UVic Sustainability Scholars Program

ASSESSING THE ROLE OF STREET SWEEPING IN STORMWATER RUNOFF QUALITY

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Disclaimer

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Territorial Acknowledgement

I acknowledge and respect the ləkʷəŋən peoples on whose territory the university stands and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.

ASSESSING THE ROLE OF STREET SWEEPING IN STORMWATER RUNOFF QUALITY

Sustainability Scholar Program – May 2025 to August 2025

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LAND ACKNOWLEDGMENT

The authors acknowledge that this study took place within the City of Victoria which is located on the homelands of the Songhees Nation and the Xwsepsum Nation.

Further, the authors acknowledge and and respect the lək̓ʷəŋən peoples on whose territory the university stands and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.

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1. EXECUTIVE SUMMARY

Managing stormwater quality in urban environments is inherently challenging, as rainwater running off streets, rooftops, and other hard surfaces can carry a wide range of pollutants into the storm drain system and local waterways. The variability of rainfall events, diversity of land uses, complexity of drainage infrastructure and range of source control efforts all contribute to dynamic water quality conditions that can be difficult to measure, interpret, and manage. Without effective ways to visualize and analyze this information, valuable insights can remain buried in raw datasets, limiting the ability of municipalities to target interventions, track progress, and communicate outcomes.

This study represents the first effort at the City of Victoria to comprehensively visualize historical stormwater outfall water quality data and evaluate how certain stormwater interventions, like street sweeping and catch basin design, may influence water quality. While stormwater quality concerns throughout the City are not new, this work aims to present the data in various ways, thereby helping internal staff, technical professionals, and the broader community better understand contaminants in the City's storm drain system. By highlighting spatial and temporal patterns in historical data, this project supports more informed decision-making for future interventions to improve stormwater quality.

Rather than focusing solely on historical contaminant issues, this work recognizes the opportunity to build on ongoing efforts to improve stormwater management and pollutant source control. In particular, the project explores how the City's robust and growing street sweeping program—which operates at a frequency much higher than most Canadian municipalities—is helping to reduce contaminant loading into the City's storm drain system via the removal of debris from streets.

In addition, the study begins to examine the role of catch basins and catch basin design, including the use of inverted tees. Understanding how different catch basin configurations influence contaminant capture is important when developing source control strategies and may inform future design standards, retrofits, or maintenance priorities.

By developing visualizations of the City's current and historical stormwater quality data, this project also aims to support education and outreach efforts. Public and industry awareness is essential compliance with regulations, and to long-term improvements in water quality. For example, businesses and property owners should be aware of the materials that are prohibited from entering the City's storm drain, the impacts of these discharges on the receiving environment and infrastructure, and their responsibility to prevent, respond to, and report spills that do occur.

Overall, this research is foundational for more transparent, collaborative, and evidence-based approaches to stormwater quality management in the City of Victoria.

2. INTRODUCTION

2.1 PROJECT BACKGROUND

2.1.1 City of Victoria Stormwater Quality Challenges

As cities like Victoria continue to grow and urbanize, managing the impact of stormwater runoff on local ecosystems and infrastructure has become a critical sustainability challenge. The City of Victoria's stormwater system, originally constructed over 120 years ago, was designed primarily to prevent flooding by directing rainwater away from homes and businesses. However, as urban development expanded and more surfaces became impermeable, the natural water cycle was disrupted. Instead of infiltrating into the ground, rainwater flows over streets, parking lots, and rooftops, picking up contaminants such as oil, heavy metals, sediments, microplastics, and organic pollutants. These pollutants enter the stormwater system and are discharged into local waterways and the ocean.

While stormwater quality concerns in the City are not new, the way of approaching them is evolving. In addition to ongoing issues such as legacy contamination from historical industrial activities, there is recognition that ongoing stormwater discharges continue to introduce contaminants into receiving waters. Addressing these issues requires efforts to prevent contaminants from entering the City's storm drains, expanding and maintaining a distributed network of treatment facilities, and improving our understanding of when and where areas are at the highest risk of contaminants.

This project represents the City's first initiative to compile and visualize historical stormwater outfall water quality data. By examining spatial and seasonal patterns, this project seeks to give staff, other professionals, decision-makers, and community partners better insight into potential contaminant sources and pathways. This understanding is important for developing and optimizing interventions and engaging residents, businesses, and industries in shared stewardship of local water quality.

2.1.2 Water Quality Monitoring Efforts

The Capital Regional District (CRD) Stormwater Quality Program has been monitoring stormwater quality at outfalls and watercourses since the early 1980s, and in nearshore marine environments since the 1990s. CRD staff identify contamination and evaluate impacts from stormwater through bacterial and chemical sampling. Data collection includes measuring contaminant concentrations in water and/or sediment samples. Public health risk ratings are assigned to stormwater discharges based on *E. coli* concentrations and the likelihood of human exposure, while environmental concern ratings are assigned based on concentrations of metals and organic contaminants, which are compared to environmental quality guidelines for the protection of marine aquatic life to assess their potential for environmental impact

Long-term monitoring has revealed patterns that help identify priority areas for management. For example, some catchments with significant industrial or high-traffic land uses show higher concentrations of heavy metals such as copper, zinc, lead, and cadmium, with exceedances most common in the winter months when rainfall is frequent. In particular, Rock Bay's outfall DOF007028 (Catchment 629) has consistently recorded some of the highest pollutant concentrations in the region.

These monitoring efforts are essential for understanding baseline conditions and tracking changes over time. However, outfall water quality results are typically presented on an annual basis, showing only the results for the previous year's sampling. This project aims to better understand trends in the City's outfall water quality by visualizing all the historical data collectively.

2.1.3 Stormwater Quality Improvement Efforts

To address these challenges, the City of Victoria has implemented an integrated stormwater management approach that targets both non-point source and point source stormwater pollution. Non-point source pollution is managed through a distributed network of conventional infrastructure, like catch basins, and Green Stormwater Infrastructure (GSI). GSI aims to mimic natural processes by capturing and treating rainwater at its source through methods such as rain gardens, bioswales, and permeable pavements. These techniques slow runoff, reduce contaminant loading by filtering out pollutants, support groundwater recharge, and retain stormwater that would otherwise go directly to the City's storm drain. Point source pollution prevention is focused on source control and enforcing compliance with City Bylaws and the Stormwater Codes of Practice Program. The Codes of Practice Program, established in 2005, regulates business types identified for their potential to contribute to contaminated stormwater runoff.

One of the City's most significant operational interventions is its street sweeping program, which has expanded substantially over the past seven years. The program operates at a higher frequency than most Canadian municipalities, with:

- Residential streets swept every 6 weeks
- Heavy-traffic areas swept at least weekly
- Industrial areas swept several times per week, and in some cases daily or twice daily, with summer street washing
- Downtown core swept daily

The City has also invested in improved vacuum equipment that more effectively removes fine particulates, which can carry heavy metals and other contaminants.

Another intervention for capturing debris before it enters the City's storm drain system are catch basins. Typical catch basins consist of a sump with an inlet (commonly a grate) and an outlet overflowing to the storm drain. Catch basin designs may vary, for example, the City's catch basin standard includes an inverted tee located on the outlet pipe. The purpose of the inverted tee is to minimize the quantity of floatable debris, leaves and oil that enters the storm drain system by drawing water from below the surface rather than the very top. Due to changing City standards over time and operational maintenance challenges, there are catch basins throughout the City with and without inverted tees. This study will assess the impact of catch basin design, the presence or absence of an inverted tee, on contaminant capture.

While the City has these interventions to remove debris and associated contaminants from storm drains and the receiving environment, the effectiveness of these strategies is not well known. This study aims to improve the understanding of the types and quantities of contaminants captured through street sweeping and catch basins. The results will help the City further develop strategies and allocate resources where they will have the largest impact on improving water quality.

2.2 PROJECT OBJECTIVES

1. **Quantify and Characterize Contaminants:** Identify the types and quantities of contaminants on City of Victoria streets.
2. **Compare Contaminants Under Different Land Uses:** Evaluate the impact of land use on the quantity and types of contaminants observed on City streets.
3. **Efficacy of Street Sweeping:** Evaluate the quantities and types of contaminants captured by the City's street sweepers.
4. **Contaminant Capture within Catch Basins:** Evaluate the quantities and types of contaminants captured by the City's catch basins.
5. **Data Visualization of the City's Outfall Water Quality Over Time:** Use historical outfall water quality data collected by the CRD to evaluate and visually communicate the City's outfall water quality over time.
6. **Inform Future Work:** Provide recommendations on areas to focus future research, potential improvements to City programs to support water quality improvements, and opportunities for community engagement and outreach.

3. METHODOLOGY

3.1 CATCHMENT SELECTION

To evaluate the effectiveness of street sweeping in capturing contaminants under different urban conditions, two representative drainage catchments were selected within the City of Victoria: Catchment 629 and Catchment 227. The location of these catchments is shown in Figure 1. These catchments were chosen based on differences in land use, contamination potential, sweeping frequency, and feasibility of collecting representative samples across the entire drainage area.

3.1.1 Catchment 629 – Industrial Land Use

Catchment 629 is located in the Rock Bay area and is characterized by nearly 100% industrial land use. It represents a high-risk area for stormwater contamination due to its proximity to heavy industrial operations, trucking routes, and frequent activity from concrete trucks and dump trucks. Long-term monitoring by the CRD has consistently identified this catchment's outfall (DOF007028) as having some of the highest concentrations of heavy metals and other pollutants in the region (CRD, 2024).

The catchment is small enough to allow for complete coverage by street sweepers during scheduled operations. Sweeping occurs five to seven times per week, typically between 12:00 am and 4:00 am. Regenerative air sweepers are most commonly used in this area due to the presence of significant dust and fines, occasionally supported by mechanical broom sweepers. The collected debris in this catchment typically includes coarse to fine aggregates such as sand, gravel, and cement dust, along with substantial amounts of litter and industrial refuse. Bay Street—particularly between Point Ellis and Douglas—is noted as one of the dirtiest corridors in the City.

This catchment was selected to provide insight into the contaminant load and street sweeping effectiveness in a heavily industrialized context, where pollutant sources are more concentrated and sweeping frequency is higher.

3.1.2 Catchment 227 – Residential Land Use

Catchment 227 is located in a low-density residential neighborhood in Gonzales. Due to the primarily residential land use, Catchment 227 provides an effective contrast to the primarily industrial Catchment 629. The catchment outfall (DOF007010) has not shown the same level of concern in CRD water quality monitoring as Catchment 629.

Sweeping in Catchment 227 occurs once every six weeks, typically during mid-day hours (10:00 am–2:00 pm), when parked vehicles are less prevalent due to residents being away. However, frequent on-street parking still poses a challenge to effective sweeping coverage. A mid-sized, high-efficiency, full-vacuum sweeper services the area, primarily collecting organic debris such as leaves, twigs, and light litter.

The smaller size of this catchment also allows for comprehensive sweeping and sampling, providing a good baseline for understanding the type and quantity of debris found in residential areas and how it compares to industrial areas.

Figure 1: City of Victoria catchment areas selected for study, Catchment 629 and Catchment 227.

3.2 SAMPLE COLLECTION AND ANALYSIS

To assess the effectiveness of street sweeping and catch basins in capturing stormwater contaminants, a detailed sampling program was conducted in two urban catchments. Samples were collected from three locations within each catchment: street sweeper debris, catch basins, and stormwater outfalls. Sampling occurred over three events per catchment to account for temporal variability.

3.2.1 Sampling Locations and Methods

Street Sweeper Debris – Composite solids samples were collected from the debris captured by the street sweeper after completing a full pass of the catchment. Debris was sampled either directly from the sweeper truck or from temporary holding bins, depending on operational constraints. Sampling involved manually collecting multiple sub-samples from various depths and locations within the debris pile, homogenizing the material in a clean metal bowl, and then sub-sampling for laboratory analysis. Each catchment was sampled over three separate events to account for variability in material composition. All sweeper samples in this study consisted of dry solids, as no sampling occurred during rainfall events.

Catch Basins – To evaluate the role of catch basins in retaining solids and pollutants, composite samples were collected from three catch basins with inverted tees and three without in each catchment. Catch basins were first visually inspected for sufficient material accumulation. Using a steel-headed shovel, solids were removed from the catch basin sump and transferred into clean metal bowls based on configuration (with or without inverted tees). The samples were homogenized manually before sub-sampling. These samples help determine the effectiveness of catch basins in capturing material not removed by street sweeping and whether inlet design influences pollutant retention.

Stormwater Outfalls – Aqueous grab samples were collected from each catchment’s outfall to characterize the quality of stormwater being discharged to the receiving environment. Sampling occurred both before and after street sweeping to examine potential short-term changes in constituent loading. At Catchment 629, outfall access was tide-dependent, limiting sampling times to low tide. In contrast, Catchment 227’s outfall was accessible during all tides, allowing additional sampling flexibility. Samples were visually assessed in the field for flow rate, clarity, odour, and presence of suds or sheen.

3.2.2 Analytical Parameters

Samples were analyzed for a comprehensive suite of constituents. For this study, only the parameters identified by the provincial BC Water Quality Guidelines as having either acute or long-term toxicity to either marine aquatic life or freshwater aquatic life were assessed.

For the aqueous outfall sampling results, a subset of metals and polycyclic aromatic hydrocarbons (PAHs) were analyzed. Metals analyzed included arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver, vanadium, and zinc. PAHs analyzed included 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, chrysene, fluoranthene, fluorene, naphthalene, and phenanthrene.

Solids samples collected from street sweeping debris and catch basins were analyzed for the same metals as the outfall samples, except for arsenic which was only measured in the aqueous outfall samples. All metals were measured as total metals within the solid samples. In addition to the PAHs that were analyzed in the aqueous outfall samples, the solid samples were analyzed for total PAH, low and high molecular weight PAHs, benzo[a]pyrene, indeno(1,2,3-cd)pyrene, dibenzo[a,h]anthracene, and benzo[g,h,i]perylene.

Samples were collected following standard procedures by trained staff from the CRD to ensure consistency in field collection and minimize potential contamination. All samples were submitted to Bureau Veritas' environmental laboratory, where analyses were conducted using accredited laboratory methods. These methods adhere to rigorous quality assurance and quality control protocols.

3.3 DATA ANALYSIS

3.1.1. Overview of Datasets

Four data sets were analyzed as part of this study.

1) CRD Historical Outfall Water Quality Data: The CRD has conducted outfall water quality sampling since the 1980s. For this work, the monitoring data from 1982 to 2024 were assessed. Additionally, outfall samples were collected during the 2025 sampling period, specially for this project. Combined, this provides four decades of historical outfall water quality data for both the industrial Catchment 629 and residential Catchment 227.
2) Street Sweeper and Catch Basin Solids Sample Results: Information on the samples collected as part of the March 2025 sampling period is provided in Section 3.2.1. The metals and PAH concentrations within the street sweeper debris and catch basin solids (both with and without inverted tees) were compared.
3) Daily Rainfall Data: Data on daily rainfall depths was obtained from Environment Canada's historical climate database. Data from Gonzales weather station was used due to the proximity to the sampling locations. The rainfall depths surrounding sampling dates were assessed to evaluate potential impacts of rainfall on observed sample concentrations.
4) BC Water-Quality Guidelines (WQG): Information on the BC WQGs is provided in Section 4.2.1. Only the BC WQGs related to freshwater and marine terrestrial life were assessed.

3.1.2. Outfall Data Analysis

The CRD provided spreadsheets containing the raw historical outfall water quality data. The data was presented with triplicate columns per analyte, where each analyte had information on the (1) value, (2) qualifier, and (3) comment. The raw data included more than 200 analytes—with various units and detection limits—and a mixture of quality assurance/quality control data provided by the laboratory that completed the sample analysis.

All the raw data was compiled into the following three tables.

1) A numeric measurement table with samples as rows and parameters as columns.
2) A sample-metadata table showing sample collection date, station code, and sample comment.
3) A parameter metadata table with detection limits and category tags.

Since more than 90% of the qualifier and comment fields were blank, these were stored separately.

Firstly, a high-level review of the historical outfall datasets for both catchments were conducted. The high-level review included visualizations of (1) total number of annual samples collected by catchment and (2) total number of each type of parameters analyzed.

Additionally, a text analysis was conducted on the comments included for each sample collection date. Sample comments were broadly categorized into words describing either the sample odour or visual observations. For example, visual descriptors included “clear”, “murky”, “turbid”, and “foam”. Since there were some inconsistencies with the wording included in the comments, it was challenging to conduct the text analysis.

When plotting the concentrations of metals and PAHs for each catchment, a single plot was not feasible due to variability in concentration magnitudes, units, detection limits, and WQG threshold values. Based on this, individual plots were developed for each parameter. Single sample frequency was irregular at times, a scatter plot was used instead of a line graph, in order to more accurately represent the data.

Next, it was decided to add rainfall data to the concentration plots to assess any trends related to sample collection following a rainfall event. To do this, daily rainfall depths were obtained from Environment Canada's historical climate database. To assess potential flushing of constituents into the storm drain during a rainfall event, samples that were collected within 24 hrs of rainfall were flagged on the plots. Additionally, the rainfall depths associated with these samples were plotted on the secondary axes.

For Catchment 629, some constituents (e.g., copper), had sample data that were orders of magnitude higher than other samples. This variability in the concentration skewed the y-axis of these plots making the typical observed concentrations more difficult to assess. To address this issue, a broken y-axis was used.

For the "5 in 30" sample results for Catchment 629, there were four datasets, (1) 2013 sampling during the dry season, (2) 2013 sampling during the wet season, (3) 2018 sampling during the dry season, and (4) 2018 sampling during the wet season. To better compare these datasets, the four plots were presented together. The y-axes were all aligned to support the comparison.

3.1.3. Sediment Sample Data Analysis

From the March 2025 sampling portion of this study, sediment samples included (1) street sweeper debris and sediment collected from catch basins (2) with inverted tees and (3) without inverted tees.

Similar to the outfall data, the raw dataset was reshaped into the following:

1) A sample concentration matrix for the 6 samples collected (i.e., 4 street sweeper debris samples, 1 composite sample from three catch basins without inverted tees, and 1 composite sample from three catch basins with inverted tees). For this matrix, there was one row per sample and one column per parameter.
2) A parameter metadata table which included the detection limit and unit code for each sample.

Since the concentrations of the street sweeper and catch basin sediments were the same order of magnitude for each catchment, they were able to all be included on a single plot. The four street sweeper samples were plotted as a single, average value, with the standard deviation of the samples included for reference.

The visualizations created for each of the previously mentioned datasets are presented in the following Section 4, along with a discussion of the results.

4 RESULTS AND DISCUSSION

4.1 OVERVIEW OF OUTFALL SAMPLING

4.1.1 CRD Outfall Monitoring Program

The CRD Stormwater Quality Program monitors and assesses stormwater discharges, creeks, and the nearshore marine environment in partnership with municipalities and First Nations in the core area (CRD, 2024). This work supports commitments under the Core Area Liquid Waste Management Plan. Sampling focuses on bacterial and chemical indicators to detect sources of pollution, with priority ratings assigned to help municipalities target mitigation efforts. Where contamination is found, CRD staff collaborate with municipal staff to identify and address sources.

Sampling frequencies and constituents analyzed have evolved over time in response to updated regulatory guidance, emerging contaminants of concern, and shifts in monitoring priorities. The number of outfall water quality samples collected for a) Catchment 227 and b) Catchment 629 since the 1980s is outlined in Figure 2.

