of 74 ng/L. These spatial patterns are likely due to the unique mixing of Bay water, stormwater, and wastewater inputs at each site (Figure 3). The composition of PFAS was also generally similar at each station, with PFHxA, PFOS, and PFOA comprising a significant portion of sumPFAS

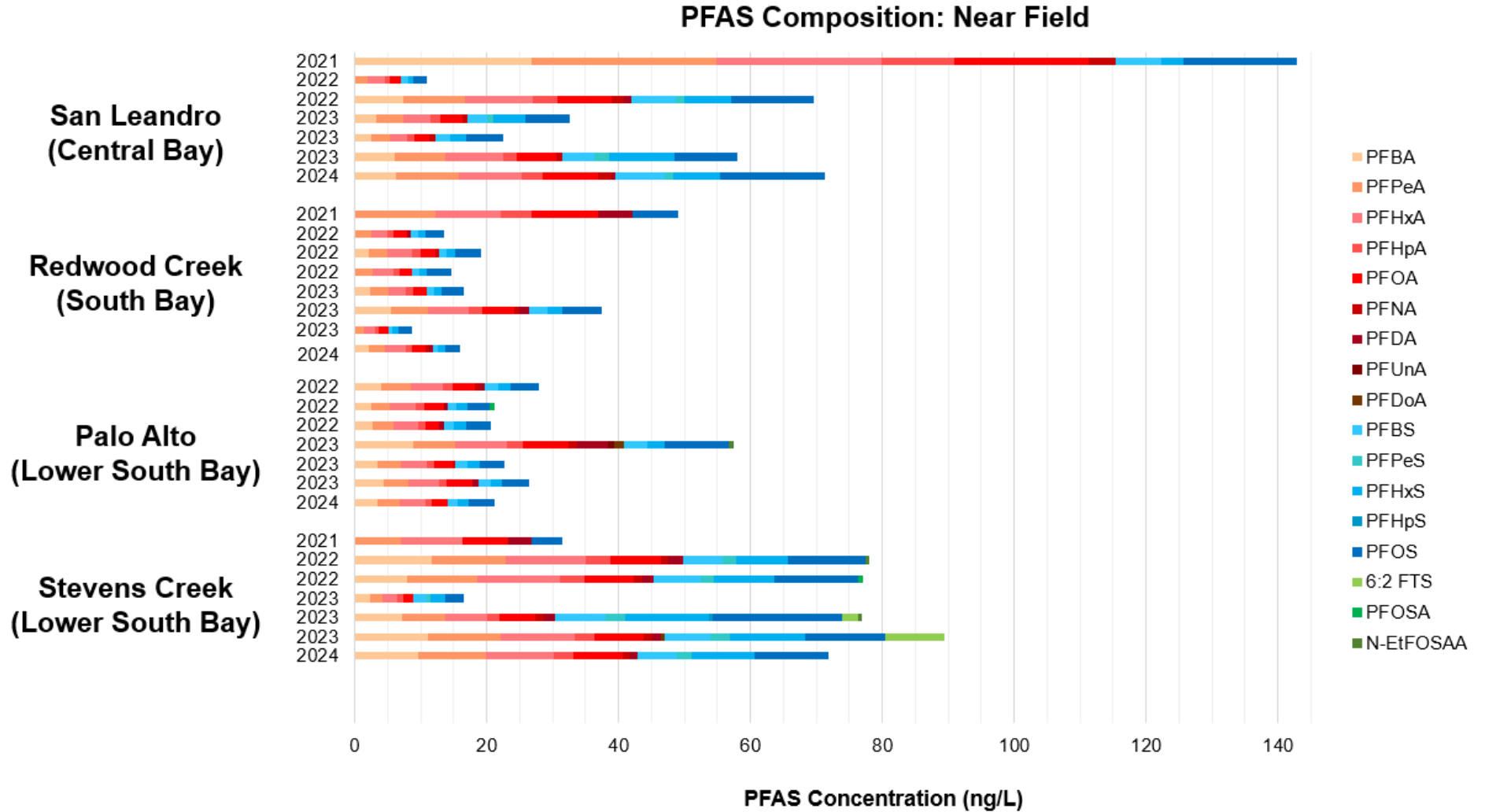


Figure 2. Concentrations of PFAS during wet seasons from fall 2021 to spring 2024 at near-field Bay water stations at various sampling events. Each station was sampled after the same storms in this period, with the exception of Palo Alto, which was not sampled in 2021. From Mendez et al. (2025). Station 23 is paired with the San Leandro Bay near-field station; station 31 is paired with the Redwood Creek near-field station; station 33 is paired with the Palo Alto near-field station; and station 34 is paired with the Stevens Creek near-field station.

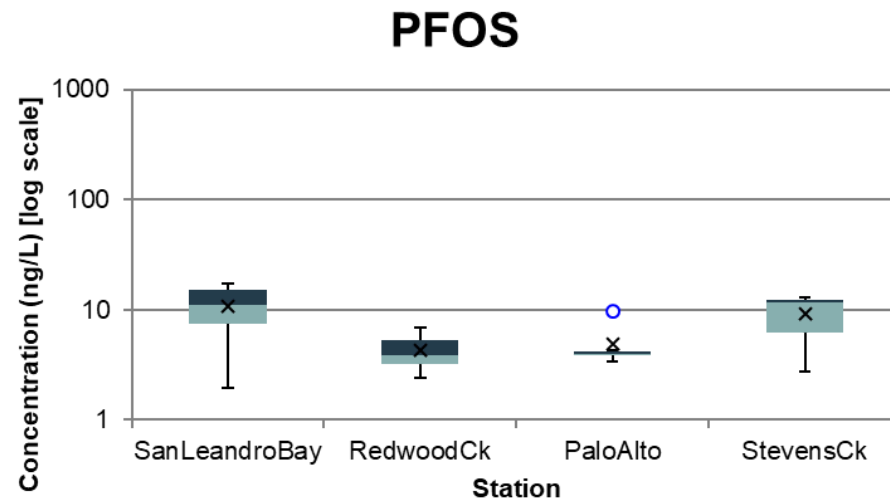
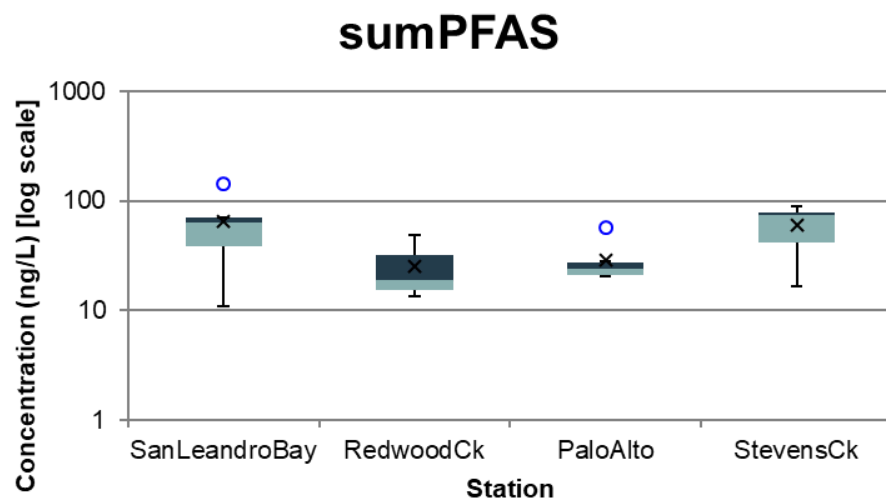


Figure 3. Concentrations (log) of sumPFAS and PFOS detected in near-field Bay water samples during wet seasons from fall 2021 to spring 2024. The y-axis is on a log scale. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the gray being the 25–50% range and blue being the 50–75% range, bars indicate the maximum and minimum excluding outliers, and points indicate outliers which are more than $1.5 \times \text{IQR}$ outside the IQR. The divide between the gray and blue indicates the median value. Stations are ordered from left to right as from north to south.