Since 2013, aqueous metals sampling has been intermittently conducted at outfalls. In 2019, the CRD began a concerted effort to monitor metals consistently on an annual basis. However, due to operational constraints and shifting priorities, data collection has not been entirely consistent year-to-year.

Fecal coliforms were the primary bacterial indicator sampled from 1985 to 2017. In 2015, CRD introduced *Escherichia coli* (*E. coli*) monitoring, aligning with federal guidance that identified *E. coli* as a more reliable indicator of human health risks in freshwater recreational and receiving waters. Since then, *E. coli* has remained the standard bacterial parameter measured in stormwater.

To assess variability in outfall sampling, the CRD introduced a “5 in 30” sampling protocol at selected outfalls in 2013. This protocol involves collecting five weekly samples within a 30-day period in both the summer low flow and fall flush seasons and is conducted every 5 years. More recently, the CRD has shifted to only conducting “5 in 30” sampling protocols in streams as urban outfalls presented challenging logistics for traffic management and tidal influence. The “5 in 30” sampling protocol aligns with guidance from the BC government for determining if water samples are meeting the long-term chronic water quality guidelines (discussed in more detail in Section 4.2.1) (British Columbia Ministry of Water, Land, and Resource Stewardship, 2025).

4.1.2 Catchment 227

Outfall sampling of Catchment 227 began in 1982. As shown in **Error! Reference source not found.** a), for most years, 2 samples were collected annually.

When additional samples were analyzed beyond routine sampling, these are typically associated with upstream investigations. For example, the 6 samples collected in 2007 and 2014 were associated with upstream investigations which included outfall sampling as well. Additional samples collected could also be the result of duplication to verify accuracy of elevated sample results.

In 2022, extensive sampling of the Catchment 227 outfall was conducted. This sampling included analysis for a full suite of metals and PAHs. While PAHs were not analyzed again until 2025 (as part of this project), metals were analyzed at least once annually between 2022 and 2025. Details on these results are provided in Section 4.2.2.

4.1.3 Catchment 629

Outfall sampling in Catchment 629 has been conducted intermittently since 1986, with variable frequency and constituents measured over time. As shown in **Error! Reference source not found.** b), the number of samples collected per year has ranged from 1 to 13, reflecting shifts in monitoring priorities and available resources.

Sampling was not conducted in 2009, 2010, or 2023. The absence of data in 2009 and 2010 was due to a regional shift in the monitoring strategy, where the CRD temporarily ceased outfall monitoring to focus on identifying and addressing upstream pollution sources.

In 2013 and 2018, the CRD conducted “5 in 30” sampling of Catchment 629. Implementation proved challenging in this catchment due to tidal influence. Samples often needed to be collected late into the evening during low tide to minimize tidal-induced flows. The “5 in 30” sampling resulted in the increase in sample data during these years. Although the “5 in 30” sampling should have been conducted in 2023 (i.e., 5 years after the 2018 sampling), logistical challenges and no anticipated changes in water quality, due to no changes in land use and source control efforts, prevented the sampling from occurring.

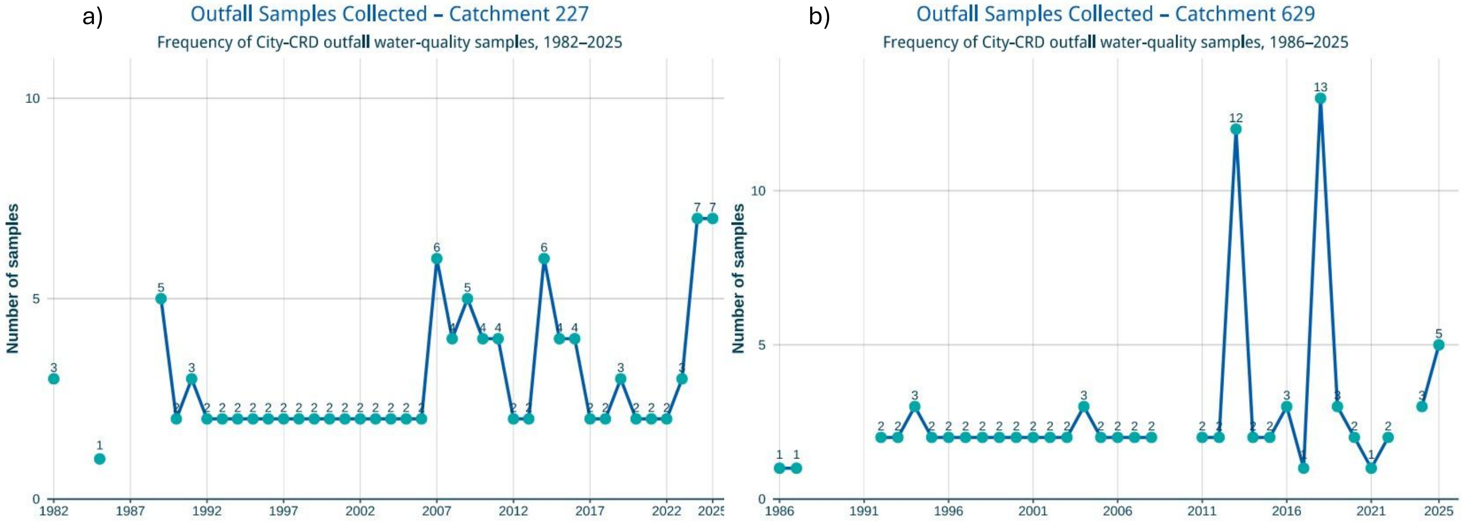


Figure 2: Number of outfall water quality samples collected between 1982 and 2025 for City of Victoria Catchment 629 and 227.

4.2 OUTFALL WATER QUALITY RESULTS

4.2.1 General

Stormwater runoff from urbanized areas often contains a range of contaminants, including metals and PAHs. These constituents may originate from vehicles (e.g., oil, grease, gasoline, tire wear), private properties (types and quantities depend on the land use), road surfaces, soils and sediments (e.g., from historical contamination), and other anthropogenic sources. PAHs are commonly associated with industrial practices making them more likely to be observed in areas with industrial land uses.

To assess the potential environmental impact of these constituents, concentrations were compared to the British Columbia Water Quality Guidelines (WQG). These guidelines represent threshold levels designed to protect aquatic life, wildlife, and agricultural uses. Specifically, the long-term chronic guidelines indicate average concentrations that are considered protective of the most sensitive species and life stages during prolonged exposure, while the short-term acute guidelines represent maximum concentrations that should not be exceeded, even briefly, to prevent immediate or severe harm (British Columbia Ministry of Water, Land, and Resource Stewardship, 2025). Although these guidelines do not carry legal authority, they are used throughout the province to inform regulatory decisions, assess environmental monitoring data, and support protective management actions. Exceeding a WQG does not necessarily indicate ecological harm but indicates a potential for adverse effects that may necessitate additional investigation or monitoring. This section presents observed constituent concentrations over time and evaluates them in the context of these provincial thresholds.

4.2.2 Catchment 227

The concentrations of a subset of the metals and PAHs collected from the Catchment 227 outfall between 2022 and 2025 are presented in Figure 3 and Figure 4, respectively. The short- and long-term BC WQGs and the laboratory detection limit for each constituent is shown on the plot for reference.

For Catchment 227, all PAHs were consistently below detention limits, indicating no measurable presence in stormwater samples.

For metal concentrations in Catchment 227, most were either below detection limits or consistently below both long-term and acute WQGs. Beryllium and silver were typically near their detection limits and remained below all WQGs. Arsenic, cadmium, chromium, manganese, nickel, selenium, and vanadium were also consistently below both long-term and acute WQG thresholds.

Lead exceeded the long-term WQG only once, in a 2023 sample. As this was an isolated event, it is unlikely to represent a chronic issue or pose a long-term risk to the receiving environment. This same 2023 sample also exceeded the long-term WQG for zinc, which had one additional exceedance during the 2025 sampling period.

The only metal that consistently exceeded both short-term and long-term WQGs was copper. While the cause of the elevated copper in Catchment 227 cannot be determined from this study, research has shown that sources in residential areas include vehicle brake wear, roofing materials, and parking lots (Bookter, 2017). Another influence of elevated copper could be that copper is a naturally occurring element that is known to have on average, higher than normal concentrations on Vancouver Island (Ministry of Environment and Climate Change Strategy, 2019).

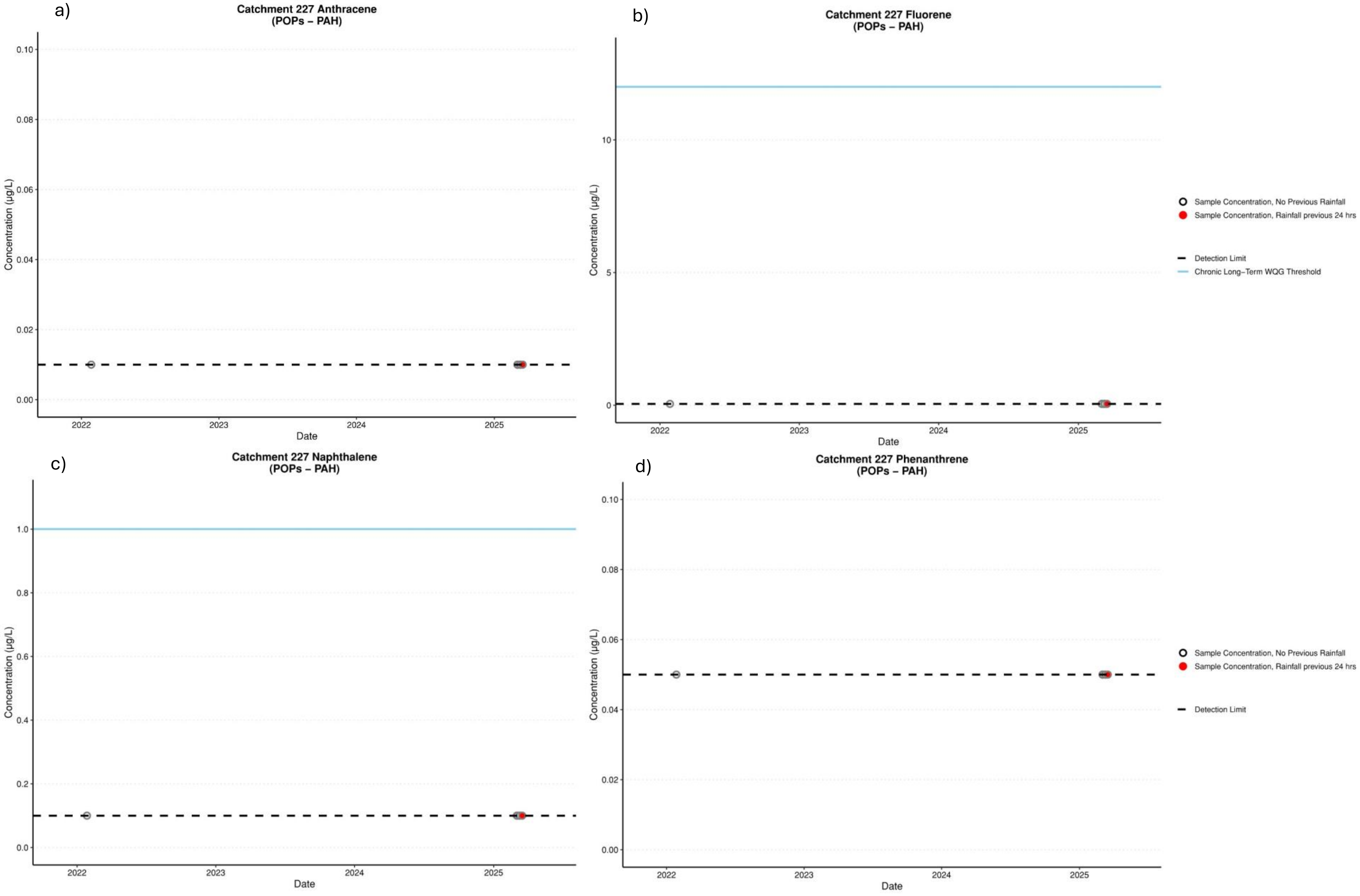


Figure 3: Concentrations of the PAHs a) anthracene, b) fluorene, c) naphthalene, and d) phenanthrene in the outfall of Catchment 227 Between 2022 and 2025. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event, and the black outlined circle are samples collected with no previous rainfall. The BC Water Quality Guidelines for long-term toxicity to either freshwater or marine aquatic life is shown with a blue line. The detection limit for each parameter is shown with a black, dotted line.

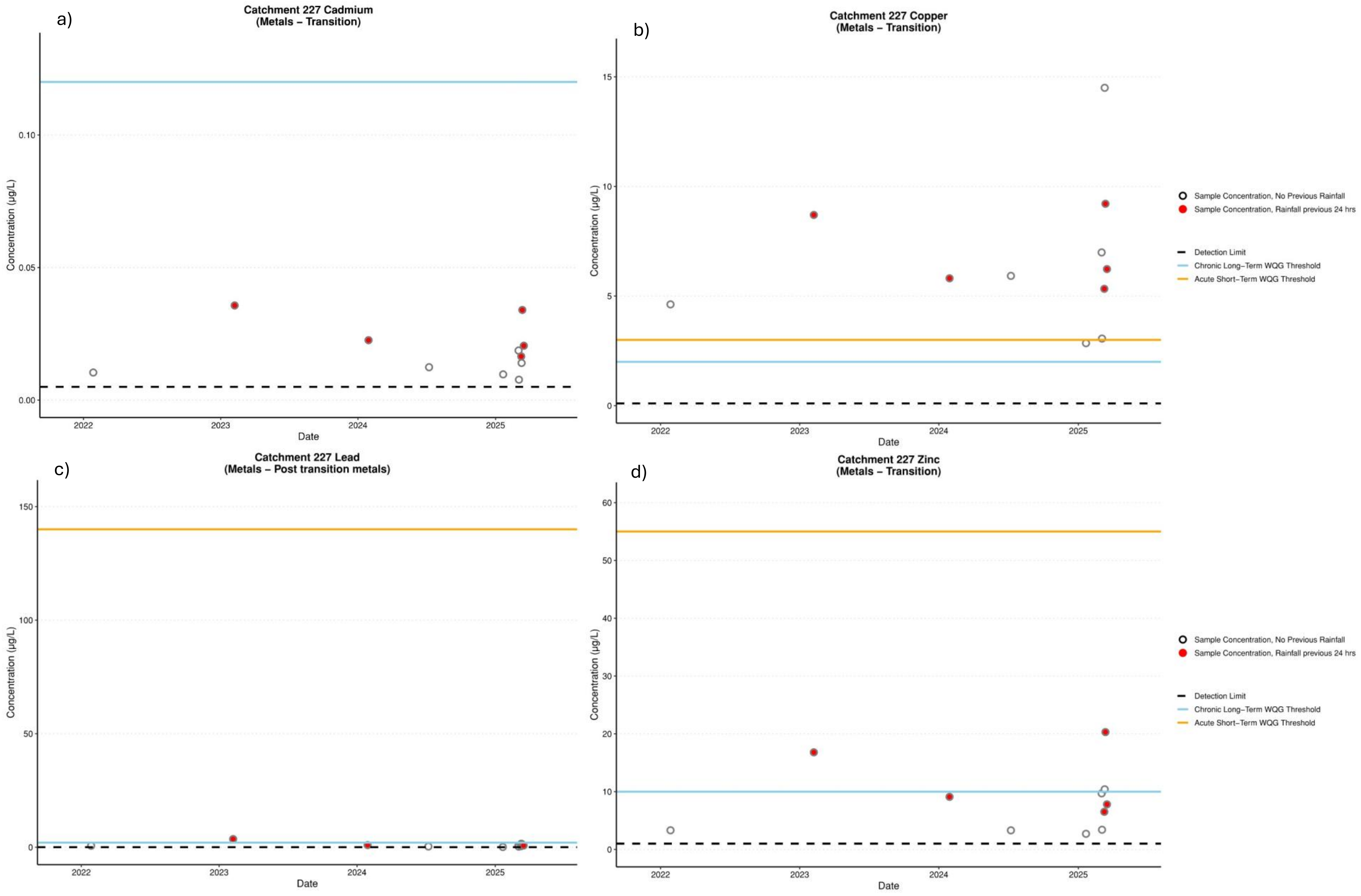


Figure 4: Concentrations of the metals a) cadmium, b) copper, c) lead, and d) zinc in the outfall of Catchment 227 Between 2022 and 2025. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event, and the black outlined circle are samples collected with no previous rainfall. The BC Water Quality Guidelines for long-term and short-term toxicity to either freshwater or marine aquatic life is shown with a blue and orange line, respectively. The detection limit for each parameter is shown with a black, dotted line.

4.2.3 Catchment 629

The concentrations of PAHs and metals in the outfall of Catchment 629 are presented in Figure 5**Error! Reference source not found.** and**Error! Reference source not found.** Figure 6, respectively. Sampling for PAHs in Catchment 629 began in 2018 when a thorough analysis of PAHs and polychlorinated biphenyls (PCBs) was conducted. The results of the PCB sampling are not presented as part of this work. Sampling for metals in the Catchment 629 outfall began in 1992 and has continued intermittently to today (i.e., 2025).

The concentrations of PAHs in the outfall of Catchment 629 are almost always below the threshold for chronic long-term impacts from the WQGs. The exception is the sample collected in March 2022 which had the highest observed concentrations of acenaphthene, anthracene, chrysene, fluoranthene, fluorene, naphthalene, and phenanthrene for the catchment. While this sample was collected as part of routine outfall sampling by the CRD, the elevated concentrations of PAHs—at least an order of magnitude higher than concentrations observed during other sampling events—suggests that a spill had occurred prior to sampling. More often, the concentrations of PAHs in the outfall samples were closer to the detection limit for PAHs, specifically, acenaphthene, anthracene, fluorene, naphthalene, and phenanthrene. This is important because it means that the typical inputs into the storm drain system in Catchment 629 are within provincial thresholds and are unlikely to have any long-term chronic impacts on the marine environment. Furthermore, efforts to improve the stormwater quality of Catchment 629 should focus on source control, since it is evident that spills into the City’s storm drain system are a major cause of WQG exceedances.

Similar to the concentrations of PAHs in the outfall of Catchment 629, the highest observed concentrations of metals occur on the same date, November 2013. This date was part of the 2013 “5 in 30” sampling for the catchment. With the concentrations on this date at least an order of magnitude higher than other sampling periods, this again suggests that this sample was collected following a spill within the catchment.

Outside the November 2013 sample, the concentrations of arsenic, beryllium, selenium, and silver were typically below the long-term WQG threshold, with beryllium typically near the detection limit.

For most metals, the second highest concentrations were observed during the 2018 "5 in 30" sampling period. Overall, the concentrations of many of the metals analyzed have generally been trending downwards since the 2013 "5 in 30" sampling period. In particular, arsenic, boron, cadmium, copper, manganese, nickel, silver, and zinc. It is unclear from this study whether that is the result of more extensive source control efforts by both the CRD and the City, the adoption of the City's Stormwater Codes of Practice in 2005, increased education for business owners and community members, increased street sweeping efforts or other factors. While concentrations are generally trending downwards, it is clear that more efforts are needed to improve the stormwater quality of Catchment 629.