Table 2. PFAS concentrations in wet season near-field stations from fall 2021 to spring 2024. Yellow values indicate J flag (value between MDL and RL), orange values indicate blank detected (censored), and blue values indicate blank detected (not censored). Station codes: San Leandro Bay: SLB, Redwood Creek: RC, Palo Alto: PA, Stevens Creek: SC

Station Code	Sample Date	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDnA	PFBS	PFPeS	PFHxS	PFOS	6:2 FTS	PFOSA	N-EtFOS AA	sumP FAS
Median Concentration		5.0	4.5	5.3	1.6	3.7	1.2	1.1	1.0	1.0	2.1	1.9	2.3	4.6	8.9	0.6	0.7	31
RC	10/24/2021	<MDL	12	9.8	4.7	10	<MDL	5.3	<MDL	<MDL	<MDL	<MDL	<MDL	6.9	<MDL	<MDL	<MDL	49
SLB	10/25/2021	27	28	25	11	20	4.2	<MDL	<MDL	<MDL	6.9	<MDL	3.4	17	<MDL	<MDL	<MDL	143
SC	10/25/2021	<MDL	7.0	9.4	<MDL	6.8	<MDL	3.7	<MDL	<MDL	<MDL	<MDL	<MDL	4.6	<MDL	<MDL	<MDL	31
PA	11/9/2022	4.0	4.5	4.9	1.6	3.4	0.7	0.7	<MDL	<MDL	2.1	<MDL	1.9	4.2	<MDL	<MDL	<MDL	28
RC	11/9/2022	<MDL	2.5	2.6	0.9	2.0	<MDL	0.6	<MDL	<MDL	1.1	<MDL	1.2	2.7	<MDL	<MDL	<MDL	13
SLB	11/9/2022	<MDL	2.0	2.5	0.8	1.7	<MDL	<MDL	<MDL	<MDL	1.1	<MDL	0.8	2.0	<MDL	<MDL	<MDL	11
SC	11/9/2022	12	11	12	3.7	7.7	1.2	2.1	<MDL	<MDL	6.1	1.9	8.0	12	<MDL	<MDL	0.5	78
PA	12/11/2022	2.5	2.9	4.0	1.3	2.9	<MDL	0.7	<MDL	<MDL	1.3	<MDL	1.6	3.4	<MDL	0.6	<MDL	21
RC	12/11/2022	2.1	2.9	3.7	1.3	2.2	0.5	<MDL	<MDL	<MDL	1.1	<MDL	1.4	3.9	<MDL	<MDL	<MDL	19
PA	12/28/2022	2.7	3.1	3.7	1.2	2.1	<MDL	0.6	<MDL	<MDL	1.7	<MDL	1.7	3.9	<MDL	<MDL	<MDL	21
RC	12/28/2022	<MDL	2.7	3.2	1.0	1.9	<MDL	<MDL	<MDL	<MDL	1.1	<MDL	1.2	3.7	<MDL	<MDL	<MDL	15
SLB	12/28/2022	7.4	9.3	10	3.6	8.2	1.9	1.1	<MDL	<MDL	6.9	1.2	7.0	12.6	<MDL	<MDL	<MDL	70
SC	12/28/2022	7.9	11	13	3.9	7.4	1.4	1.7	<MDL	<MDL	7.1	2.1	9.1	12.8	<MDL	0.7	<MDL	77
PA	2/25/2023	8.9	6.5	7.8	2.5	6.9	1.3	4.7	1.0	1.5	3.6	<MDL	2.6	9.7	<MDL	<MDL	0.9	58
RC	2/25/2023	5.6	5.5	6.2	2.0	4.9	0.7	1.5	<MDL	<MDL	2.6	<MDL	2.4	5.9	<MDL	<MDL	<MDL	37
SLB	2/25/2023	3.3	4.2	4.0	1.6	3.2	0.9	<MDL	<MDL	<MDL	3.0	0.9	4.8	6.7	<MDL	<MDL	<MDL	33
SC	2/25/2023	2.3	1.9	2.2	0.9	1.5	<MDL	<MDL	<MDL	<MDL	2.1	0.5	2.3	2.8	<MDL	<MDL	<MDL	16
PA	12/21/2023	4.3	3.9	4.5	1.3	3.8	<MDL	1.0	<MDL	<MDL	1.8	<MDL	1.9	4.1	<MDL	<MDL	<MDL	26
RC	12/21/2023	2.1	2.5	3.1	0.9	2.2	0.5	0.5	<MDL	<MDL	0.9	<MDL	1.0	2.4	<MDL	<MDL	<MDL	16
SLB	12/21/2023	6.1	7.7	8.8	2.1	5.9	1.0	<MDL	<MDL	<MDL	4.8	2.2	9.9	9.7	<MDL	<MDL	<MDL	58
SC	12/21/2023	11	11	11	3.1	7.4	1.3	1.5	<MDL	0.5	6.8	3.1	11.3	12.2	8.9	<MDL	<MDL	89
PA	1/23/2024	3.5	3.4	3.9	1.0	2.5	<MDL	<MDL	<MDL	<MDL	1.4	<MDL	1.8	3.9	<MDL	<MDL	<MDL	21
RC	1/23/2024	3.1	4.3	5.3	1.6	3.7	<MDL	0.6	<MDL	<MDL	1.5	<MDL	1.5	4.6	<MDL	<MDL	<MDL	26
SLB	1/23/2024	6.4	9.4	9.6	3.2	8.3	2.0	0.7	<MDL	<MDL	7.5	1.3	7.2	16	<MDL	<MDL	<MDL	71
SC	1/23/2024	9.7	10	10	3.1	7.5	1.1	1.1	<MDL	<MDL	5.9	2.4	9.5	11	<MDL	<MDL	<MDL	72

Open Bay

In samples collected at open Bay stations within three weeks following storm events, 11 PFAS were identified, with eight detected in over 60% of samples (Figure 4, Table 3). PFHxA was present in 100% of open Bay samples and exhibited the highest median concentration (2.7 ng/L). PFOS and PFOA were also frequently detected (92% of samples), with median concentrations of 2.7 ng/L and 2.1 ng/L, respectively. Three short-chain PFCAs, PFBA, PFPeA, and PFHpA, along with two PFSA, PFBS and PFHxS, were also detected in more than 60% of samples, with median concentrations ranging from 1.0–2.3 ng/L. The long-chain PFCAs and PFSA, PFNA and PFDA, were detected in fewer samples and at lower concentrations (<0.84 ng/L). One precursor compound, PFOSA, was detected in a single sample at a concentration of 0.52 ng/L.

Spatial analysis revealed a gradient of increasing sumPFAS concentrations from north to south (Figure 5). Both Lower South Bay stations have higher levels of sumPFAS than the Central Bay station (p -value: 0.001 for both stations 33 and 34 versus 23). However, this initial dataset is limited, indicating the need for more data and sampling in the future. Station 23 in the Central Bay exhibited the lowest median concentration (2.9 ng/L), while higher concentrations were observed at stations 31 and 33 in the South Bay (medians: 11.5 ng/L and 16.4 ng/L, respectively). Station 34, located in the Lower South Bay, consistently exhibited the highest sumPFAS concentrations, with a median of 19.9 ng/L. These spatial patterns are consistent with expectations given the hydrodynamics of the Bay. Like the near-field, the composition of PFAS was also generally similar at each station, with PFHxA, PFOS, and PFOA signatures comprising a significant portion of sumPFAS.

Near-field Versus Open Bay

Overall, PFAS concentrations in near-field samples were higher than those in paired open Bay water samples collected during the same wet season events (Figures 6 and 7). Median sumPFAS in near-field samples was 32 ng/L, more than twice the median observed in open Bay waters (15 ng/L). This distribution pattern also holds for most individual PFAS, including PFHxA, PFOA, and PFOS (Figure 8). These elevated concentrations are consistent with the proximity of the near-field stations to pathway inputs and the strong influence of stormwater runoff at these sites at the time of collection.

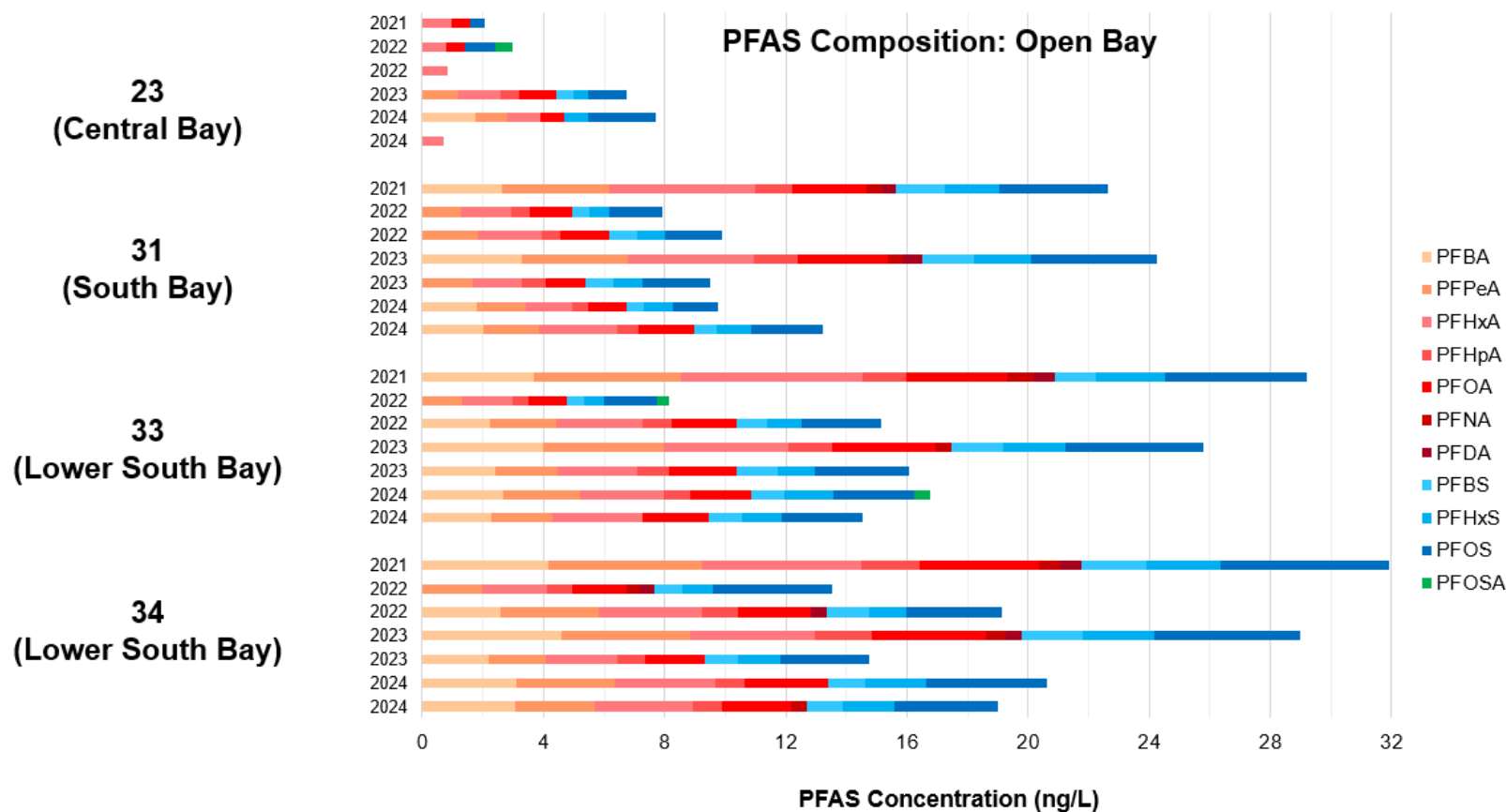


Figure 4. Concentrations of PFAS detected during wet season sampling from fall 2021 to spring 2024 at open Bay water stations across various sampling events. Each station was sampled after the same storms in this period, with the exception of Palo Alto, which was not sampled in 2021. From Mendez et. al (2025). Station 23 is paired with the San Leandro Bay near-field station; station 31 is paired with the Redwood Creek near-field station; station 33 is paired with the Palo Alto near-field station; and station 34 is paired with the Stevens Creek near-field station.

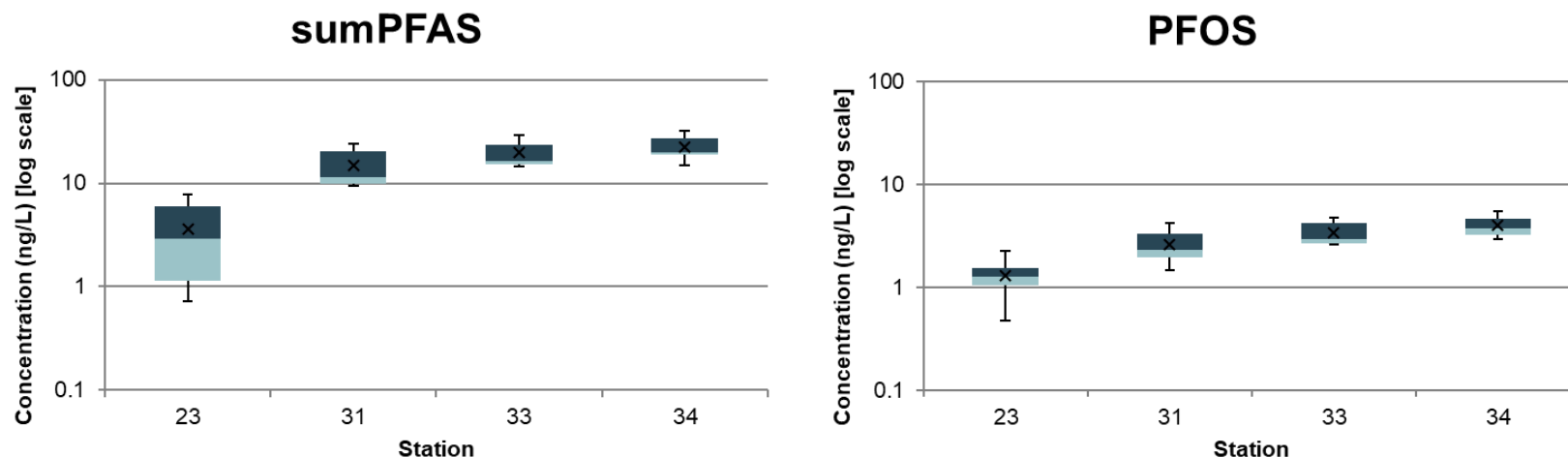


Figure 5. Concentrations (log) of sumPFAS and PFOS detected in open Bay water samples during wet seasons from fall 2021 to spring 2024. The y-axis is on a log scale. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the gray being the 25–50% range and blue being the 50–75% range, bars indicate the maximum and minimum excluding outliers, and points indicate outliers which are more than $1.5 \times \text{IQR}$ outside the IQR. The divide between the gray and blue indicates the median value. Stations are ordered from left to right, as from north to south.

Table 3. PFAS concentrations in wet season open Bay stations from fall 2021 to spring 2024. All units in nanograms per liter (ng/L). Yellow values indicate J flag (value between MDL and RL).