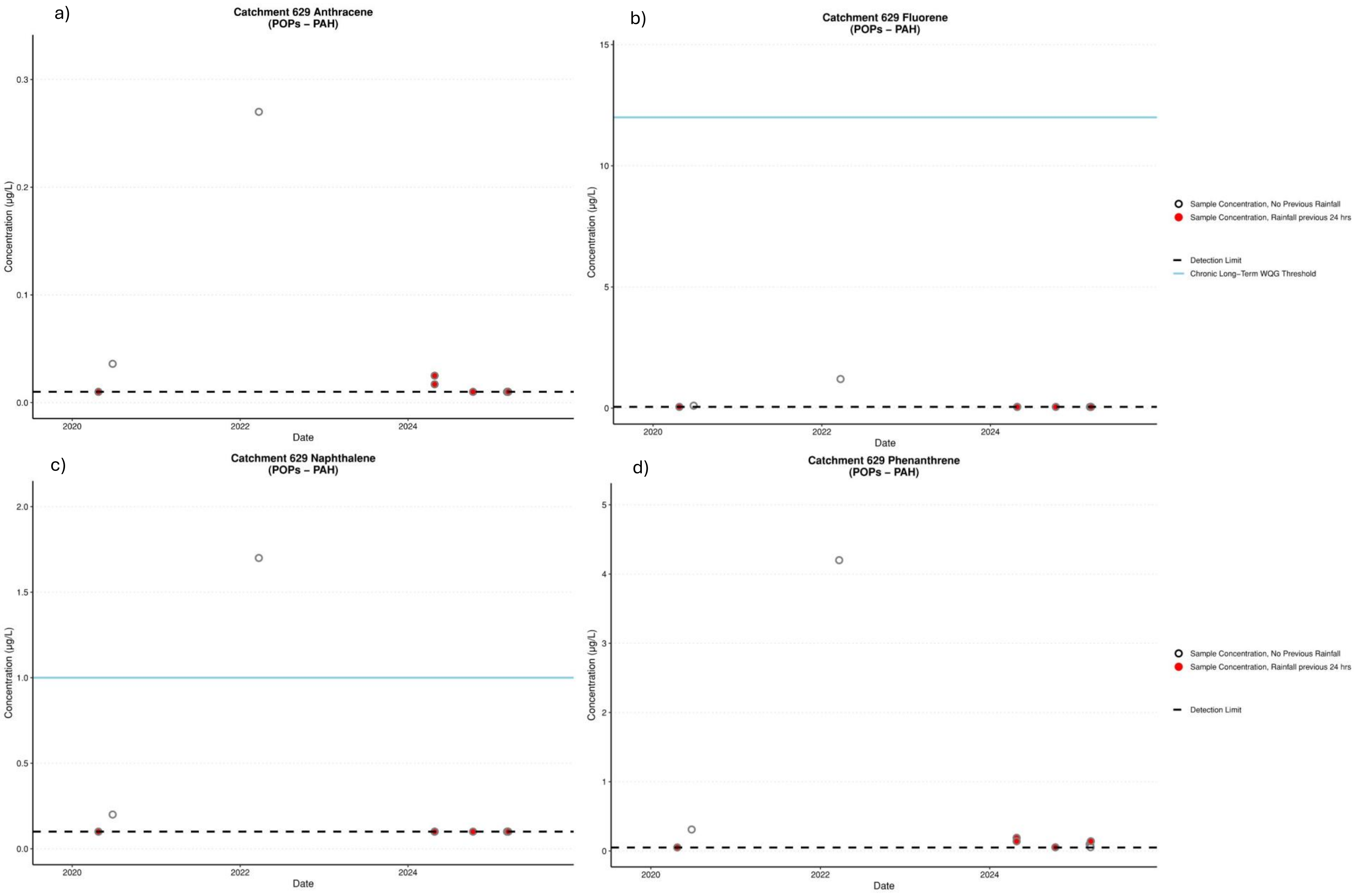


Figure 5: Concentrations of the PAHs a) anthracene, b) fluorene, c) naphthalene, and d) phenanthrene in the outfall of Catchment 629 Between 2020 and 2025. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event, and the black outlined circle are samples collected with no previous rainfall. The BC Water Quality Guidelines for long-term toxicity to either freshwater or marine aquatic life is shown with a blue line. The detection limit for each parameter is shown with a black, dotted line.

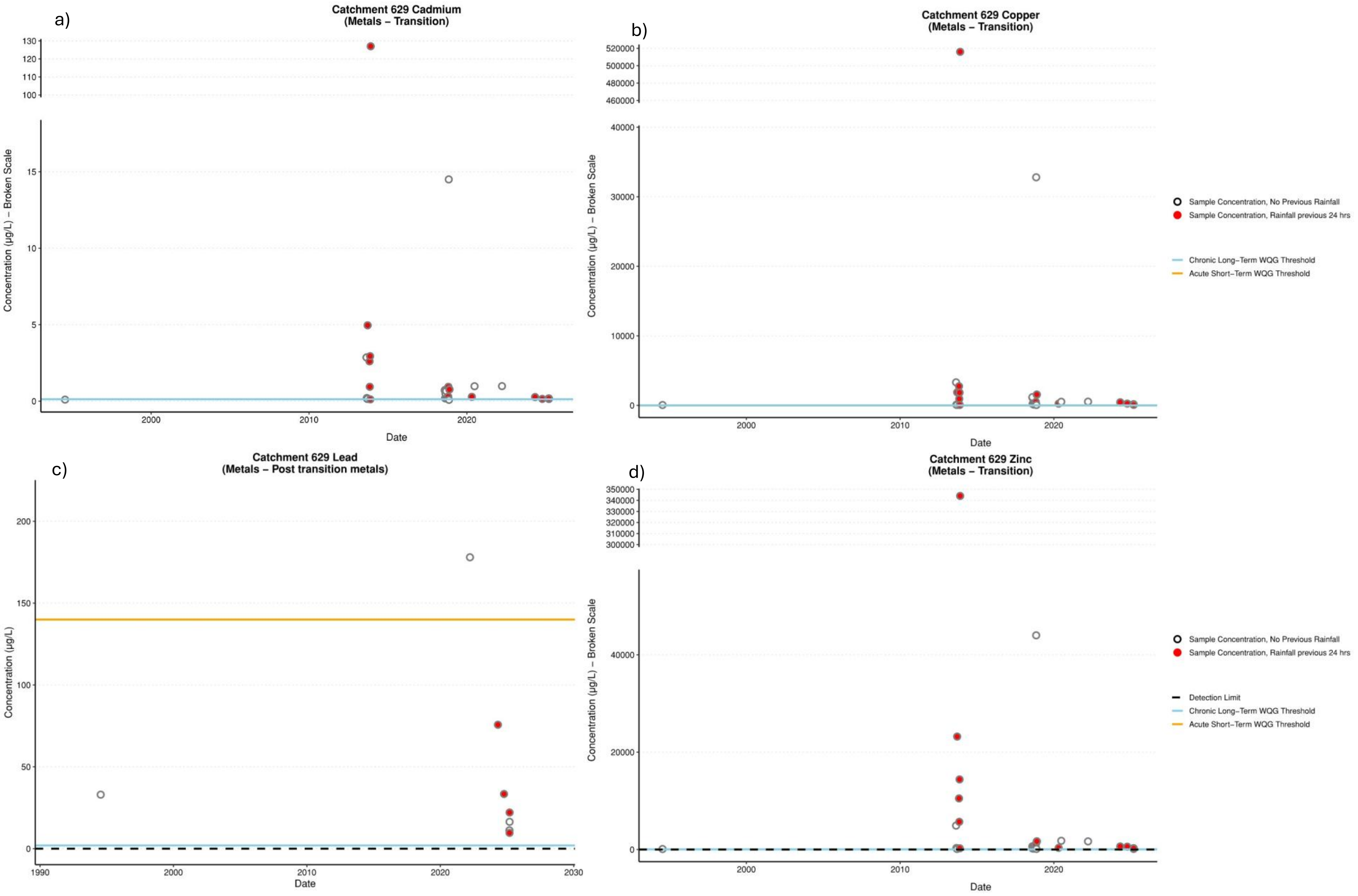


Figure 6: Concentrations of the metals a) cadmium, b) , c) lead, and d) zinc in the outfall of Catchment 629 Between 2022 and 2025. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event, and the black outlined circle are samples collected with no previous rainfall. The BC Water Quality Guidelines for long-term and short-term toxicity to either freshwater or marine aquatic life is shown with a blue and orange line, respectively. The detection limit for each parameter is shown with a black, dotted line.

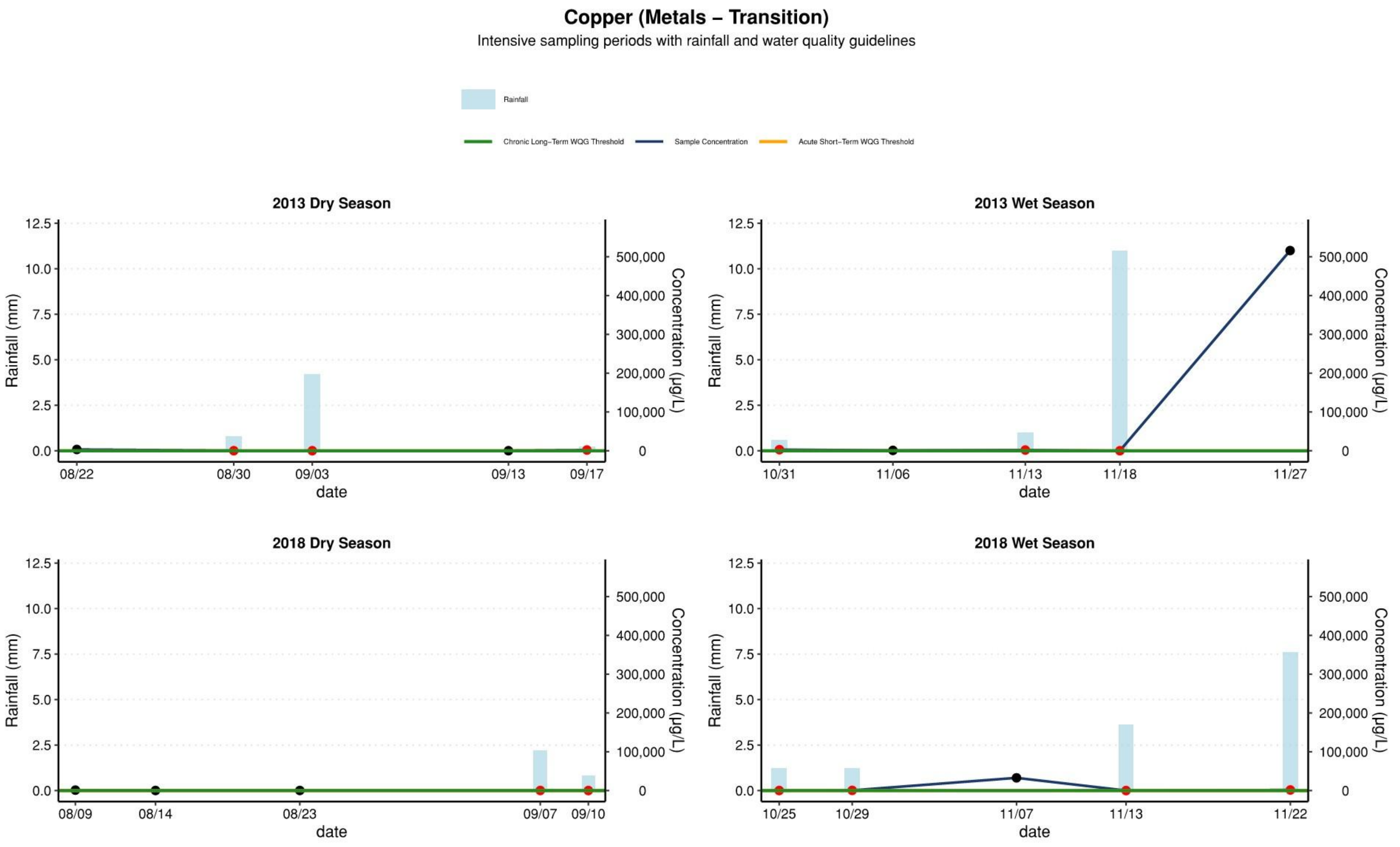
4.2.4 Detailed “5 in 30” Results for Catchment 629

In 2013 and 2018, the CRD conducted “5 in 30” sampling of Catchment 629. Two “5 in 30” sampling events were conducted in both years to better understand trends during the dry season (i.e., August and September sampling) and wet season (i.e., October and November sampling). The results of these sampling periods are presented in Figure 7 for copper and Figure 8 for zinc. The results for all other metals are provided in APPENDIX C – DATA RESULTS.

As mentioned in Section 4.2.3, the highest observed concentration of all metals presented in this study were from the “5 in 30” sampling on November 27, 2013. According to the CRD, the sample was collected in the evening to align with low tide. From both visual observations of the sample and the very high metals concentrations, it was concluded that a spill or prohibited discharge into the City’s storm drain was likely captured.

Beyond the November 27, 2013, sample, metal concentrations were generally more consistent. Additional elevated concentrations varied by metals. For example, elevated concentrations of boron and manganese were observed on September 13, 2013, arsenic, boron, and chromium on September 7, 2018, and cadmium, manganese, and nickel on November 7, 2018. There is not enough data and context to determine whether these elevated concentrations are associated with spills, prohibited discharges, or other inputs into the City's storm drain system.

Since samples were collected anywhere from 3 to 15 days apart and were not scheduled to consider rainfall events, there is not enough data to determine the impacts of rainfall on the observed outfall water quality. This could be an area for future research.



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Figure 7: Copper concentrations for Catchment 629 during a dry season and wet season "5 in 30" sampling in 2013 and 2018. The concentrations are shown on the secondary y-axis. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event. The BC Water Quality Guidelines (BC WQGs) for long-term and short-term toxicity to either freshwater or marine aquatic life is shown with a green and orange line, respectively. The detection limit for each parameter is shown with a black, dashed line. The rainfall depth 24 hours prior to the sampling event is shown as a blue bar on the primary y-axis.

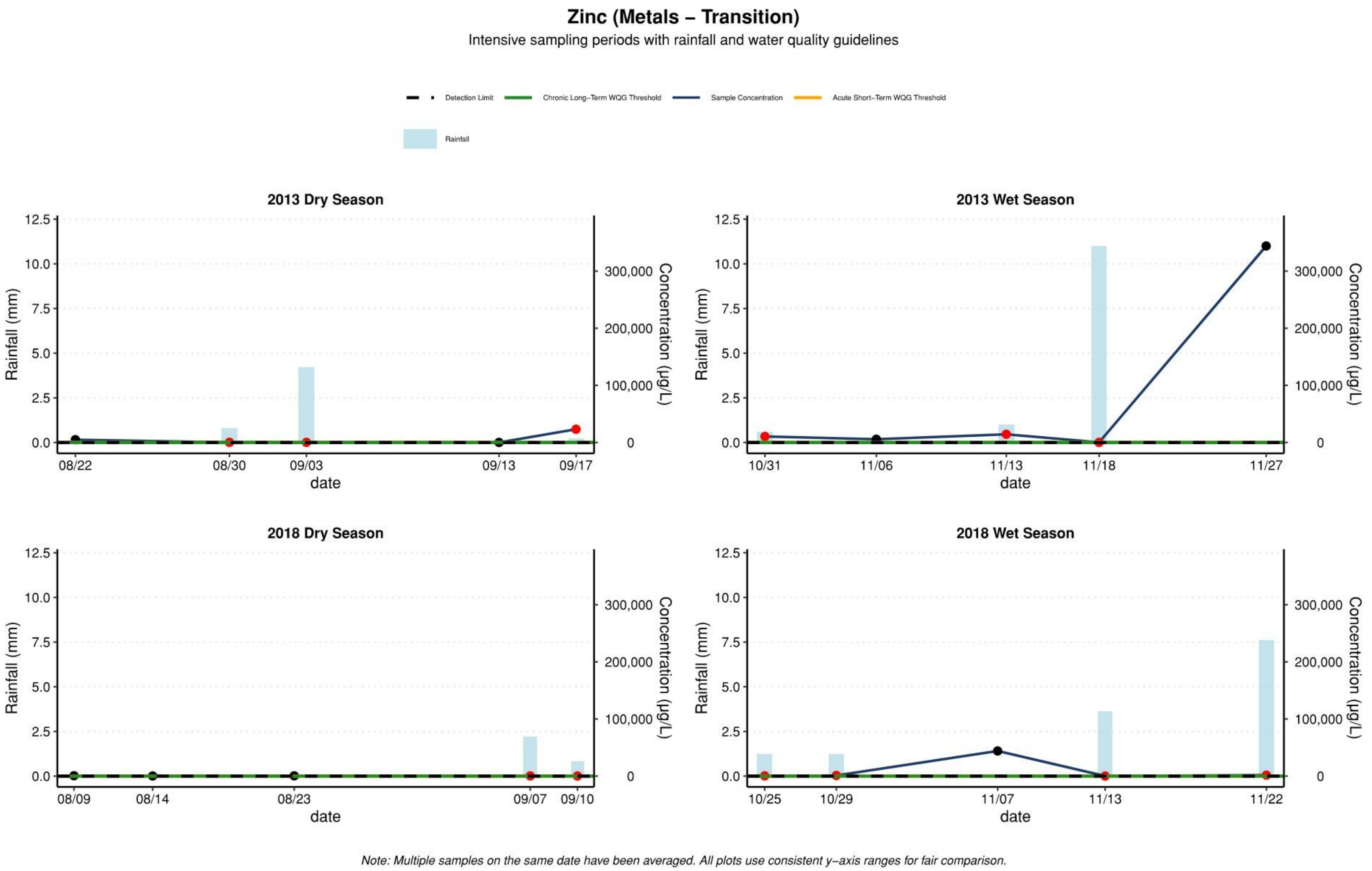


Figure 8: Zinc concentrations for Catchment 629 during a dry season and wet season "5 in 30" sampling in 2013 and 2018. The concentrations are shown on the secondary y-axis. The sampling points identified with a red, filled circle represent the samples that were collected within 24 hours of a rainfall event. The BC Water Quality Guidelines (BC WQGs) for long-term and short-term toxicity to either freshwater or marine aquatic life is shown with a green and orange line, respectively. The detection limit for each parameter is shown with a black, dashed line. The rainfall depth 24 hours prior to the sampling event is shown as a blue bar on the primary y-axis.

4.3 INTERVENTIONS INFLUENCING WATER QUALITY

4.3.1 Catch Basin Design

Figure 9 and Figure 10 provide a comparison of the concentrations of metals and PAHs within catch basins with and without inverted tees in Catchment 227 and Catchment 629, respectively.

For both Catchment 629 (industrial) and Catchment 227 (residential), the catch basins with inverted tees retained higher concentrations of PAHs, including total PAH, and high and low molecular weight PAHs. This is likely because PAHs have a low solubility in water which results in an increased sorption to particulate matter (McGrath et al., 2019). If the presence of inverted tees promotes more sedimentation in catch basins than those without, this increase could be causing the subsequent accumulation of PAHs in the catch basins with inverted tees.

For Catchment 629, the catch basins with inverted tees typically contained higher concentrations of metals than catch basins without inverted tees. The opposite trend is observed for Catchment 227 where the catch basins without inverted tees generally had higher concentrations of metals than those with inverted tees. Additionally, the catch basins with inverted tees in Catchment 629 typically had the highest concentration of metals compared to other catch basin samples from either Catchment 629 or Catchment 227. It is possible that the inverted tees are increasing the accumulation of particulate matter in the catch basins in Catchment 629. Due to land use, Catchment 629 has more dust and debris than Catchment 227. If metals and PAHs are bound to particulate matter retained within the catch basins, this could be causing the higher observed concentrations. More work is needed to understand the accumulation and release of constituents from catch basins throughout the City.

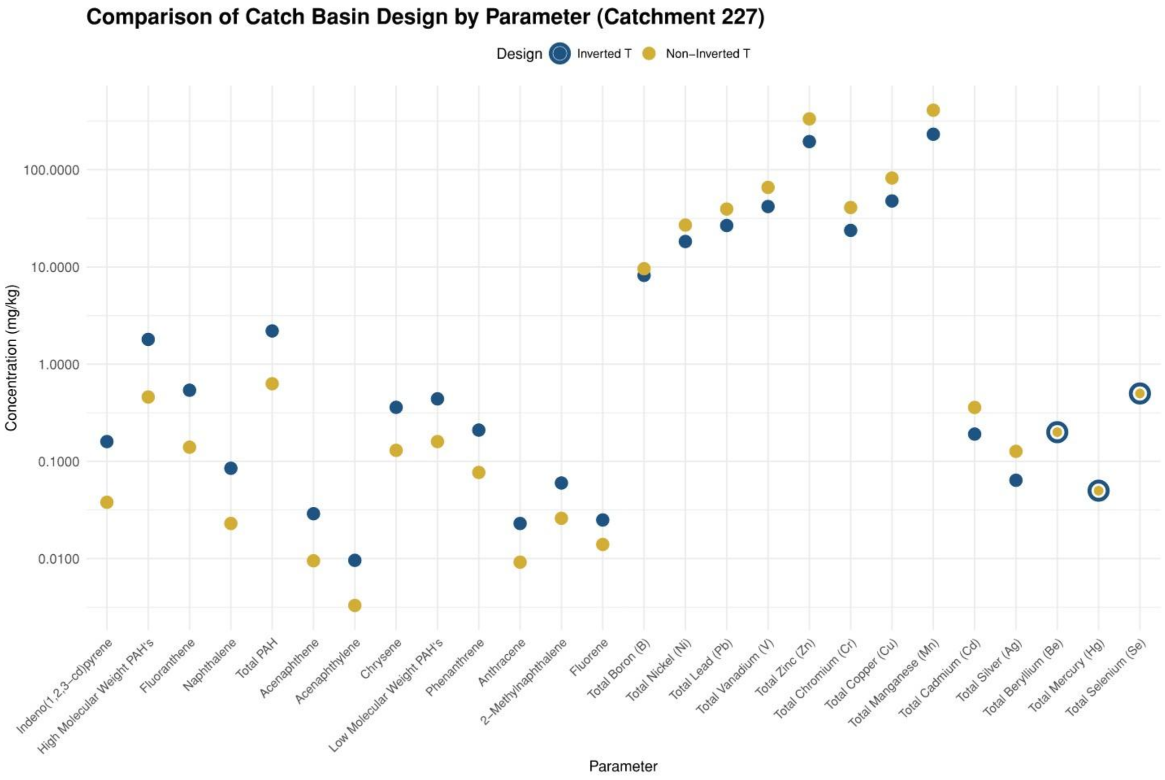


Figure 9: Concentrations of Metals and PAHs in catch basins with and without inverted tees in Catchment 227.

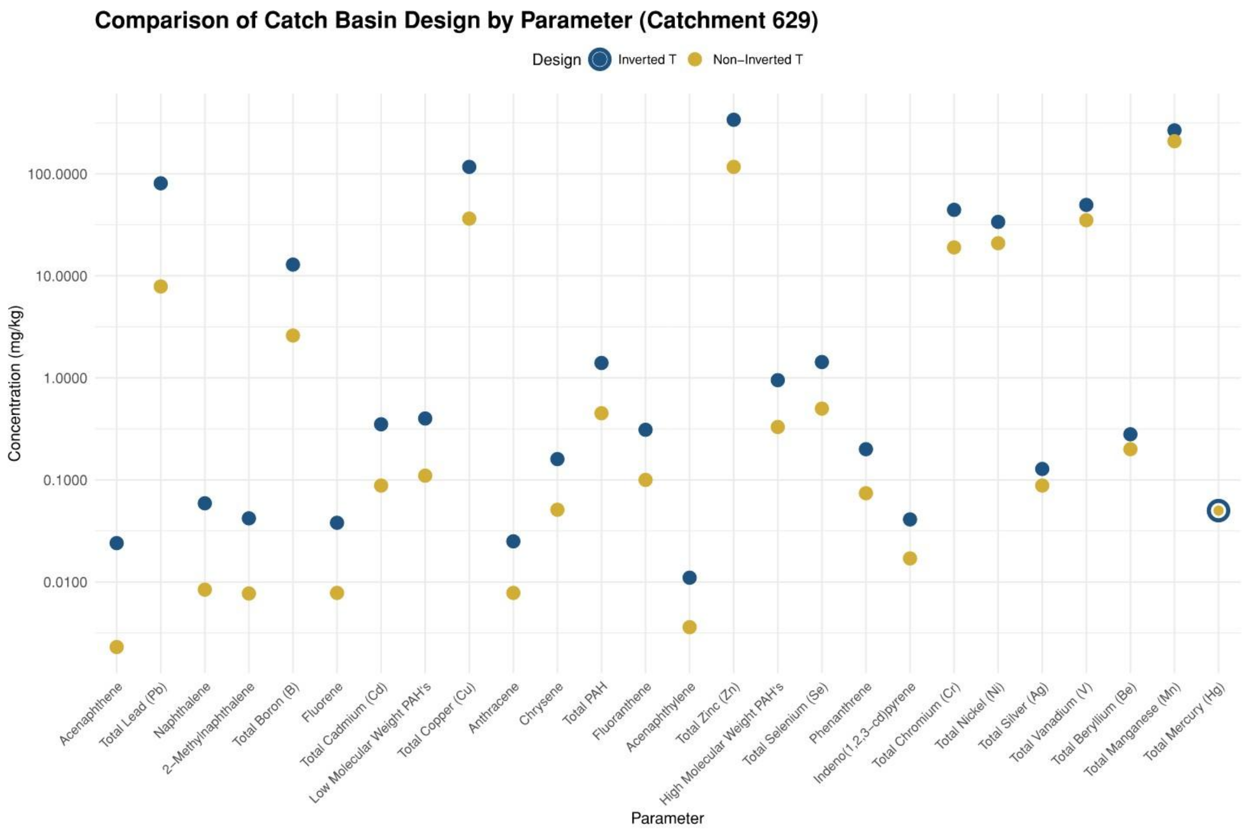


Figure 10: Concentrations of Metals and PAHs in catch basins with and without inverted tees in Catchment 629.

4.3.2 PAHs

Figure 11Figure 11 provides the concentrations of PAHs in catch basins and street sweeper debris from Catchment 629 and Catchment 227. Concentrations were compared for catch basins with and without inverted tees. The results provided in Figure 11 is only a subset of the PAH data, the remainder of the results are provided in APPENDIX C – DATA RESULTS.

The concentrations of PAHs in catch basins were consistently higher than the concentrations found in street sweeper debris. This was expected as the PAHs are likely accumulating in the catch basins over time. Catch basins without inverted tees had only slightly higher PAH concentrations than the street sweeper debris. This suggests that the absence of an inverted tee may limit the catch basin's ability to retain PAHs. These findings imply that the addition of inverted tees to catch basins are an effective strategy and economical retrofit option for retaining PAHs within the catch basin to reduce downstream transport.

When comparing across land uses, PAH concentrations were consistently higher in Catchment 227 (residential) than in Catchment 629 (industrial), regardless of sample type. This could be because maintenance and cleaning of Catchment 629 occurs more frequently than Catchment 227 due to the industrial land use. In particular, street sweeping occurs at least once daily in Catchment 629 to manage the dust and debris from the industrial sites and high truck traffic. In contrast, the lower frequency of cleaning in Catchment 227 may allow for more accumulation of PAHs.

4.3.3 Metals

Figure 12 presents the concentrations of metals from street sweeper debris and catch basins (with and without inverted tees) from Catchment 629 and Catchment 227. The results provided in Figure 12 is only a subset of the metals data, the remainder of the results are provided in APPENDIX C – DATA RESULTS.

Of the metals analyzed, beryllium and selenium concentrations were typically around the detection limit, except for the concentrations within the catch basins with inverted tees in Catchment 629 (see APPENDIX C – DATA RESULTS for additional results).

Similar to the PAHs, the concentrations of metals in the catch basins were generally higher than the street sweeper debris. It is likely that any metals bound to particulate matter could accumulate within catch basins as sediment builds up. It should be noted that the metal concentrations within the two catch basin configurations and the street sweeper debris were more similar than the PAH concentration in catch basins with inverted tees compared to catch basins without inverted tees and street sweeper debris. This result suggests that inverted tees might be more effective as retaining PAHs within catch basins than metals.

Additionally, the catch basins with inverted tees in Catchment 629 typically had the highest concentration of metals compared to other catch basin and street sweeper debris samples from either Catchment 629 or Catchment 227. As mentioned in Section 4.3.1, the higher observed concentrations of metals in the catch basins with inverted tees in Catchment 629 might be due to the catchment generally having higher quantities of dust and debris which then accumulate in catch basins with inverted tees.

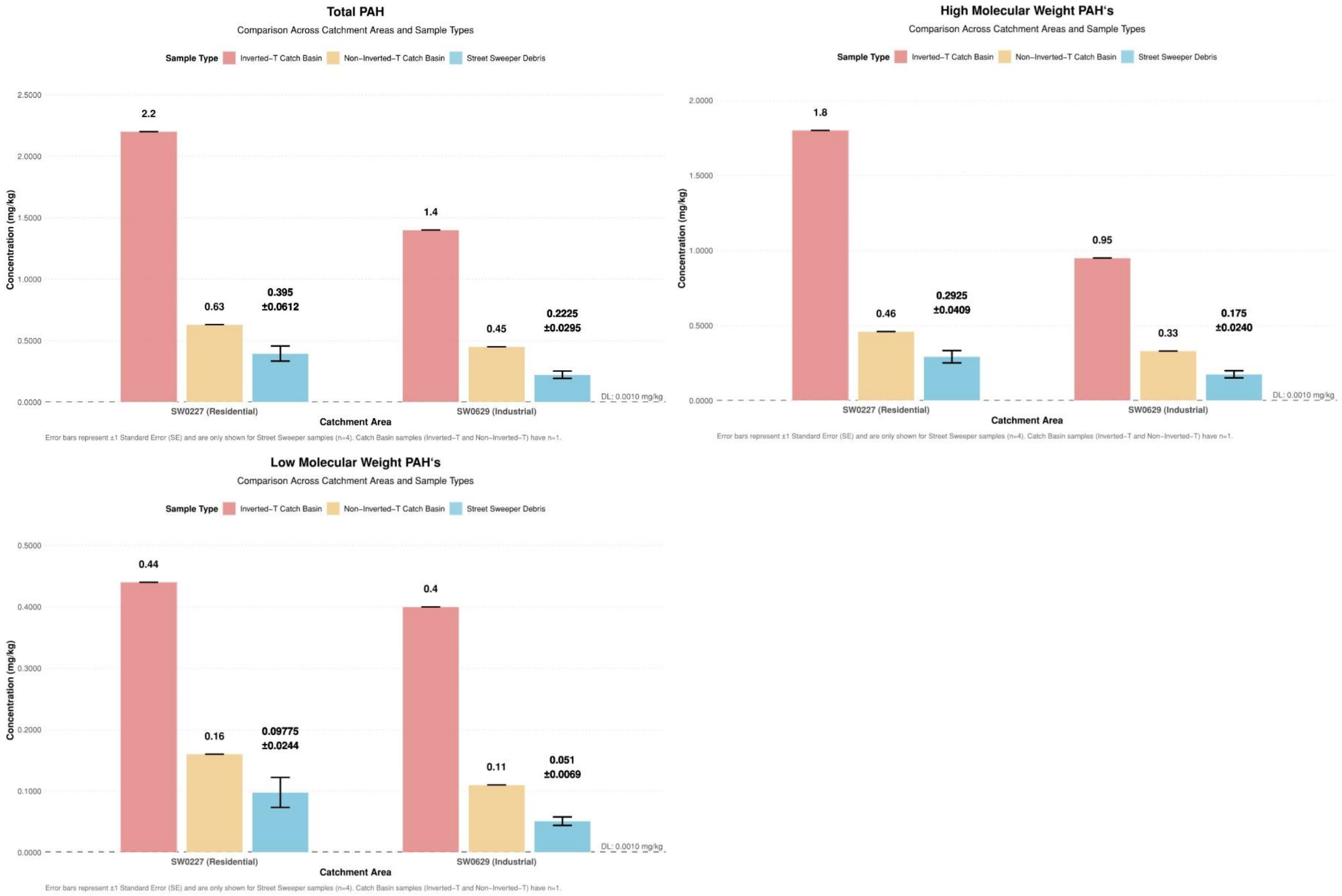


Figure 11: Concentrations of PAHs in the street sweeper debris and catch basins with and without inverted tees within Catchment 629 and 227.

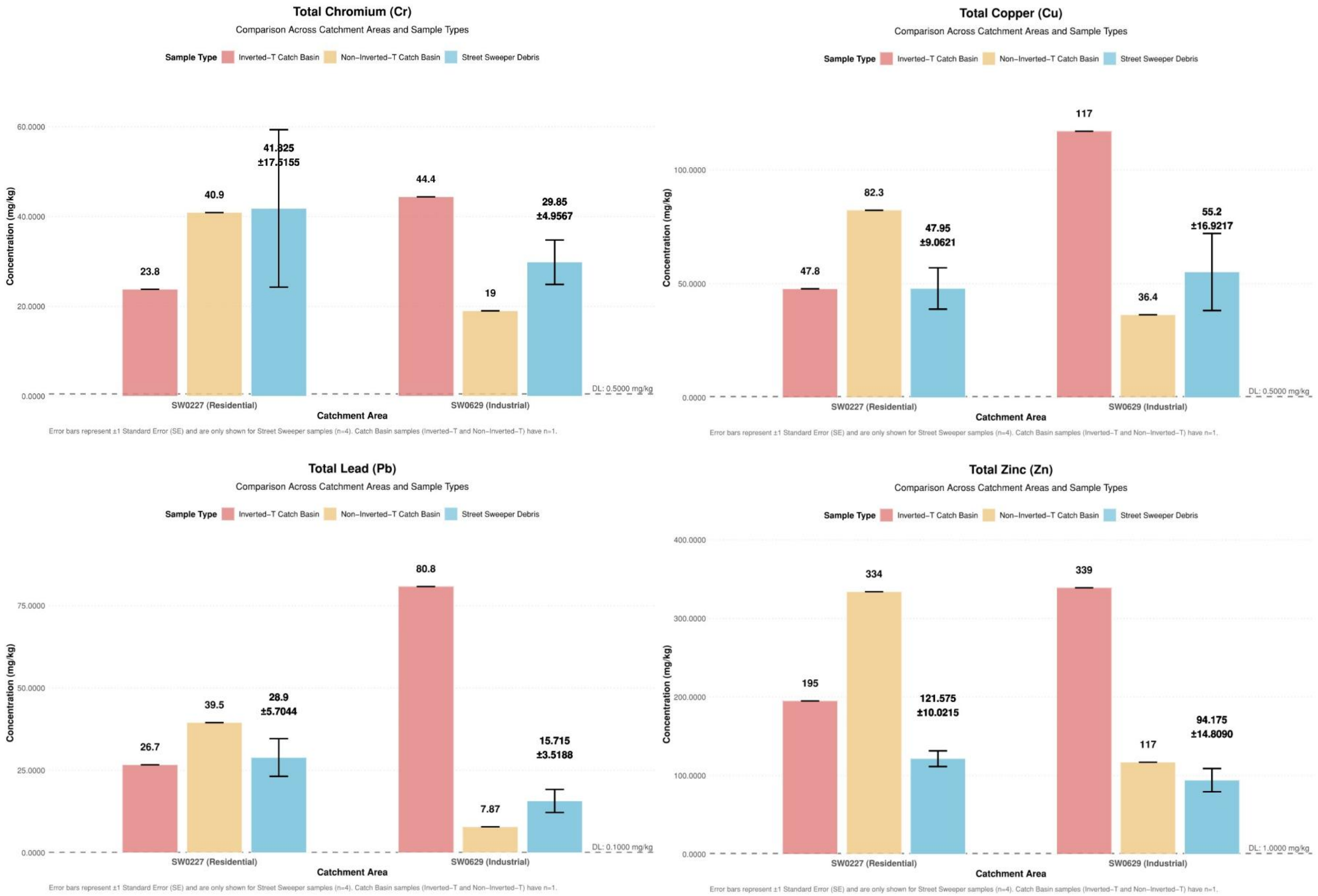


Figure 12: Concentrations of metals in the street sweeper debris and catch basins with and without inverted tees within Catchment 629 and 227.

5 SUMMARY AND FUTURE WORK

5.1 SUMMARY

This study is the first at the City of Victoria attempting to visualize historical stormwater outfall quality data to better assess long-term trends. This study also attempts to better understand the role of various interventions on stormwater quality, including the City's extensive street sweeping program, catch basins, and catch basin design (i.e., catch basins with and without inverted tees).

The historical outfall water quality results for Catchment 227 showed that all PAHs were consistently below detention limits and most metals were either below detection limits or consistently below both long-term and acute WQGs. This demonstrates that the City should not prioritize resources to improve the stormwater quality of this catchment. Efforts should focus on catchments with observed and ongoing water quality issues.

For Catchment 629, the concentrations of many of the metals analyzed have generally been trending downwards since the 2013 "5 in 30" sampling period. It is unclear from this study whether that is the result of more extensive source control efforts by both the CRD and the City, the adoption of the City's Stormwater Codes of Practice, increased education for business owners and community members, or other factors. While concentrations are generally trending towards, it is clear that more efforts are needed to improve the stormwater quality of Catchment 629.

Due to the significant current and historical industrial land uses throughout Catchment 629, the frequency and severity of contaminant releases into the storm drain is higher relative to primarily residential catchments such as Catchment 227. To improve the outfall water quality in Catchment 629, efforts should focus on source control and ensuring compliance with City Bylaws. It is essential that businesses and property owners are aware of the materials that are prohibited from entering the City’s storm drain. Further outreach and education can help increase the understanding of the impacts and implications of prohibited discharges and how to prevent, respond to, and report spills that do occur.

In terms of interventions for improving stormwater quality, the concentration of PAHs in catch basins with inverted tees were consistently higher than catch basins without inverted tees or in the street sweeping debris for both Catchment 227 and Catchment 629. This suggests that the addition of inverted tees to catch basins is an effective strategy and economical retrofit option for retaining PAHs within the catch basin to reduce downstream transport. The impact of inverted tees on metals retention within catch basins is less clear.

While the concentration of metals and PAHs in the street sweeping debris were consistently lower than the concentrations in the catch basins, this was expected since the catch basins have had significantly longer periods for accumulation. Comparing the concentration of street sweeper debris between Catchment 227 and Catchment 629, the concentrations of all metals and PAHs are similar even though Catchment 227 was swept once per week and Catchment 629 was swept daily. This result demonstrates the importance of more frequent street sweeping in catchments with heavy industrial land uses.

The visualizations developed through this work will help staff and other professionals identify patterns, focus resources, and refine strategies to address water quality issues. The visualizations could also be used for education and outreach, encouraging residents, businesses, and industries to be more proactive and involved in improving water quality throughout the City.