Sample Year	Station Code	Sample Date	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFBS	PFHxS	PFOS	PFOSA	SumPFAS
Median Concentrations			2.6	2.4	2.7	1.0	2.2	0.5	0.6	1.2	1.3	2.8	0.52	15
2021	23	11/4/2021	<MDL	<MDL	1.0	<MDL	0.62	<MDL	<MDL	<MDL	<MDL	0.48	<MDL	2.1
2021	31	11/4/2021	2.6	3.6	4.8	1.2	2.5	0.52	0.44	1.6	1.8	3.6	<MDL	23
2021	33	11/4/2021	3.7	4.9	6.0	1.4	3.4	0.84	0.71	1.4	2.3	4.7	<MDL	29
2021	34	11/4/2021	4.2	5.1	5.3	1.9	4.0	0.70	0.68	2.2	2.5	5.5	<MDL	32
2022	23	11/15/2022	<MDL	<MDL	0.83	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.83
2022	31	11/15/2022	<MDL	1.9	2.1	0.61	1.6	<MDL	<MDL	0.94	0.90	1.9	<MDL	9.9
2022	33	11/15/2022	2.2	2.2	2.9	0.94	2.2	<MDL	<MDL	1	1.2	2.6	<MDL	15
2022	34	11/15/2022	2.6	3.2	3.4	1.2	2.4	<MDL	0.51	1.4	1.2	3.2	<MDL	19
2023	23	1/23/2023	<MDL	1.2	1.4	0.60	1.2	<MDL	<MDL	0.58	0.49	1.2	<MDL	6.7
2023	31	1/23/2023	3.3	3.5	4.2	1.4	3.0	0.48	0.66	1.7	1.9	4.2	<MDL	24
2023	33	1/23/2023	4.0	4.0	4.1	1.4	3.4	0.53	<MDL	1.7	2.1	4.6	<MDL	26
2023	34	1/23/2023	4.6	4.3	4.1	1.9	3.8	0.64	0.54	2.0	2.4	4.8	<MDL	29
2023	22	3/1/2023	<MDL	<MDL	0.98	<MDL	0.93	<MDL	<MDL	<MDL	0.55	1.3	<MDL	3.7
2023	31	3/1/2023	<MDL	1.7	1.6	0.77	1.3	<MDL	<MDL	0.93	0.95	2.3	<MDL	9.5
2023	33	3/1/2023	2.4	2.0	2.6	1.1	2.2	<MDL	<MDL	1.4	1.2	3.1	<MDL	16
2023	34	3/1/2023	2.2	1.9	2.4	0.95	2.0	<MDL	<MDL	1.1	1.40	3.0	<MDL	15
2024	34	1/2/2024	3.1	3.2	3.3	0.96	2.8	<MDL	<MDL	1.3	2.0	4.0	<MDL	21
2024	33	1/2/2024	2.7	2.6	2.8	0.87	2.0	<MDL	<MDL	1.1	1.6	2.7	0.52	17
2024	23	1/2/2024	1.7	1.1	1.1	<MDL	0.79	<MDL	<MDL	<MDL	0.79	2.3	<MDL	7.7
2024	31	1/2/2024	1.8	1.6	1.5	0.53	1.3	<MDL	<MDL	0.6	0.97	1.5	<MDL	9.8
2024	23	11/1/2024	<MDL	<MDL	0.72	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.72
2024	34	11/1/2024	3.1	2.6	3.3	0.95	2.3	0.50	<MDL	1.2	1.7	3.4	<MDL	19
2024	33	11/1/2024	2.3	2.0	3.0	<MDL	2.2	<MDL	<MDL	1.1	1.3	2.7	<MDL	15
2024	31	11/1/2024	2.0	1.9	2.6	0.71	1.8	<MDL	<MDL	0.72	1.1	2.4	<MDL	13

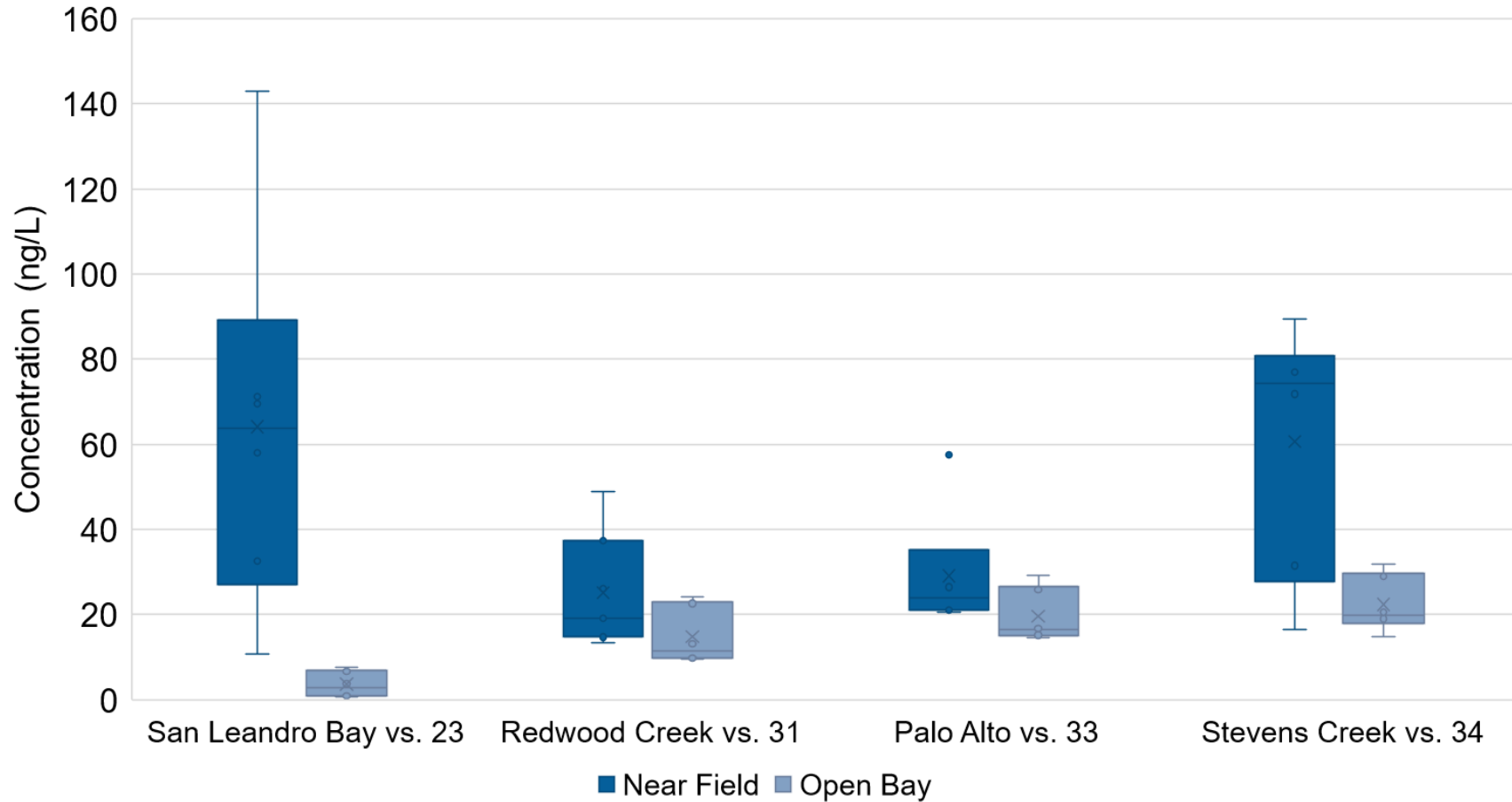


Figure 6. Wet season near-field versus open Bay sumPFAS concentrations from storms sampled from fall 2021 to spring 2024. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum excluding outliers, and points indicate outliers which are more than 1.5×IQR outside the IQR.

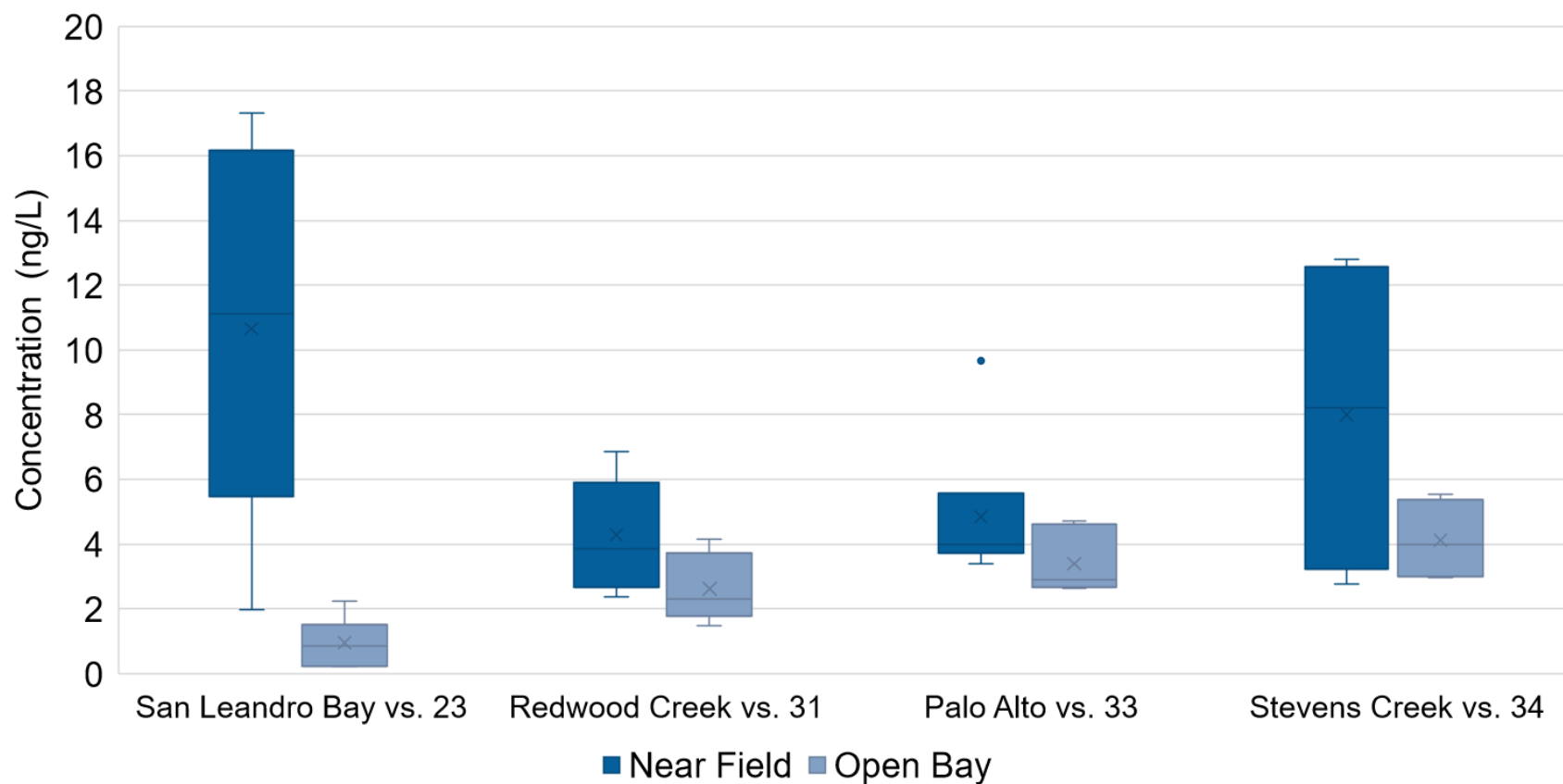


Figure 7. Wet season near-field versus open Bay PFOS concentrations from six storms sampled from fall 2021 to spring 2024. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum excluding outliers, and points indicate outliers which are more than 1.5×IQR outside the IQR.

Table 4. Median and 90th percentile concentrations for PFHxA, PFOS, PFOA, and sumPFAS in samples taken from 2022–2024 in the dry season (near-field water, n = 8; open Bay water, n = 8) and from fall 2021 to spring 2024 for the wet season (near-field water, n = 25; open Bay water, n = 24). All values are in ng/L.

PFAS	Median				Range				MDL of All Samples
	Dry Season	Dry Season	Wet Season	Wet Season	Dry Season	Dry Season	Wet Season	Wet Season	
	Open Bay	Near Field	Open Bay	Near Field	Open Bay	Near Field	Open Bay	Near Field	
PFHxA	1.7	3.3	2.7	5.3	ND - 4.1	1.5 - 11	0.72 - 6.0	2.2 - 25	0.5
PFOS	1.8	4.7	2.7	4.6	ND - 4.2	2.0 - 20	ND - 5.5	2.0 - 17	0.5
PFOA	1.3	2.5	2.1	3.7	0.43 - 2.7	1.5 - 5.5	ND - 4.0	1.5 - 20	0.5
sumPFAS	9.2	22	15	32	0.83 - 24	8.6 - 104	0.72 - 32	11 - 142	NA

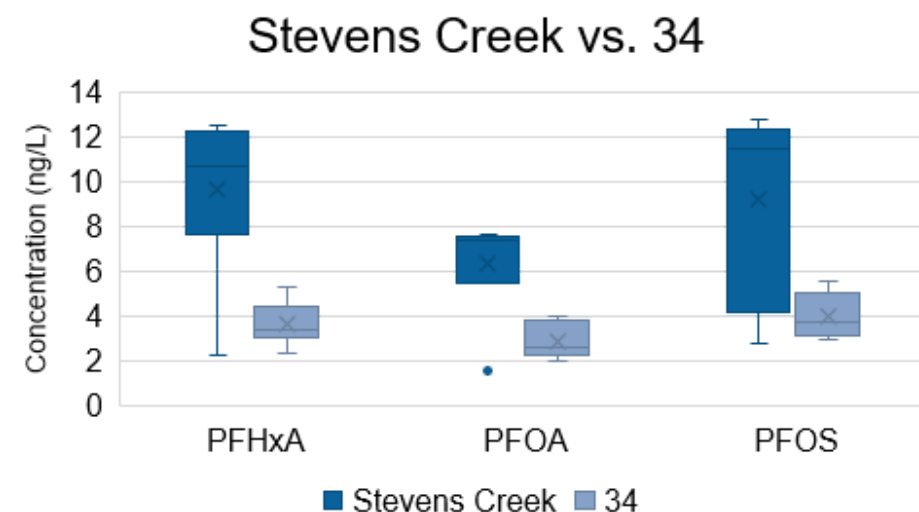
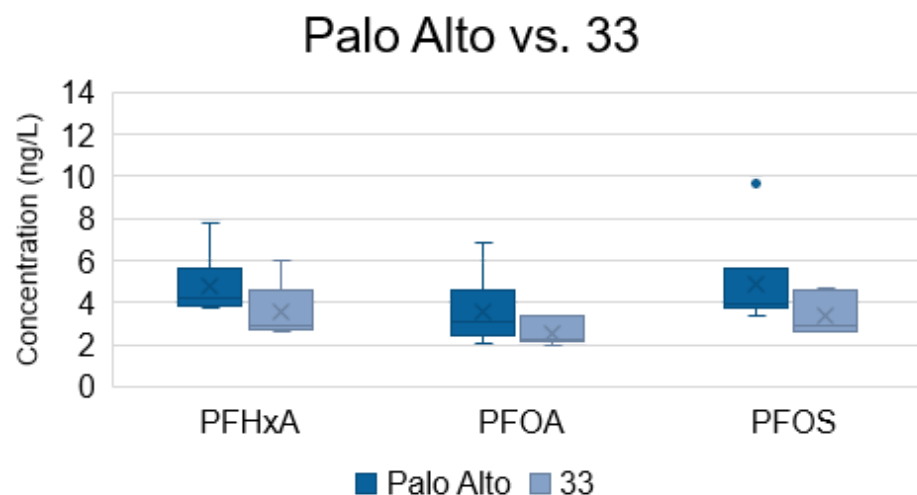
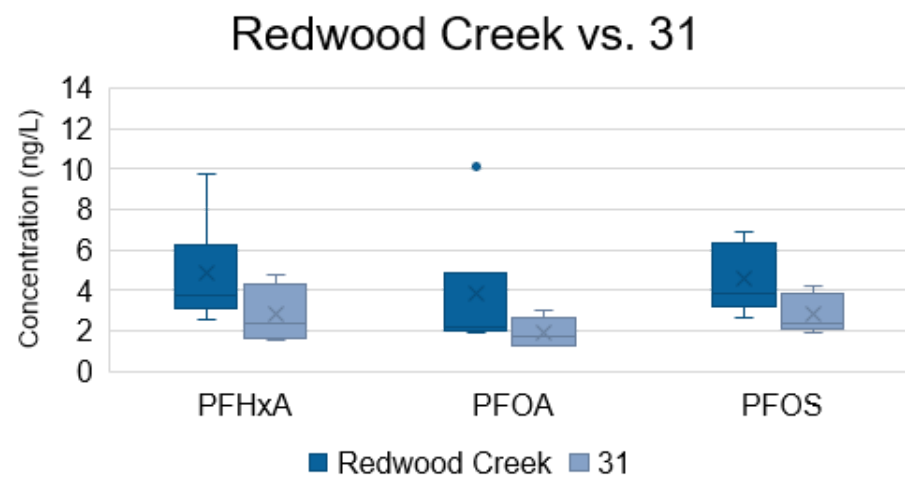
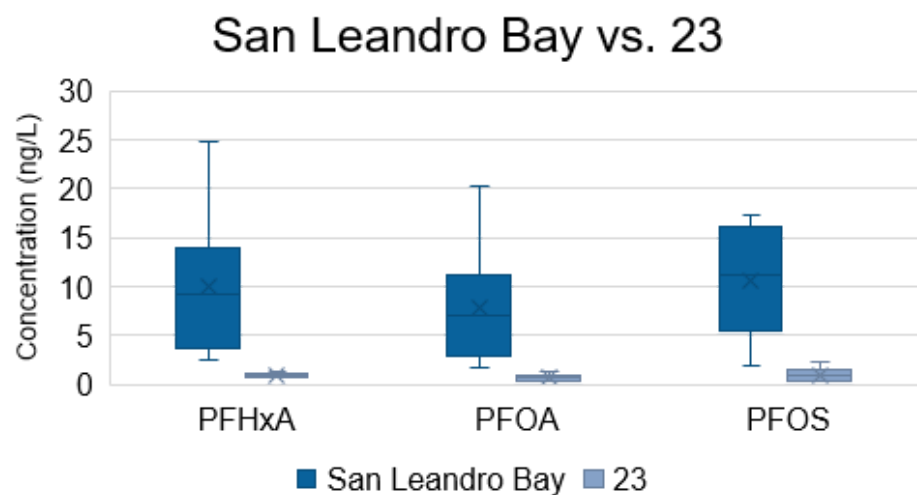


Figure 8. PFHxA, PFOA, and PFOS concentrations at paired near-field and open Bay stations. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum excluding outliers, and points indicate outliers which are more than 1.5×IQR outside the IQR.