5.2 FUTURE WORK

Since this study was a starting point for better understanding the City's stormwater quality, there are numerous other areas of research and work that can expand on this study, such as:

- Explore the seasonal influence of rainfall on outfall water quality, including tidal influence.
- Consider the use of existing and emerging monitoring and sampling technologies.
- Expand the street sweeping and catch basin intervention analysis to look at additional stormwater catchments across the City.
- Leverage the functionality of the Data Visualisation Dashboard (using the Shiny package in R) for use by the CRD and other municipalities.
- Develop outreach and educational materials for businesses and residents.

APPENDIX A – REFERENCES

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APPENDIX B – SAMPLING PLAN

CATCHMENT INFORMATION

Parameter	Catchment 629	Catchment 227
General Catchment Information	• **Street**: Bay St between Bridge St and Rock Bay Ave, John St between Turner St and Government St, Hillside Ave between Rock Bay Ave and Government St, Rock Bay Ave between Hillside Ave and Bay St, and Ludgate St. • **Catch Basins**: See the 629 SD Catchment map. • **Outfall**: 629 (CoV asset ID: DOF007028)	• **Streets**: Hollywood Cres, Ross St between St Charles St and Beechwood Ave, Passmore St between Hollywood Cres and Pinewood Ave, Wildwood Ave and Beechwood Ave between Hollywood Cres and south of Lillian Rd, Robertson St south of Ross St, Hollywood Place • **Catch Basins**: See the 227 SD Catchment map. • **Outfall**: 227 (CoV Asset ID: DOF007010)
Street Sweeping Schedules and Equipment	• Swept 5-7 times per week between 12:00am-4:00am • Most commonly used piece of equipment is a regenerative air-sweeper • Occasionally area is swept with mechanical broom sweeper • Sweepers remove a heavy volume of fine to coarse aggregates. Refuse is mostly composed of sand, gravel and cement dust. Other common constituents include large amounts of litter and other debris. • Bay St between Point Ellis and Douglas is the worst street in town.	• Swept once every six weeks between 10:00am-2:00pm • Scheduled for mid-day as this is when most vehicles are away from residential areas • Area is serviced by a high-efficiency, mid-sized, full-vacuum sweeper • Collected refuse is mostly organic materials including leaves, other tree-debris, and light litter
Traffic Data	• Heavy industrial traffic • Highest volume of concrete truck, roll-off and dump truck traffic in City • Dense concentration of heavy-industrial plants and yards, which are serviced by multi-axle, heavy commercial vehicles	• Primarily residential traffic
Street Condition	• Limited parked cars during sweeping hours (12:00am-4:00am) • Road surface conditions are poor-good throughout catchment	• Frequent high concentrations of parked carks • Road surface condition is average throughout catchment

CONSTITUENTS TO MEASURE

- **Core Constituents:**
    - Based on constituents being sampled as part of the Code of Practice - Schedule D (and BC Water Quality Guidelines).
    - Prohibited waste with discharge standards provided: pH, Total Suspended Solids (TSS), Total Oil and Grease, Chloride (Cl), total hydrocarbons.

Aqueous Sample Parameters	Solid Sample Parameters
1-Methylnaphthalene**	Soluble (2:1) pH***
2-Methylnaphthalene**	Moisture
Acenaphthene***	Low Molecular Weight PAH`s***
Acenaphthylene***	High Molecular Weight PAH`s***
Acridine*	Total PAH***
Aluminum*	Naphthalene***
Anthracene***	2-Methylnaphthalene**
Antimony*	Acenaphthylene***
Arsenic***	Acenaphthene***
Barium*	Fluorene***
Benzo(B)Fluoranthene + Benzo(J)Fluoranthene**	Phenanthrene***
Benzo(K)Fluoranthene*	Anthracene***
Benzo[a]anthracene**	Fluoranthene***
Benzo[a]pyrene***	Pyrene
Benzo[ghi]perylene***	Benzo(a)anthracene**
Beryllium***	Chrysene***
Bismuth	Benzo(b&j)fluoranthene*
Boron***	Benzo(b)fluoranthene*
Cadmium***	Benzo(k)fluoranthene*
Calcium	Benzo(a)pyrene***
Chromium***	Indeno(1,2,3-cd)pyrene***
Chrysene***	Dibenz(a,h)anthracene***
Cobalt*	Benzo(g,h,i)perylene***
Copper***	Total Aluminum (Al)*
D14-Terphenyl	Total Antimony (Sb)*
D8-NAPHTHALENE (sur.)	Total Arsenic (As)***
dibenzo(a,h)anthracene***	Total Barium (Ba)*
E. Coli***	Total Beryllium (Be)***
Flow Rate	Total Bismuth (Bi)
Fluoranthene***	Total Boron (B)***
Fluorene***	Total Cadmium (Cd)***
Hardness (as CaCO3)	Total Calcium (Ca)
High Molecular Weight PAH`s**	Total Chromium (Cr)***
Indeno(1,2,3-C,D)Pyrene***	Total Cobalt (Co)*
Iron*	Total Copper (Cu)***
Lead***	Total Iron (Fe)*
Lithium	Total Lead (Pb)***
Low Molecular Weight PAH`s***	Total Lithium (Li)

Magnesium Manganese*** Maxxam Surrogate Recovery_1 Maxxam Surrogate Recovery_3 Molybdenum* Naphthalene*** Nickel*** Phenanthrene*** Potassium Pyrene Quinoline* Selenium** Silicon Silver*** Sodium Strontium* Sulfur Thallium* Tin* Titanium Total PAH*** Uranium* Vanadium*** Zinc*** Zirconium	Total Magnesium (Mg) Total Manganese (Mn)*** Total Mercury (Hg)*** Total Molybdenum (Mo)* Total Nickel (Ni)*** Total Phosphorus (P)* Total Potassium (K) Total Selenium (Se)*** Total Silver (Ag)*** Total Sodium (Na) Total Strontium (Sr)* Total Thallium (Tl)* Total Tin (Sn)* Total Titanium (Ti) Total Tungsten (W) Total Uranium (U)* Total Vanadium (V)*** Total Zinc (Zn)*** Total Zirconium (Zr) Total Organic Carbon (C)*

* - Concern for freshwater aquatic life

** - Concern for marine aquatic life

*** Concern for both freshwater & marine aquatic life

SAMPLE TYPES & QUANTITIES

For both catchments, samples were collected from (1) the street sweeper, (2) catch basins, and (3) the stormwater outfalls.

Street Sweeper Debris:

- Composite samples of the street sweeper refuse were collected following the sweeper completing a thorough pass across the catchment.
- Sampling was repeated over 3 sampling periods per catchment to help understand variability and heterogeneity of the debris.
- During periods of rainfall, the street sweeper refuse consists of both solid and aqueous portions. However, none of the sampling days of this study occurred during rainfall events. Therefore, the composite sample of the street sweeper refuse consisted only of solids.

Catch Basins:

- Collect a composite sample of solids captured, retained, and accumulated in catch basins across each catchment. Composite samples will be collected from both catch basins with and without inverted tees to understand if the configuration has any impact on the types of constituents retained within the catch basins. catch basins are additive to the street sweeping program and can capture constituents that aren't being removed by sweeping.
- 3 composite solids samples were collected from multiple catch basins with and without inverted tees within each catchment.

Stormwater Outfalls:

- Samples were collected from the outfall of each catchment. The outfall water quality is important to understand the types and quantities of constituents entering the receiving environment. This gives an indication of what needs to be managed and a baseline for improvements.
- Sampling was repeated over 3 sampling periods per catchment to help account for variability.

SAMPLING PROCEDURE

General Notes on Sampling:

- Will use the same sweeping equipment for both catchments (CityCat VR50 compact sweeper).

Catchment 629:

1. Catch basins provided sweeping route of entire catchment to Operations staff.
2. Operations staff allowed debris to accumulate for 2 days prior to completing the first sweep of Catchment 629. This is the maximum accumulation possible to minimize impacts and schedule disruptions for PW.
3. Operations staff weighed the empty, clean sweeper truck prior to completing the sweep of the catchment. Due to the close proximity of Catchment 629 to the Public Works Yard, the mass of street sweeping debris captured from this catchment was measured by weighing the sweeper truck before and after sweeping.
4. Operations staff swept the provided route beginning at approximately 6:00 am.
5. Following sweeping, operations staff returned with the sweepings to the Public Works Yard and weighed the full truck. For the first sampling day, the sweeping debris was deposited into a roll-off

bin for sampling. This was to allow the sweeper to continue with operations in a timely manner. For subsequent sampling days, samples were taken directly from the sweeper truck.

6. At the Public Works Yard, City Stormwater staff and CRD staff collected sediment samples directly from the sweeper truck. Several samples from various locations throughout the entire refuse pile were transferred into a clean, metal bowl. The composite sample was homogenized via vigorous hand mixing before sub-samples were collected for analysis.
7. City Stormwater staff and CRD staff also collected outfall samples at the end of day on the same day as the street sweeping. The timing of the outfall samples for this catchment was based on the tides because the outfall is only accessible for sampling during low tide.
8. Steps 3 to 7 were repeated for 2 additional days to have street sweeping samples collected from the catchment over 3 consecutive days.
9. City Stormwater staff and CRD staff collected a composite sample from the solids retained within several catch basins (1) containing inverted tees, and (2) without inverted tees throughout the catchment area.
10. Samples were collected from catch basins using the following steps:
    a. City Stormwater staff first completed a visual inspection of catch basins within the catchment area to determine which had inverted tees installed and which did not.
    b. On the sampling day, City Stormwater staff and CRD staff selected three catch basins with inverted tees and three catch basins without inverted tees. Selection was based on the presence of sufficient material accumulation.
    c. Staff utilized a steel head shovel to remove material from the catch basins. From this removed material, several large scoops were placed it into a clean metal bowl. Two bowls were used: one for a composite sample from catch basins with inverted tees, and one for a composite sample from catch basins without inverted tees.
    d. The composite sample was homogenized via vigorous hand mixing before sub-samples were collected for analysis

Other Data to Collect:

- City Stormwater staff to collect GPS data from operations staff regarding the sweeper truck route.
- Weather: temperature, rainfall, wind, etc.
- Photos: Capture pre- and post-sweeping of area as well as sweeper in action. Record any notable features during sampling.

Catchment 227:

1. City Stormwater staff provided sweeping route of entire catchment to Operations staff.
2. Due to the distance of Catchment 227 to the Public Works Yard, the mass of street sweeping debris collected was not measured.
3. Operations staff swept the provided route on three consecutive Mondays between 10:00 am-2:00 pm.
4. At the same time that operations staff was sweeping the catchment, City Stormwater staff and CRD staff collected outfall samples. Since the 227 outfall is accessible during all tides, additional outfall samples were able to be collected compared to the 629 outfall.
5. Following sweeping, operations staff brought the sweeper truck to a nearby park. For the first sampling day, a different sweeper truck was used which is more difficult to sample from directly. To address this, operations staff dumped the sweeper contents into a bin for sampling. For subsequent sampling days, samples were taken directly from the sweeper truck.

6. City Stormwater staff and CRD staff took measurements to estimate the volume of captured debris and collected a composite sample of the sweeper refuse. Several samples from various locations throughout the entire refuse pile were transferred into a clean, metal bowl. The composite sample was homogenized via vigorous hand mixing before sub-samples were collected for analysis.
7. City Stormwater staff and CRD staff also collected outfall samples the Tuesday following the street sweeping.
8. This process was repeated over a three-week period to account for variability in the captured street sweeping refuse.
9. City Stormwater staff and CRD staff collected a composite sample from the solids retained within several catch basins (1) containing inverted tees, and (2) without inverted tees throughout the catchment area.
10. Samples were collected from catch basins using the following steps:
    a. City Stormwater staff first completed a visual inspection of catch basins within the catchment area to determine which had inverted tees installed and which did not.
    b. On the sampling day, City Stormwater staff and CRD staff selected three catch basins with inverted tees and three catch basins without inverted tees. Selection was based on the presence of sufficient material accumulation.
    c. Staff utilized a steel head shovel to remove material from the catch basins. From this removed material, several large scoops were placed it into a clean metal bowl. Two bowls were used: one for a composite sample from catch basins with inverted tees, and one for a composite sample from catch basins without inverted tees.
    d. The composite sample was homogenized via vigorous hand mixing before sub-samples were collected for analysis

SAMPLING SCHEDULE

Catchment 629

Sample Description	Sample	Sample Date	Sample ID	Matrix	Comments
Outfall (DOF007028)	1	07-Mar-25	2025-0006707	Stormwater (discharge)	brown flow with sulphur odour, estimated flow 32L/min
			2025-0006708	Stormwater (discharge, E.coli duplicate)	Brown flow with sulphur odour, estimated flow 32L/min. Bacteria sample collected in addition to other samples.
	2	10-Mar-25	2025-0009588	Stormwater (discharge), no E.coli collected due to hold time	murky amber flow with sulphur odour, estimated flow of 30L/min, ~280 kg of refuse collected.
	3	11-Mar-25	2025-0009594	Stormwater (discharge), no E.coli collected due to hold time	murky amber colour with sulphur/metalic odour, estimated flow 45L/min
	4	12-Mar-25	2025-0009596	Stormwater (discharge), no E.coli collected due to hold time	brown flow with some suds and sulphur odour, estimated flow of 40L/min
Street Sweeper Refuse	1	10-Mar-25	2025-0009582	Sediment (street sweeper waste, duplicate)	medium grey sand with various materials (plastic, fabric, wood, etc)
			2025-0009583	Sediment (street sweeper waste, duplicate)	medium grey sand with various materials (plastic, fabric, wood, etc)
	2	11-Mar-25	2025-0009589	Sediment (street sweeper waste)	medium grey sand/fines with some orgaincs (leaves, wood) and debris (plastics, etc.)
	3	12-Mar-25	2025-0009595	Sediment (street sweeper waste)	wet, dark grey sand/fines with some organic (leaves/wood) and road debris (plastics, etc.)
Catch Basins **CBs with Inverted Tees**	Composite (DCB004913 DCB002377 DCB004914)	10-Mar-25	2025-0009584	Sediment (catch basin composite, inverted T design)	Wet mixture of dark sand/fines with some organics (leaves, wood) and road debris (plastics, etc). Catch basins contained significantly less organic material than the 227 CBs. A couple of the CBs were dry. CBs with water in them contained significant sediment. The CB directly on Bay (DCB004925) had an oily sheen.
CBs without Inverted Tees	Composite (DCB000098 DCB004925 DCB000113)	10-Mar-25	2025-0009585	Sediment (catch basin composite, non inverted T design)	

Catchment 227						
Sample Description		**Sample**	**Sample Date**	**Sample ID**	**Matrix**	**Comments**
Outfall (DOF007010)		1	03-Mar-25	2025-0006679	Stormwater (discharge)	Slighty murky with slight sewer odour, flow estimated 8L/min. Flow from outfall was higher than other days, even though there hadn't been ain for a few days.
		2	04-Mar-25	2025-0006684	Stormwater (discharge)	slighty murky with no odour, flow estimated at 4L/min
		3	10-Mar-25	2025-0009587	Stormwater (discharge)	Slighty murky with no odour, flow estimated at 4L/min. Bacteria sample collected in addition to other samples.
		4	11-Mar-25	2025-0009590	Stormwater (discharge)	Slighty murky with earthy odour, flow estimated at 20L/min. Additional bacteria samples collected from manholes DMH000005 and DMH000004.
		5	17-Mar-25	2025-0009606	Stormwater (discharge)	slighty murky with no odour, flow estimated at 6L/min
Street Sweeper Refuse		1	03-Mar-25	2025-0006682	Sediment (street sweeper waste, duplicate)	Drier organics (leaves/wood) with fines and some sand. ~0.448 m^3 of refuse from sweeper (~140 cm x 80 cm x 40 cm pile)
				2025-0006683	Sediment (street sweeper waste, duplicate)	
		2	10-Mar-25	2025-0009586	Sediment (street sweeper waste)	Moist, medium grey sand/fines with organics (leaves, wood). Very little refuse collected from catchment, ~0.1 m^2. Large rainfall event over weekend.
		3	17-Mar-25	2025-0009604	Sediment (street sweeper waste)	moist organics (leaves and wood) with some sand/fines
Catch Basins	**CBs with Inverted Tees**	Composite (DCB005298 DCB005290 DCB005301 DCB005307)	03-Mar-25	2025-0006681	Sediment (catch basin composite, inverted T design)	Catch basin samples contained significant quantities of leaf and organic refuse. Had to use a shovel to remove the organics prior to collecting a solids/aqueous sample from the bottom of the CB. Wet mixture of sand/fines with organics (leaves, wood).
	CBs without Inverted Tees	Composite (DCB005672 DCB002159 DCB005300)	03-Mar-25	2025-0006680	Sediment (catch basin composite, non inverted T design)	


629 SD Catchment
629 Catch Basin No T - Sampled
629 Catch Basin - No T
629 Catch Basin Inverted T - Sampled
629 Catch Basin Inverted T
Storm Drain Outfall (Discharge)
Hillside Ave
John St
Ludgate St
Rock Bay Ave
Bridge St
Bay St
DCB002379
DCB001671
DCB002387
DCB002388
DCB002873
DCB002874
DCB002377
DCB004914
DCB004913
DCB001247
DCB004947
DCB001246
DCB001248
DCB007527
DCB004921
DCB004920
DCB004919
DCB000113
DCB000114
DCB000113
DCB000098
DCB000098
DCB004949
DCB004948
DCB004925
DCB004925
DCB004122
DCB000111
DCB000112
DCB004952
DCB004924
DCB007438
DCB004951
DCB006256
DCB006234
DCB004937
N
0 510 20 Meters

227 SD Catchment
🟥 227 Catch Basin Inverted T - Sampled
🟧 227 Catch Basin Inverted T
🟩 227 Catch Basin No T - Sampled
🟩 227 Catch Basin No T
Storm Drain Outfall (Discharge)
Gonzales Beach Park
Hollywood Cres
Wild
Beechwood Ave
Robertson St
DCB001744
DCB001743
DCB001742
DCB001739
DCB001740
DCB001738
DCB005960
DCB005676
DCB005672
DCB005668
DCB005669
DCB005671
DCB002154
DCB002158
DCB002156
DCB002160
DCB002157
DCB002155
DCB002159
DCB005298
DCB005299
DCB005289
DCB005288
DCB005287
DCB005305
DCB005283
DCB005306
DCB005304
DCB005307
DCB005286
DCB005284
DCB005301
DCB005302
DCB005282
DCB005300
DCB005303
DCB005290
DCB005285
DCB007426
0 5 10 20 Meters
N

SAMPLE ANALYSIS

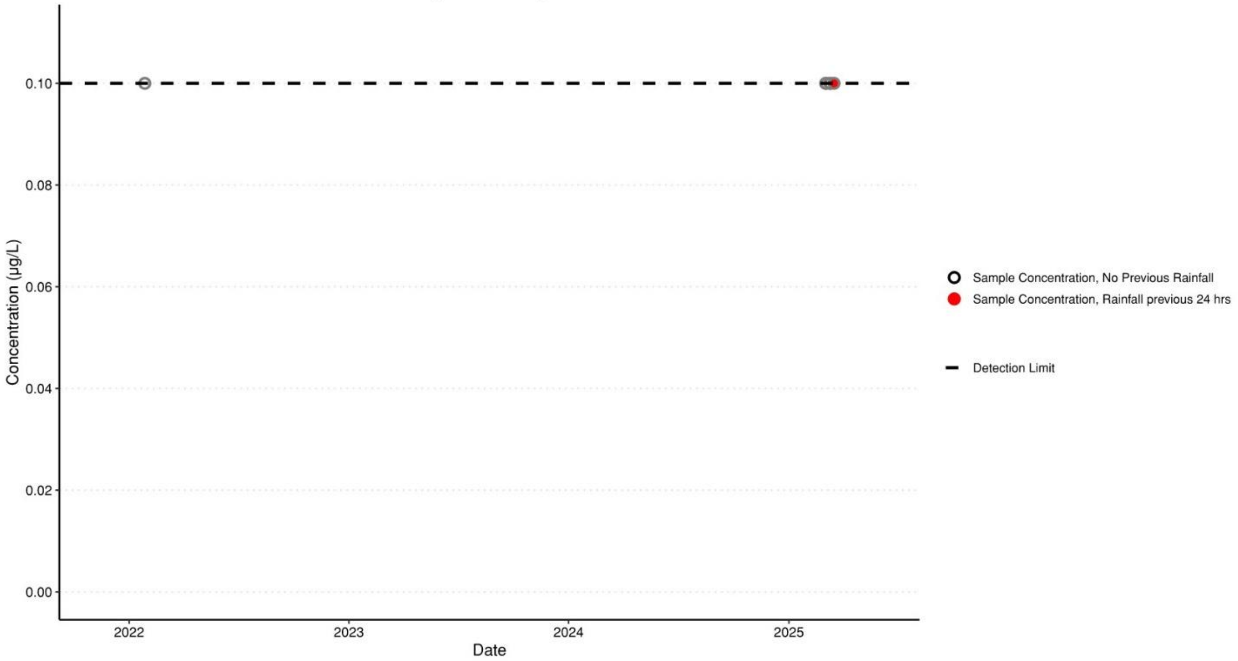
Bureau Veritas (BV) Labs:

- Total hydrocarbons and metals within aqueous and solid samples will be completed by Bureau Veritas (BV) labs.
- The CRD will coordinate the analysis of these samples as they currently utilize BV labs to analyze their environmental samples.

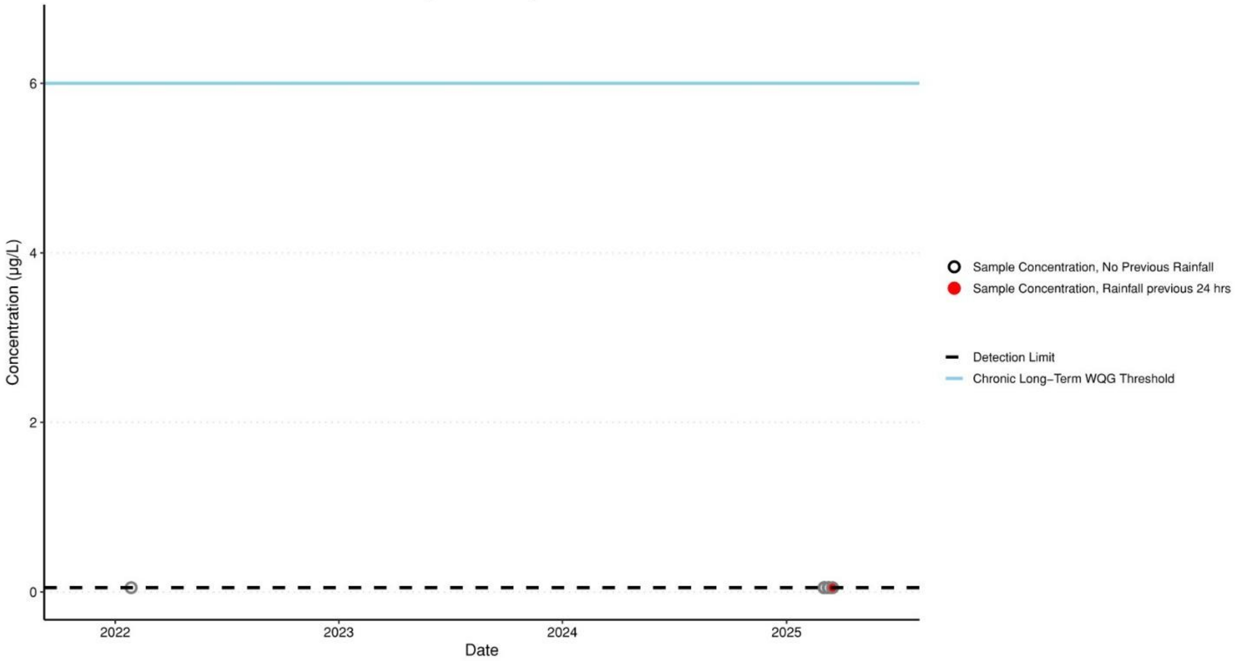
APPENDIX C – DATA RESULTS

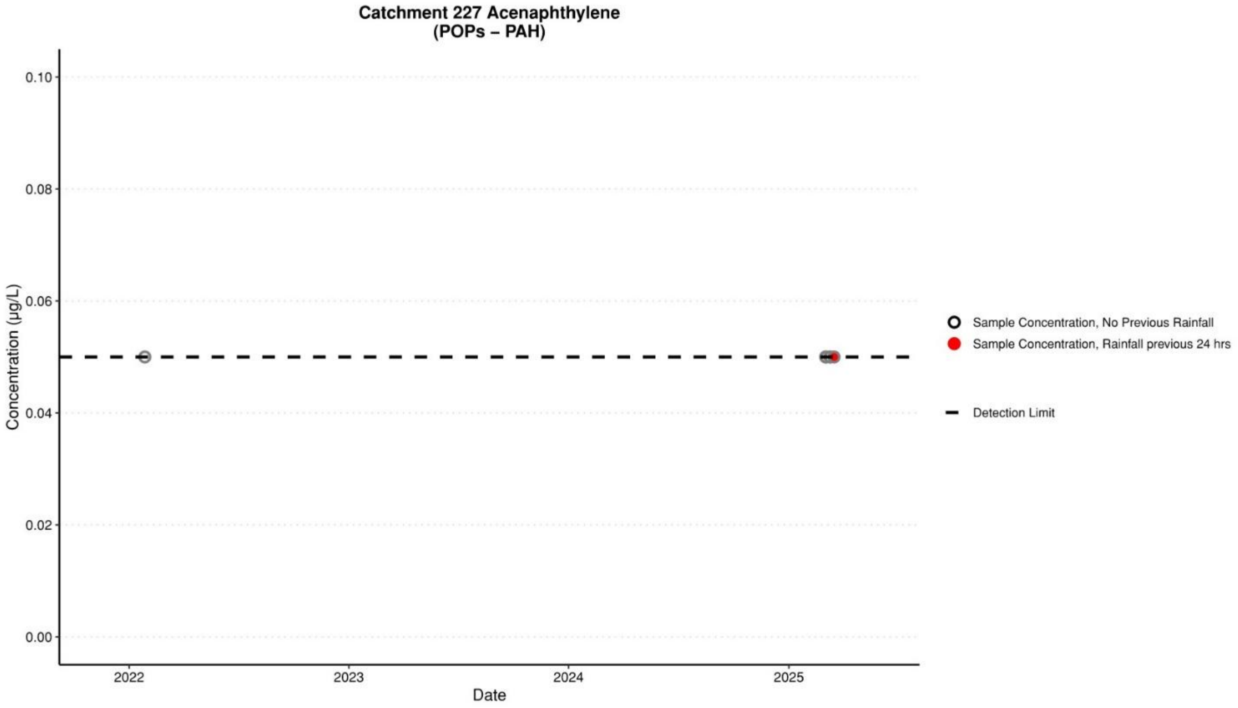
CATCHMENT 227 HISTORICAL OUTFALL WATER QUALITY RESULTS

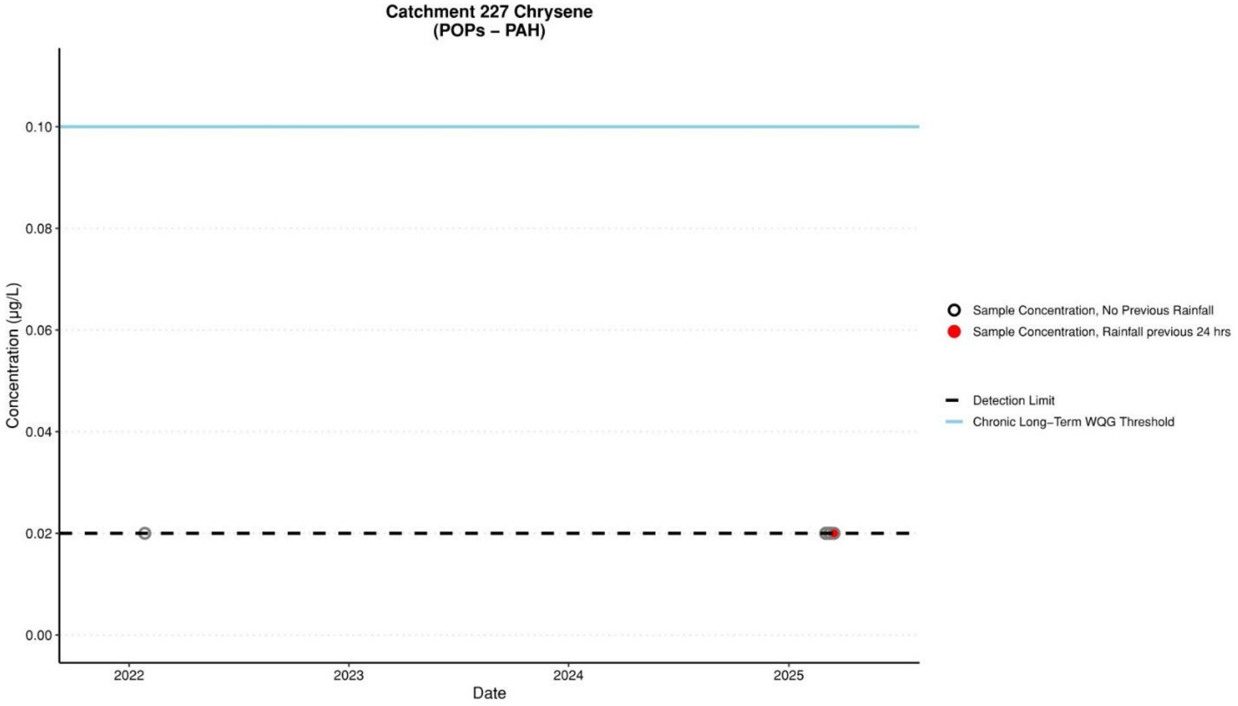
Catchment 227 2–Methylnaphthalene
(POPs – PAH)

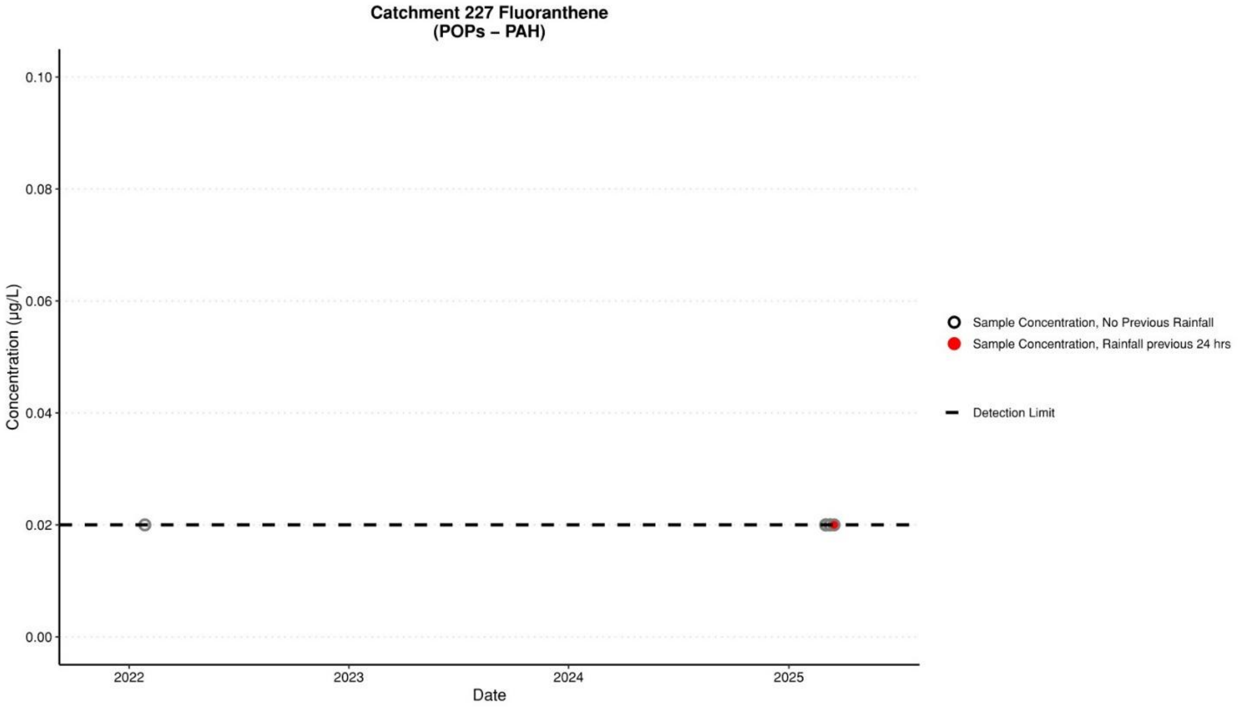


Catchment 227 Acenaphthene
(POPs – PAH)

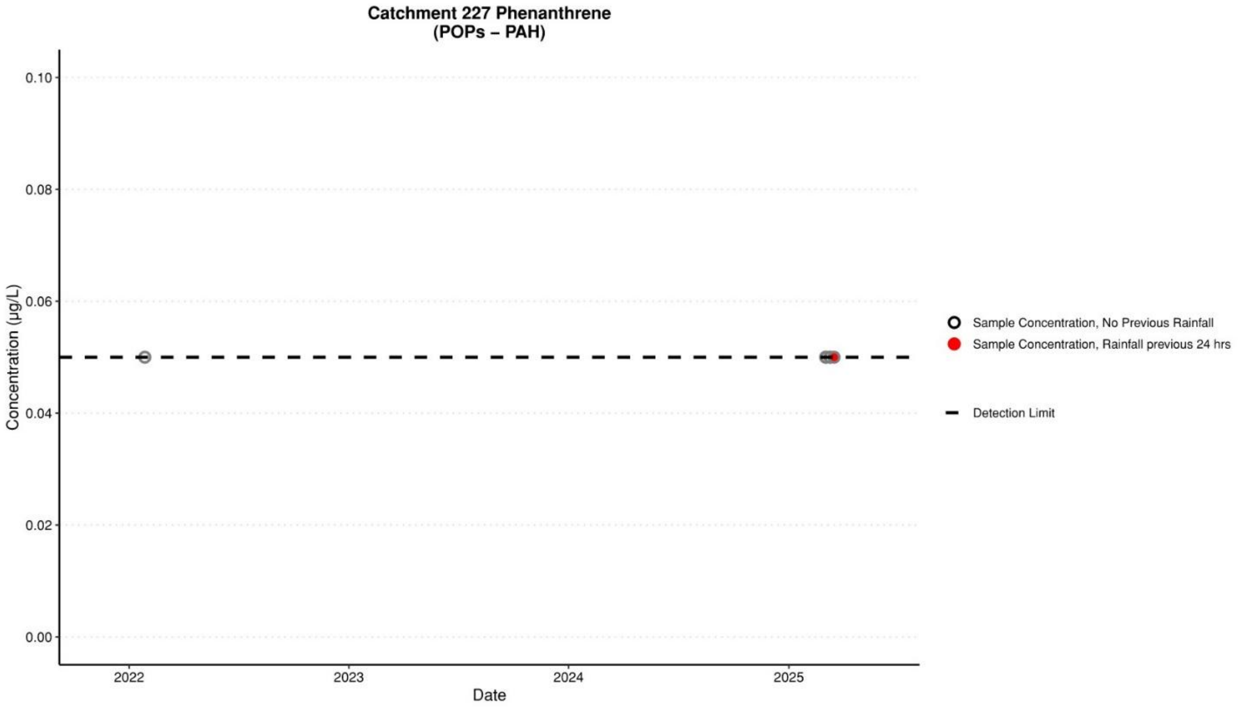



Catchment 227 Acenaphthylene
(POPs – PAH)
Concentration (µg/L)
0.10
0.08
0.06
0.04
0.02
0.00
2022
2023
2024
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit


Catchment 227 Chrysene
(POPs – PAH)
Concentration (µg/L)
0.10
0.08
0.06
0.04
0.02
0.00
2022
2023
2024
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit
Chronic Long−Term WQG Threshold