Wet Season Versus Dry Season

Dry season sampling was conducted less frequently than wet season sampling, with only two sampling events occurring for both the near-field and open Bay at each of the four pairs of stations (n = 8 for both).

A comparison of concentrations in the wet season to the dry season found slightly elevated levels in the wet season for both near-field and open Bay compared to the wet season, but not to the extent originally expected (Figure 9 and Table 4). In the near-field, the sum of PFAS had a median of 32 ng/L in the wet season compared to 22 ng/L in the dry season. Likewise, in the open Bay, the sum of PFAS had a median of 15 ng/L in the wet season compared to 9 ng/L in the dry season. Dry season levels of PFOS (4.7 ng/L) were similar to wet season levels (4.6 ng/L) in the near-field. These relatively high levels in the dry season could be a consequence of the persistence of PFAS in the environment as well as, at some locations, non-stormwater influences such as wastewater.

Dry-season samples had a different PFAS profile from wet-season samples. Although PFOS, PFHxA, and PFOA comprised most of each fingerprint in both the near-field and open Bay wet season samples, PFOS concentrations were highest in the dry season (medians: 4.7 and 1.8 ng/L). PFHxA followed with medians of 3.3 and 1.7 ng/L and PFOA with medians of 2.5 and 1.3 ng/L for the near-field and open Bay, respectively.

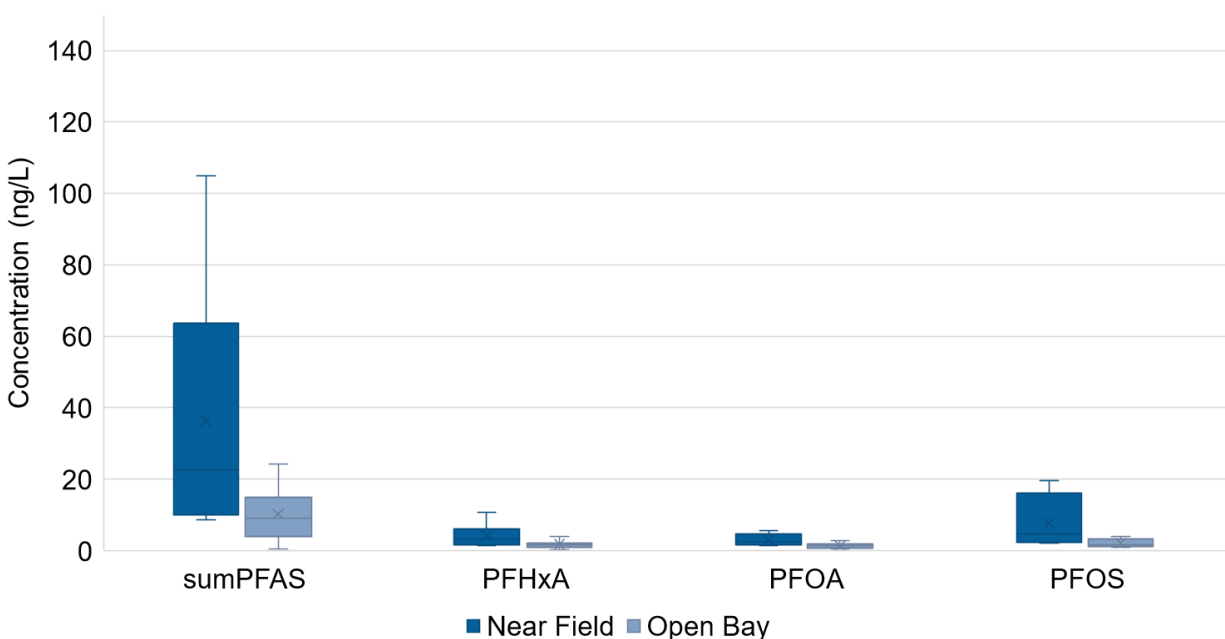


Figure 9. sumPFAS, PFHxA, PFOA, and PFOS concentrations compared between near-field and open Bay in the dry season. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum.

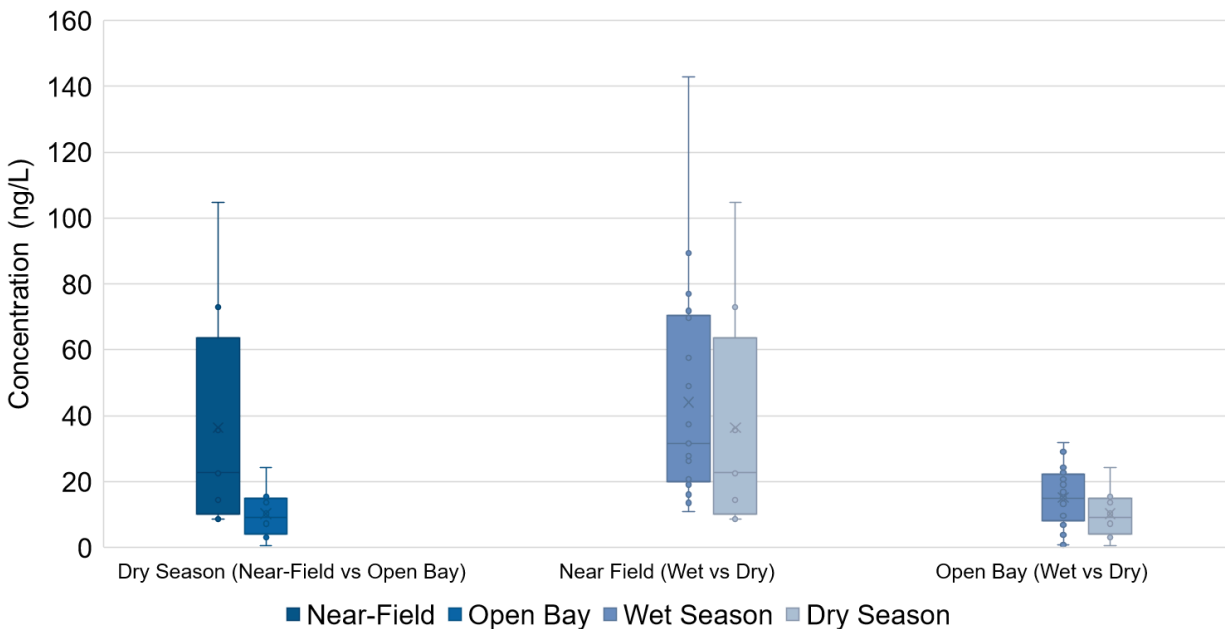


Figure 10. sumPFAS concentrations compared between near-field and open Bay in the dry season, and between wet and dry seasons in the near-field and open Bay. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum.

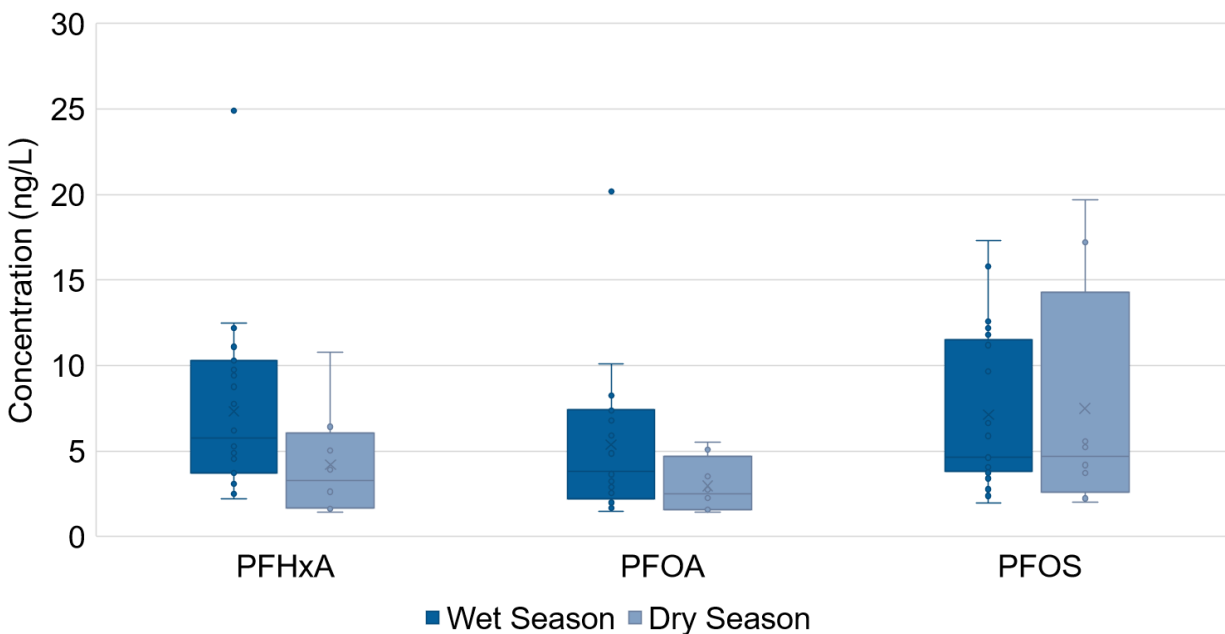


Figure 11. Near-field concentrations of PFHxA, PFOA, and PFOS in the wet and dry seasons. Points indicate individual sample concentrations. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum excluding outliers.

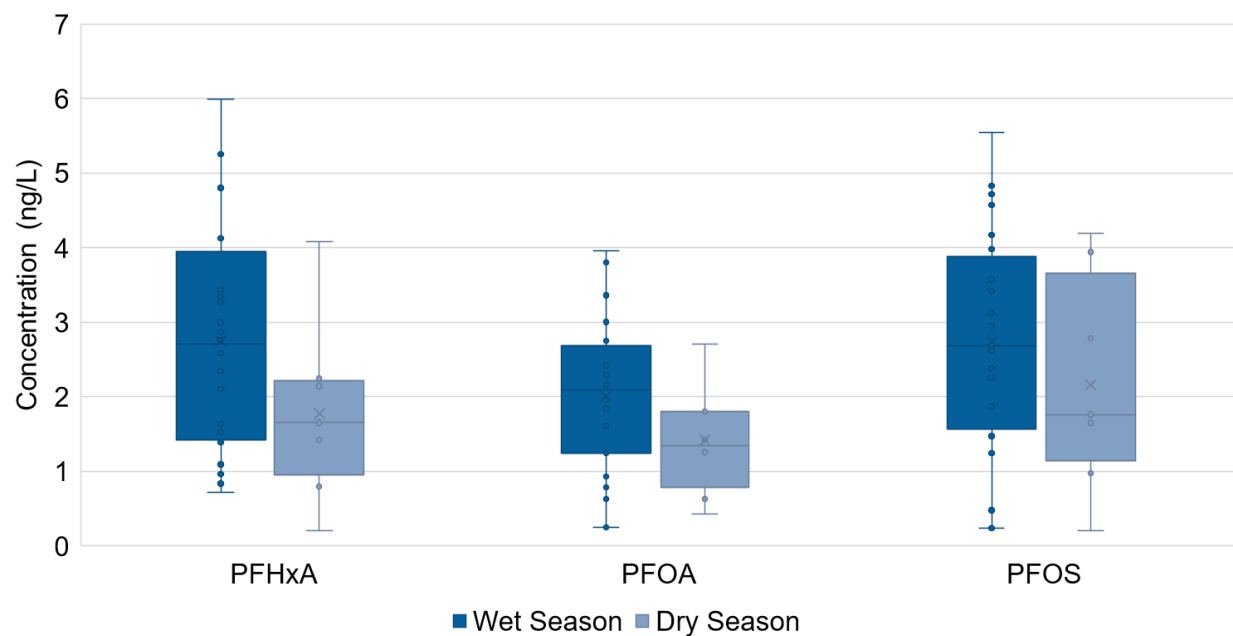


Figure 12. Open Bay concentrations of PFHxA, PFOA, and PFOS in the wet and dry seasons. Points indicate individual sample concentrations. Xs indicate the mean, boxes indicate the 25–75% interquartile range (IQR) with the line inside indicating the median, whiskers indicate the maximum and minimum excluding outliers.

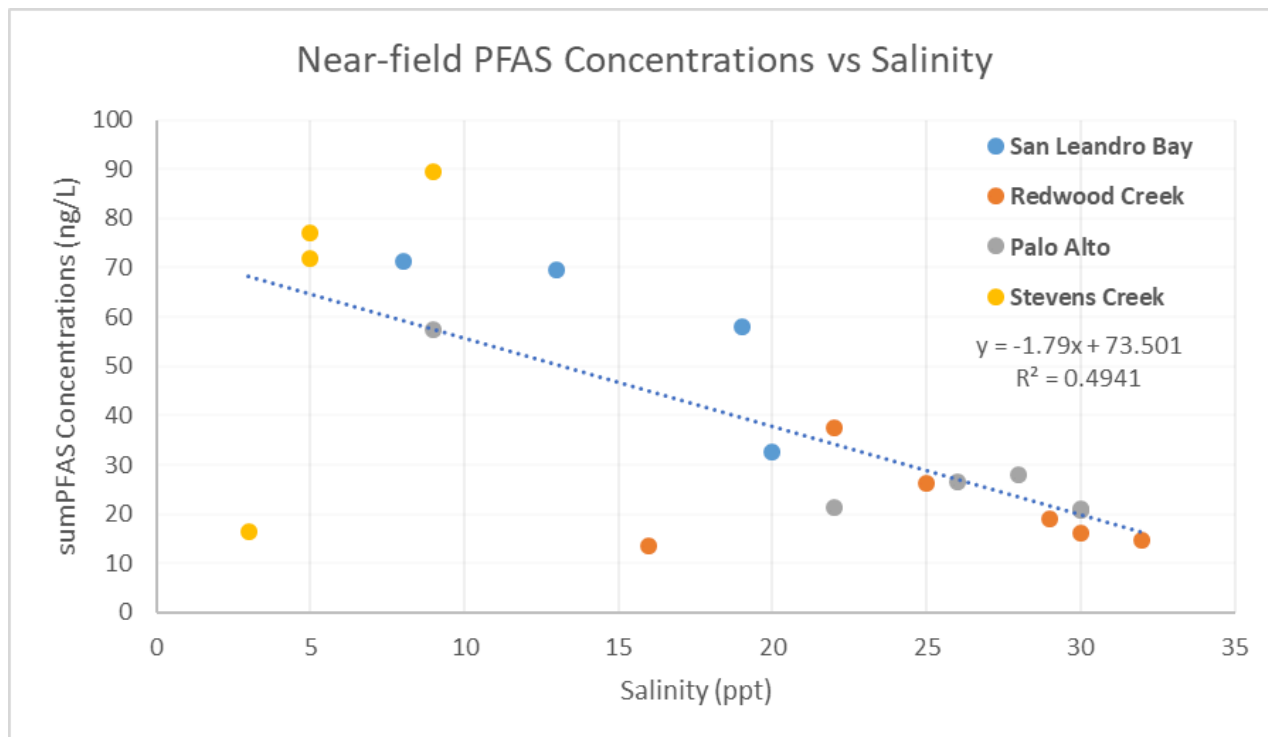


Figure 13. Wet season sumPFAS concentrations at near-field stations compared with salinity.