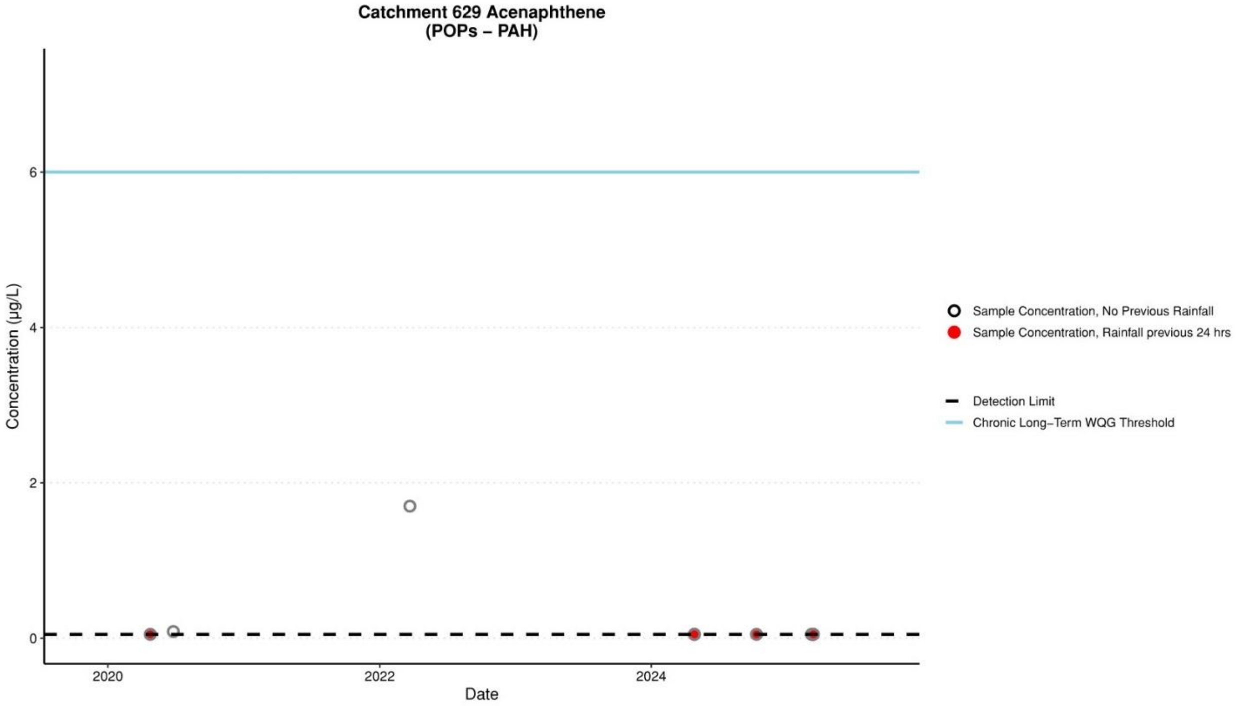


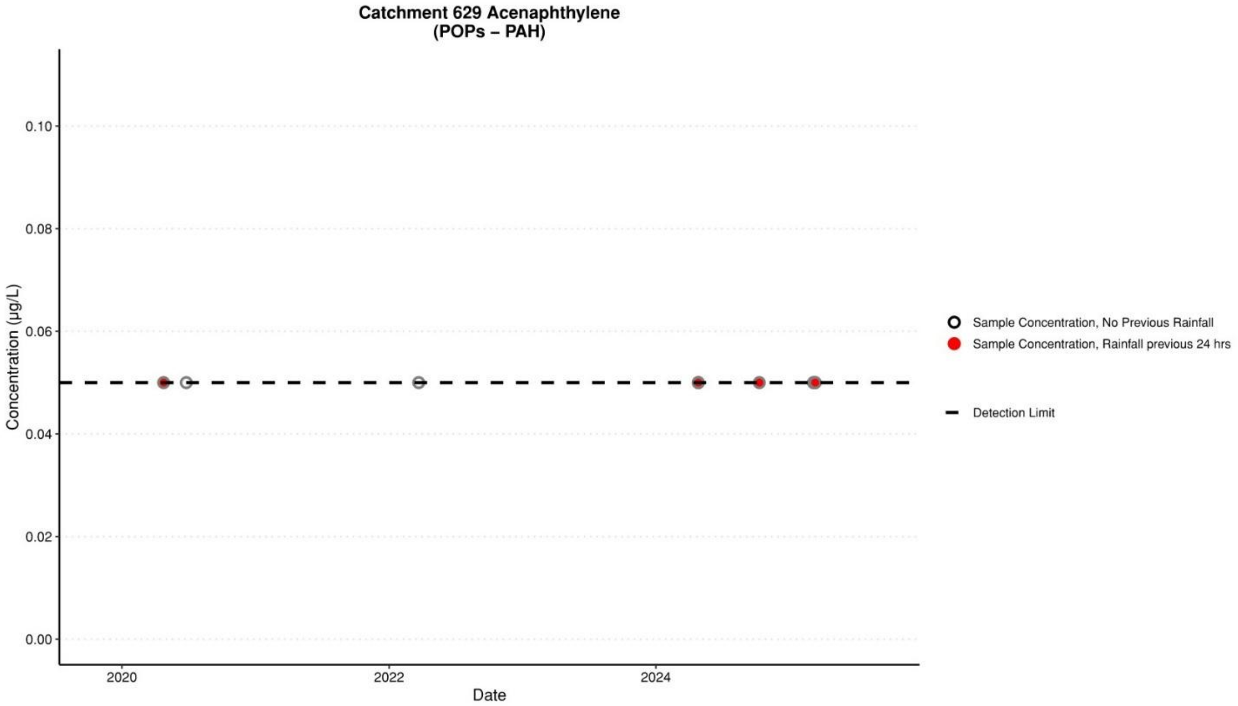
Catchment 227 Fluoranthene
(POPs – PAH)
Concentration (µg/L)
0.10
0.08
0.06
0.04
0.02
0.00
2022
2023
2024
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit

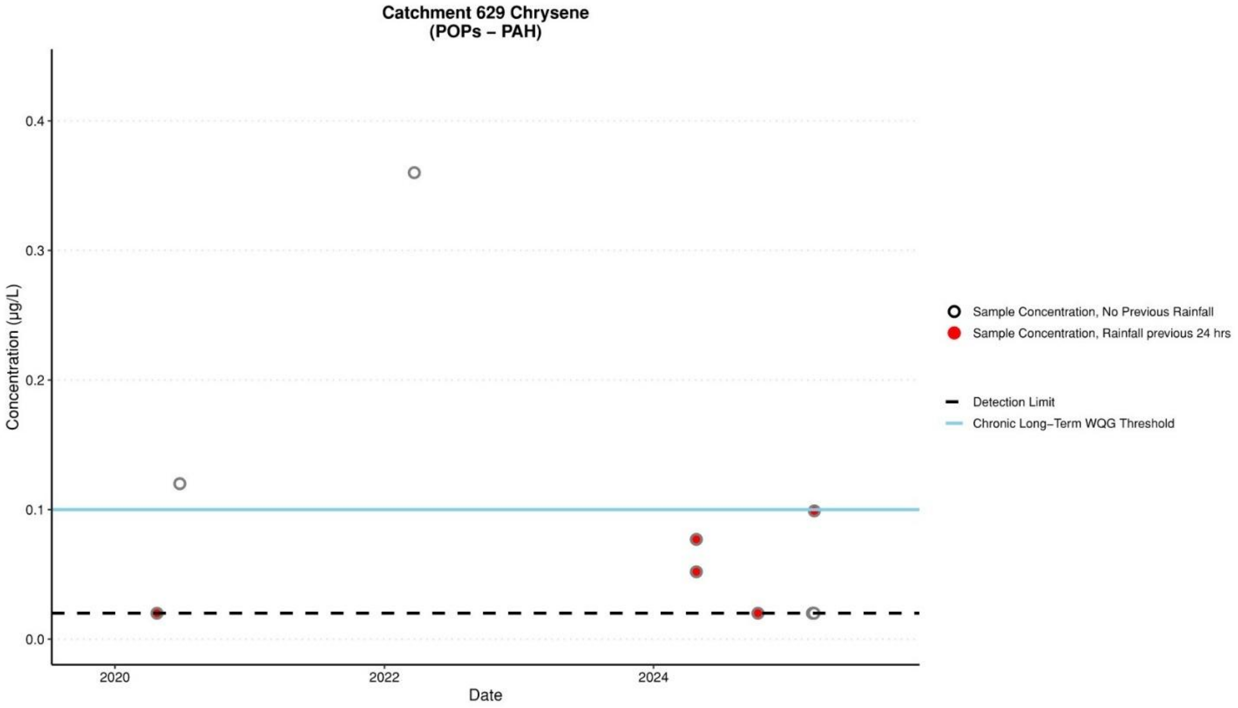


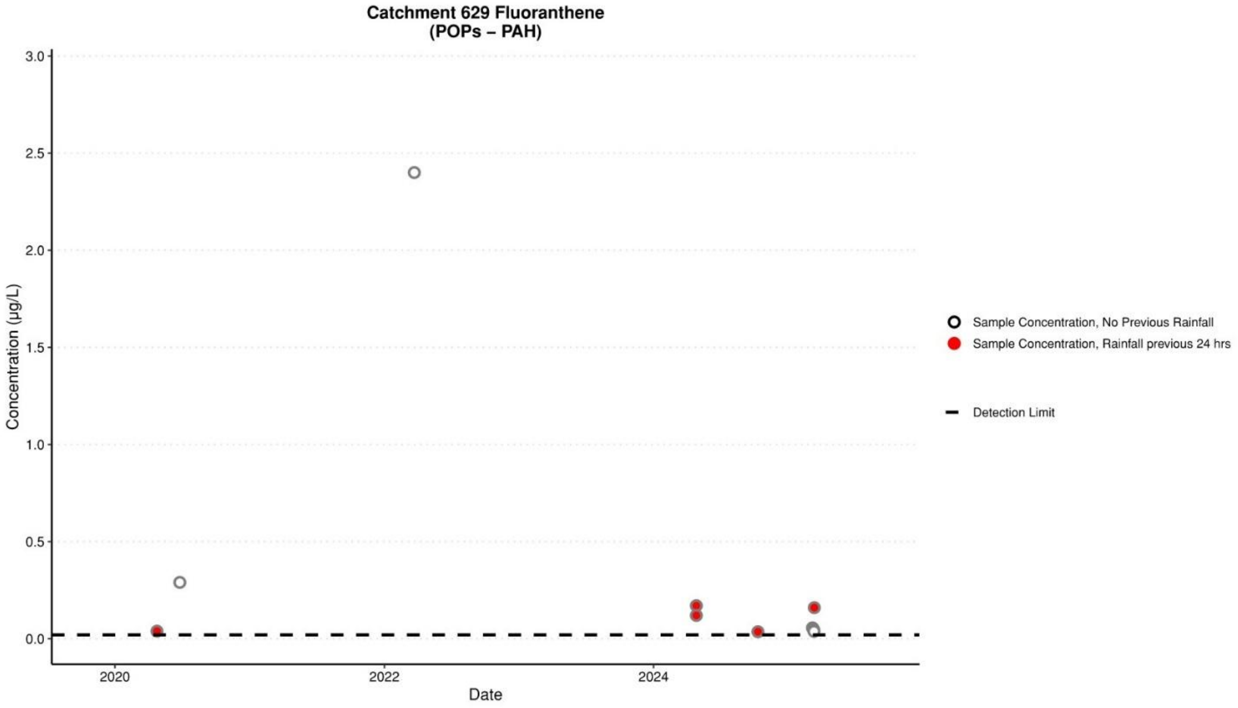
Catchment 227 Phenanthrene
(POPs – PAH)
Concentration (µg/L)
0.10
0.08
0.06
0.04
0.02
0.00
2022
2023
2024
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit

CATCHMENT 629 HISTORICAL OUTFALL WATER QUALITY RESULTS

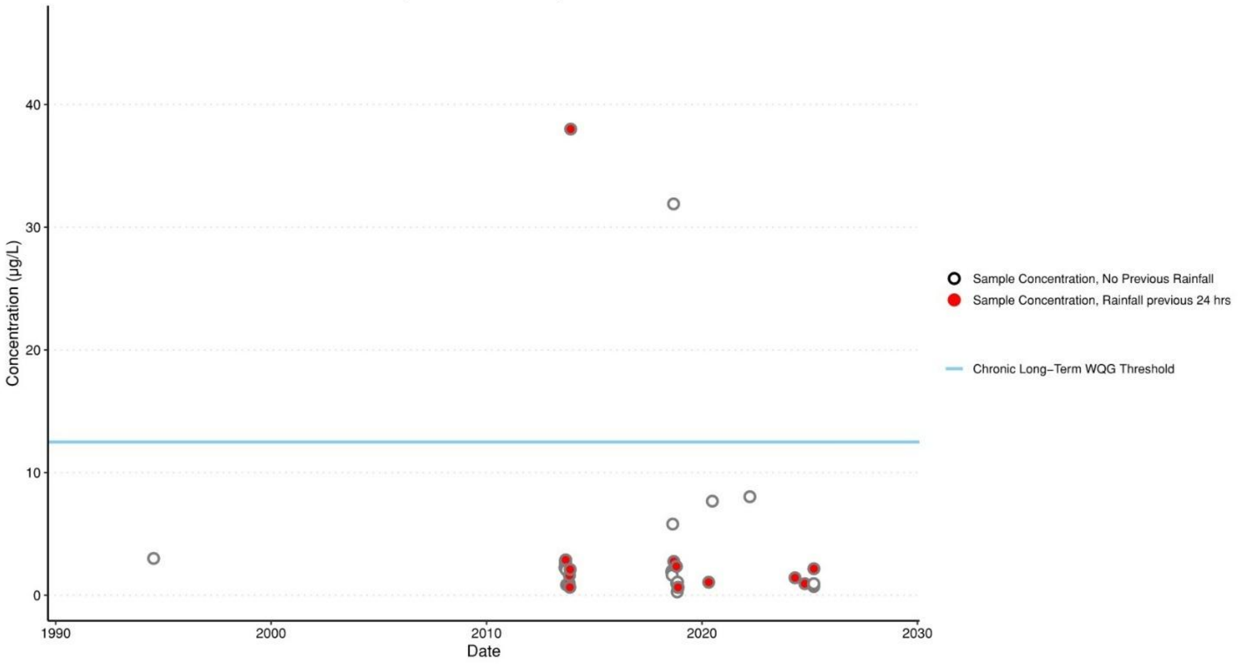




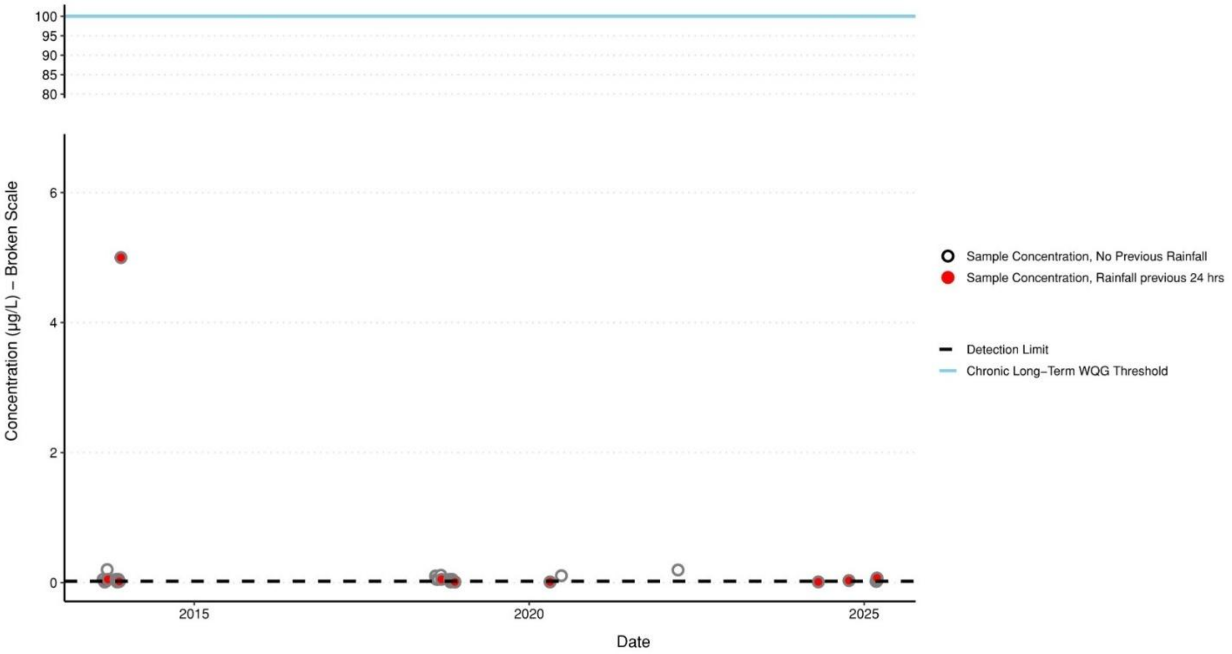

Catchment 629 Chrysene
(POPs – PAH)
Concentration (µg/L)
0.0
0.1
0.2
0.3
0.4
2020
2022
2024
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit
Chronic Long−Term WQG Threshold

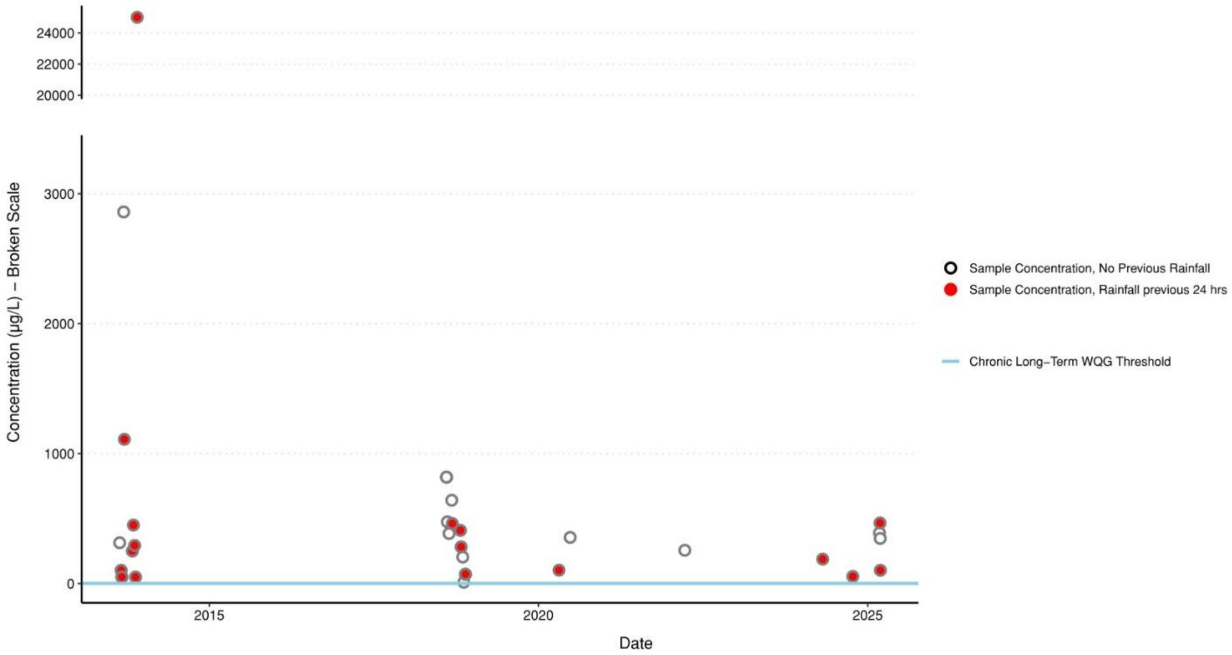

Catchment 629 Fluoranthene
(POPs – PAH)
Concentration (µg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2020
2022
2024
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit

Catchment 629 Arsenic
(Metals – Metalloid)

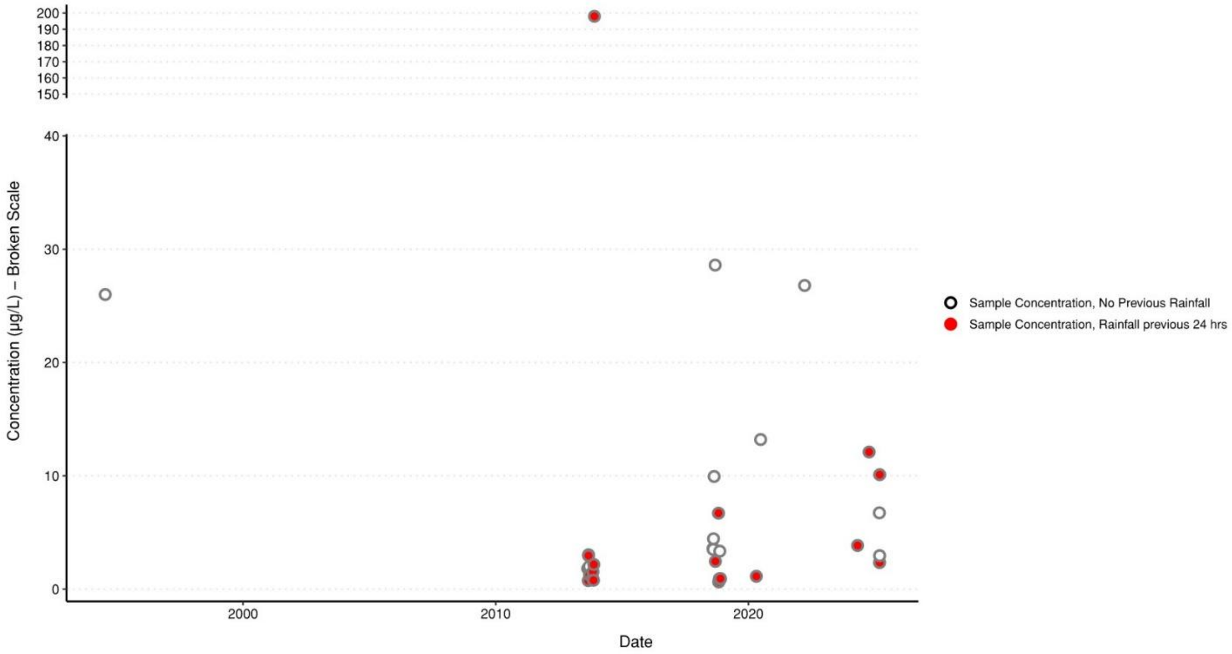


Catchment 629 Beryllium
(Metals – Alkaline earth)