For near-field stations, the sampling design aimed to capture water that was a mix of Bay water and stormwater runoff. Specifically, the goal was to collect samples when the salinity was greater than 15 ppt (half Bay water) or ideally greater than 20 ppt (~2/3 Bay water). Collection was to occur after at least two high tides following a storm event of at least 0.25 inches of rainfall, and preferably during a time in which stormflow from the watershed had already or was receding back to baseflow. This was meant to ensure that there had been enough mixing of stormwater with Bay water. If the sampling occurred after an extended period of high precipitation, the salinity may not have risen to the target range despite tidal mixing. These efforts were somewhat successful, with nine of 20 recorded salinity measurements above 20 ppt, and another three between 15–20 ppt, (Figure 12). However, all of the samples from Stevens Creek were below the target, at only 3–9 ppt. Despite this range of measured salinities, a clear inverse linear relationship was observed between PFAS concentrations and salinity (p -value = 0.0046). This relationship indicates that, as expected, the degree of mixing with Bay water is an important driver of variation in near-field concentrations. Although this mixing effect was difficult to control through sampling timing, it can be accounted for statistically using observed correlations with salinity or through modeling, as illustrated by a recent integrated watershed-Bay effort modeling dissolved tracers in the Lower South Bay (King et al. in preparation). The sampling design aimed to capture near-field waters with a consistent degree of mixing with Bay water; this target was not consistently achieved across sites and events. Observed salinities varied widely, and higher salinity consistently corresponded with lower PFAS

concentrations. These results highlight the importance of carefully accounting for mixing conditions when interpreting near-field data. Comparisons of concentrations across sites or seasons should not be interpreted as differences in stormwater loading alone, but rather as the combined influence of storm characteristics, watershed inputs, and the degree of Bay water mixing at the time of sampling.

Because salinity exerts a strong control on observed concentrations, future interpretation and analysis should explicitly account for salinity effects to avoid over-interpreting apparent spatial or temporal differences. Dissolved tracer and hydrodynamic modeling approaches provide a means to control for these effects and to place observed concentrations in an appropriate mixing and exposure context.

These results suggest that near-field PFAS concentrations are strongly influenced by mixing processes and that sampling designs emphasizing characterization of the near-field mixing zone may provide more consistent insights into short-term exposure conditions than efforts focused on individual stormwater inputs.

3.2. OPEs and Bisphenols

OPEs and bisphenols were included as part of the study design for this S&T wet season pilot effort. As these pollutants were added to the S&T water monitoring program, the RMP transitioned analysis to a commercial lab. Due to unresolved methodological and QA/QC issues, the OPE and bisphenol datasets have been censored from interpretation.

For OPEs, as previously noted, field blanks had frequent contamination hits. These high blank concentrations could not be dismissed as random anomalies, as some blank sample results matched or significantly surpassed the highest field sample readings.

Efforts to address the issue included standardizing field blank procedures from both the lab and the field sampling team. Going forward, the RMP will implement new protocols, such as requiring labs to retain blank samples for comparison in the event of contamination detection. This measure will ensure that any contamination observed in shipped samples can be traced to its source, whether in the lab or the field. There are also inherent background contamination challenges in labs, particularly with compounds like TBOEP, which can be found in lab environments in sealants and cleaners.

There were also discrepancies in reported bisphenol levels, which could be attributed to method issues across multiple years. Results in 2023 showed unexpectedly low detection frequencies for BPA and BPS, despite earlier data from 2021 indicating consistent detection of these compounds. This inconsistency could be related to BPA's presence in specific phases, such as particulate versus dissolved forms, highlighting that recent dissolved-phase monitoring efforts showed minimal BPA detection. Additionally, BPS was not detected in any sample. These factors contributed to the decision to censor the entire dataset for the time being. To address these uncertainties, the RMP will conduct an interlaboratory comparison to assess consistency among analytical methods for OPEs and bisphenols.

3.3. Vehicle-Related Emerging Contaminants

Tire- and vehicle-derived contaminants were added to the wet season pilot effort as a special study. The opportunistic sampling took place concurrently with this S&T CECs pilot. Further information can be found in Miller et al. (2025). Various tire- and vehicle-derived contaminants have been observed in Bay Area stormwater, including the salmonid toxicant 6PPD-quinone, derived from a ubiquitously used tire preservative chemical (Peter et al., 2024; Sutton et al., 2024; Tian et al., 2021). The Miller et al. study found that tire- and vehicle-derived contaminants reach detectable concentrations in Bay water both near stormwater discharge locations and in the center of the Bay, even with dilution from mixing. Many of these contaminants followed expected dilution patterns, but the data indicate non-stormwater inputs of benzotriazoles. For contaminants with available toxicity thresholds, most Bay concentrations were below these thresholds. However, 6PPD-quinone reached concentrations that may be of concern for sensitive species, although more sublethal toxicity data are needed for a robust understanding of potential risk.

4. RECOMMENDATIONS FOR FUTURE S&T WET SEASON WATER MONITORING

This pilot study yielded valuable information on the occurrence and fate of CECs in the Bay. PFAS are classified as High Concern for the Bay based on their known environmental persistence, widespread detection, and potential toxicity, including concerns relating to human exposures via consumption of contaminated sport fish (Sutton et al., 2024b). Data on Bay water concentrations are important to understand accumulation and exposure in aquatic biota, especially species consumed by humans.

Additional information is needed for OPEs and bisphenols given the limited data for these contaminants in the Bay. OPEs are also currently classified as High Concern and are not monitored in any other matrices as part of S&T. Bisphenols are classified as Moderate Concern and are currently monitored in sediment as part of RMP S&T.

Overall, the findings presented here demonstrate a need for continued wet season water monitoring throughout the Bay, with an emphasis on stations in the South and Lower South Bays, where the influence of wastewater and stormwater is stronger, as well as continued monitoring in the Central Bay and potentially the North Bay. Specific aspects of this recommendation are as follows:

- Continue PFAS monitoring to strengthen interpretation of spatial and seasonal patterns. This pilot study generated a small initial dataset that provides insights into PFAS spatial patterns and seasonal variation; additional data are needed to evaluate whether these patterns are consistent across years and conditions. .
- Resume implementation of the pilot sampling design for OPEs and bisphenols once reliable analytical methods have been established. Although analytical results were produced for OPEs and bisphenols, unresolved methodological and QA/QC issues currently prevent their use in interpretation. OPEs and bisphenols may show different spatial and temporal patterns than PFAS, and comparing patterns among these three classes would be informative.
- Continue open Bay sampling that is temporally linked to near-field sampling . The Stevens Creek dissolved tracer study (King et al. in prep) quantified a weak relationship between open Bay concentrations and near-field concentrations in Stevens Creek, but open Bay data provide valuable information on CEC exposure at the regional scale. Additional data will also support future modeling efforts.
- Consider adding sites if funding becomes available. Additional stations could improve spatial coverage and help evaluate whether observed patterns are representative of broader Bay conditions.
- Continue and potentially expand salinity monitoring at selected sites. Since salinity strongly influences observed concentrations, continued salinity monitoring would help avoid overinterpreting spatial and temporal patterns.

Pairing near-field stations with locations sampled farther upstream in watersheds could improve interpretability in some cases; however, this approach presents substantial logistical challenges. Differences in access, storm timing, safety constraints, and watershed infrastructure limit the feasibility of consistent up-watershed sampling within

the current sampling framework. As a result, expanded watershed linkage is not anticipated for WY26, but could be explored conceptually in future planning discussions, including through coordination with the Fixed Station Monitoring Network (FSMN) and other RMP stormwater efforts.

4.1. Decisions for future S&T Wet Season Water Monitoring

For WY26, wet season monitoring will proceed under the existing sampling framework, adding a new near-field station in Richmond and expanding open Bay coverage to include approximately half of the stations sampled by the USGS during wet season cruises. Analysis will focus on PFAS, non-target analysis, suspended sediment concentration, and selected add-on RMP special studies analytes. Bisphenols and organophosphate esters will remain on hold pending completion of laboratory intercomparison efforts.

Topics for future water years include the potential value of a dedicated wet season open Bay cruise, expanded spatial coverage beyond the central Bay spine, additional near-field locations, coordination with FSMN and PMU efforts, and determination of the spatial and temporal resolution needed to support modeling objectives. Decisions regarding sampling frequency and design will be informed by the growing dataset and evolving management and modeling needs.

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