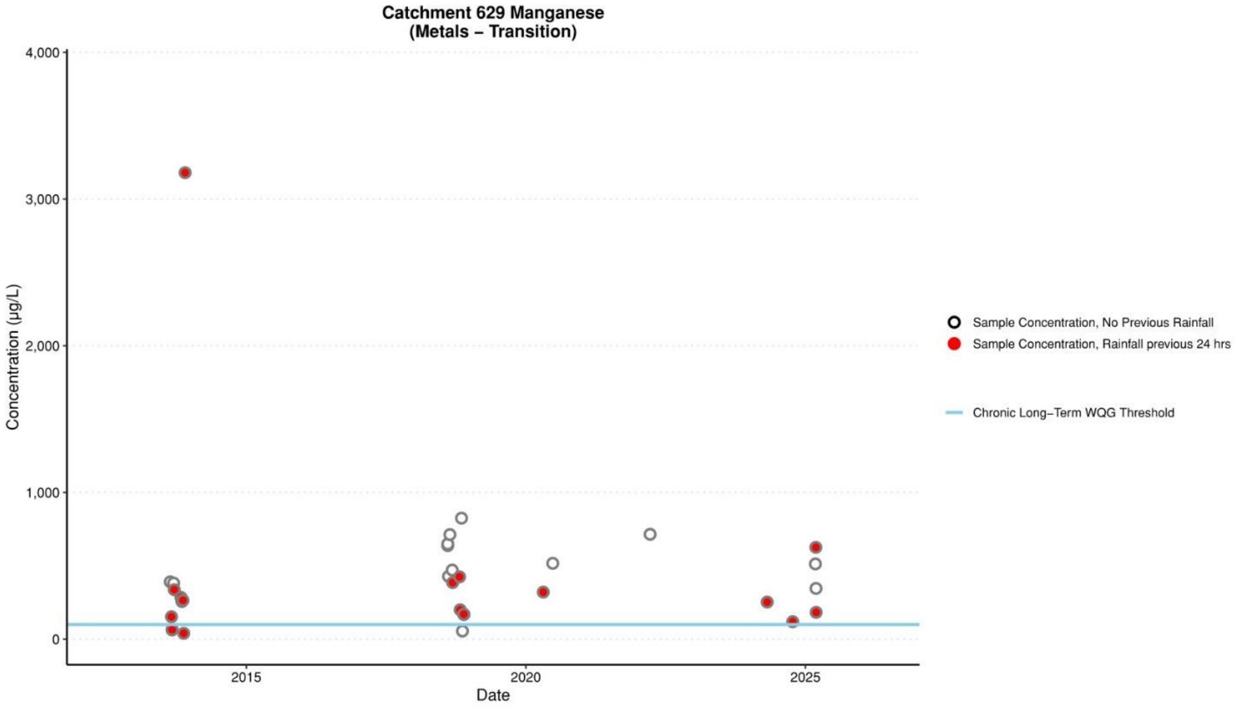


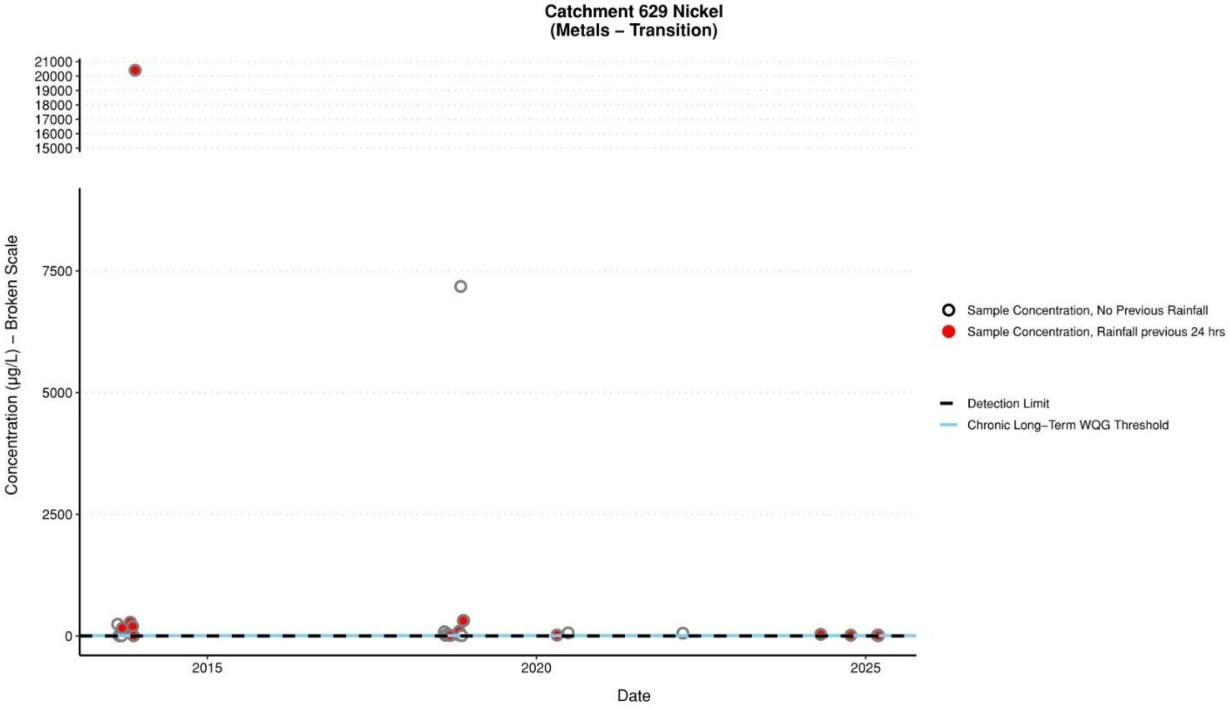


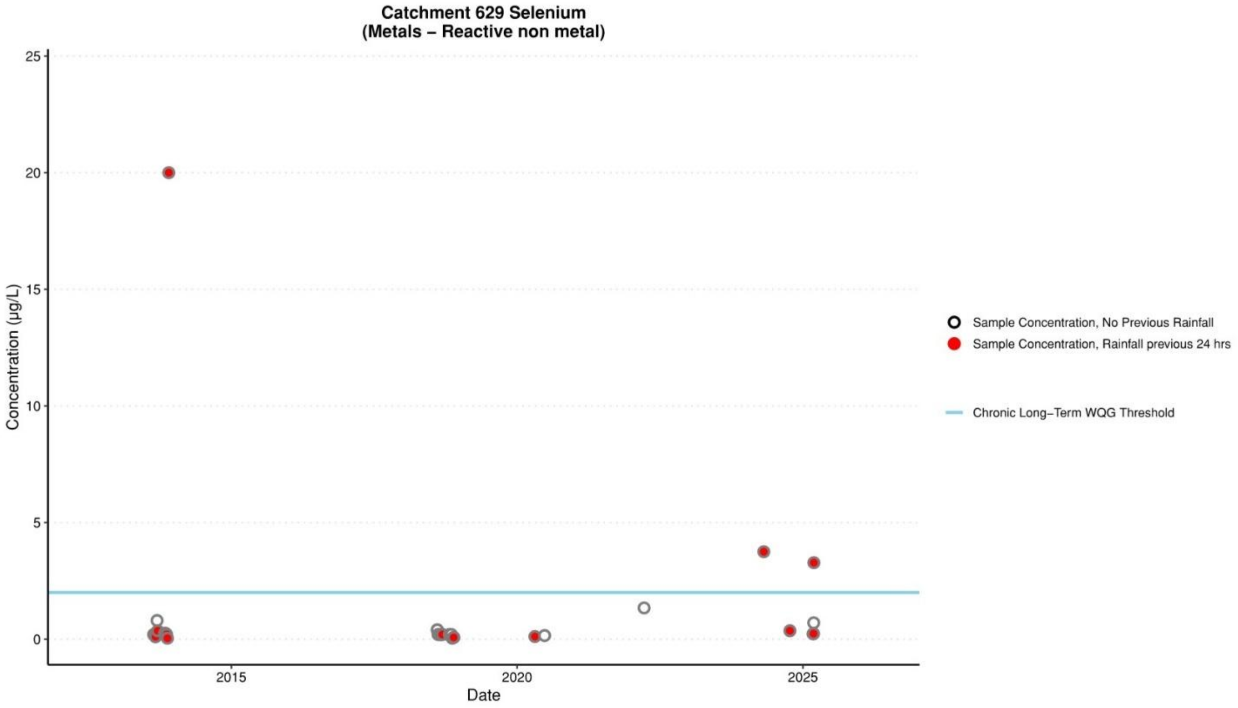
Catchment 629 Boron
(Metals – Metalloid)

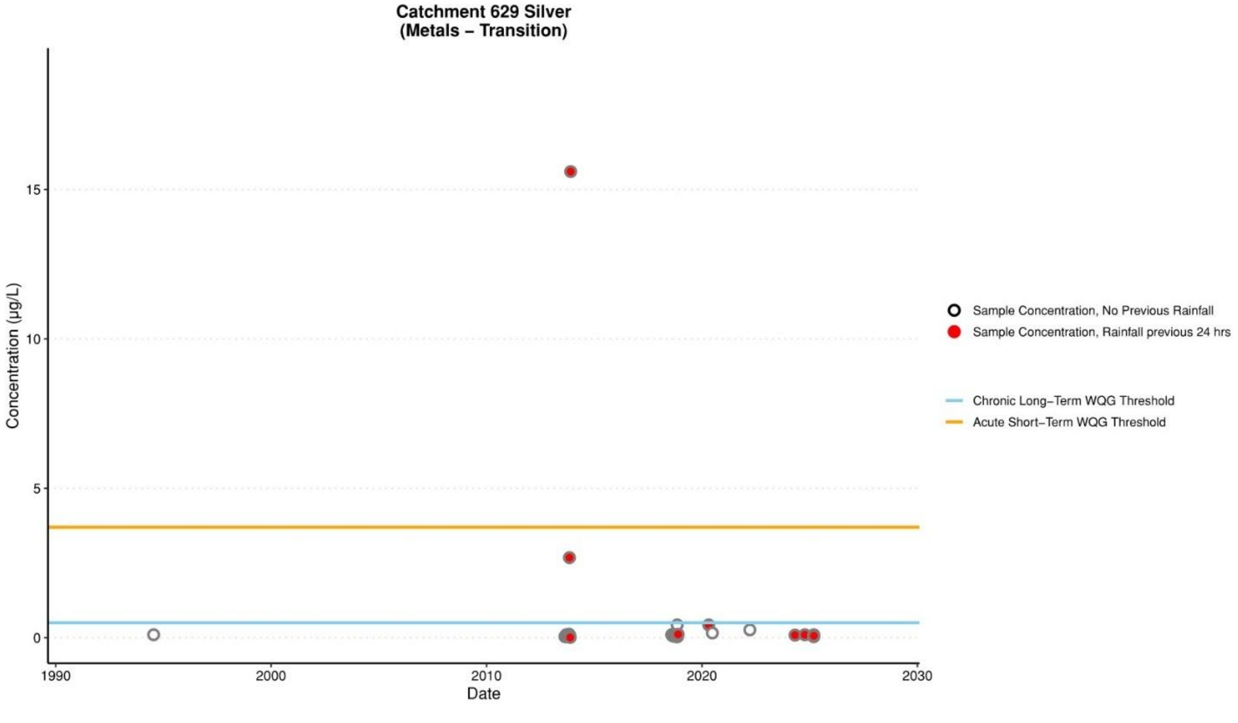


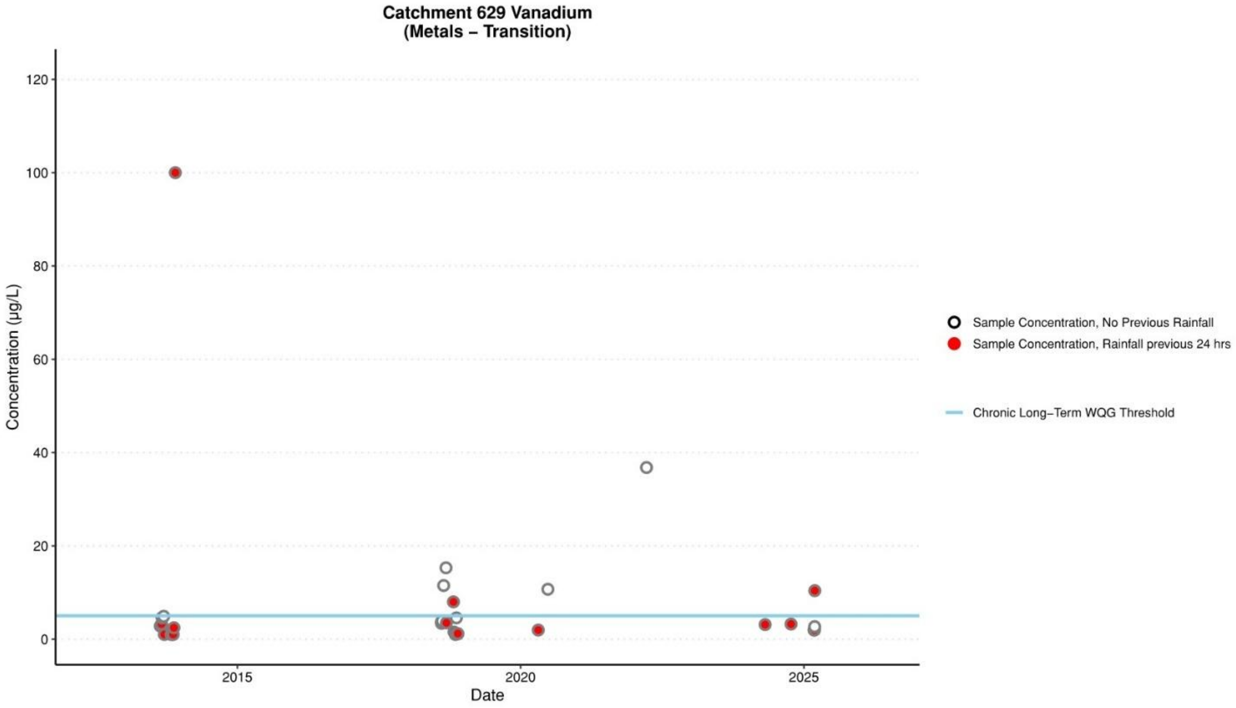
Catchment 629 Chromium
(Metals – Transition)


Catchment 629 Manganese
(Metals – Transition)
Concentration (µg/L)
4,000
3,000
2,000
1,000
0
2015
2020
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Chronic Long–Term WQG Threshold

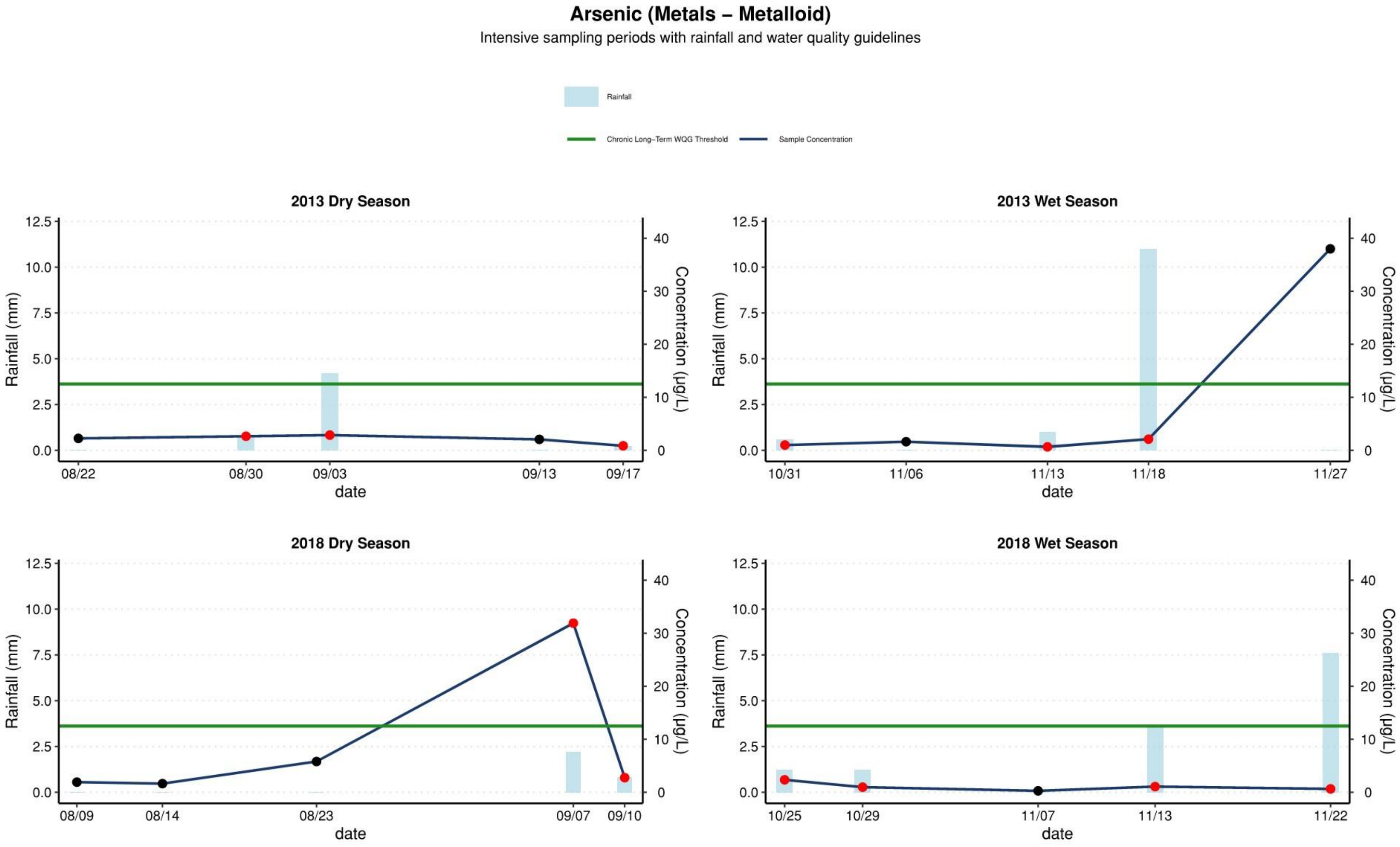

Catchment 629 Nickel
(Metals – Transition)
Concentration (µg/L) – Broken Scale
21000
20000
19000
18000
17000
16000
15000
7500
5000
2500
0
2015
2020
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Detection Limit
Chronic Long–Term WQG Threshold


Catchment 629 Selenium
(Metals – Reactive non metal)
Concentration (µg/L)
25
20
15
10
5
0
2015
2020
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Chronic Long–Term WQG Threshold


Catchment 629 Silver
(Metals – Transition)
Concentration (µg/L)
15
10
5
0
1990
2000
2010
2020
2030
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Chronic Long–Term WQG Threshold
Acute Short–Term WQG Threshold


Catchment 629 Vanadium
(Metals – Transition)
Concentration (µg/L)
120
100
80
60
40
20
0
2015
2020
2025
Date
Sample Concentration, No Previous Rainfall
Sample Concentration, Rainfall previous 24 hrs
Chronic Long−Term WQG Threshold

CATCHMENT 629 “5 IN 30” RESULTS



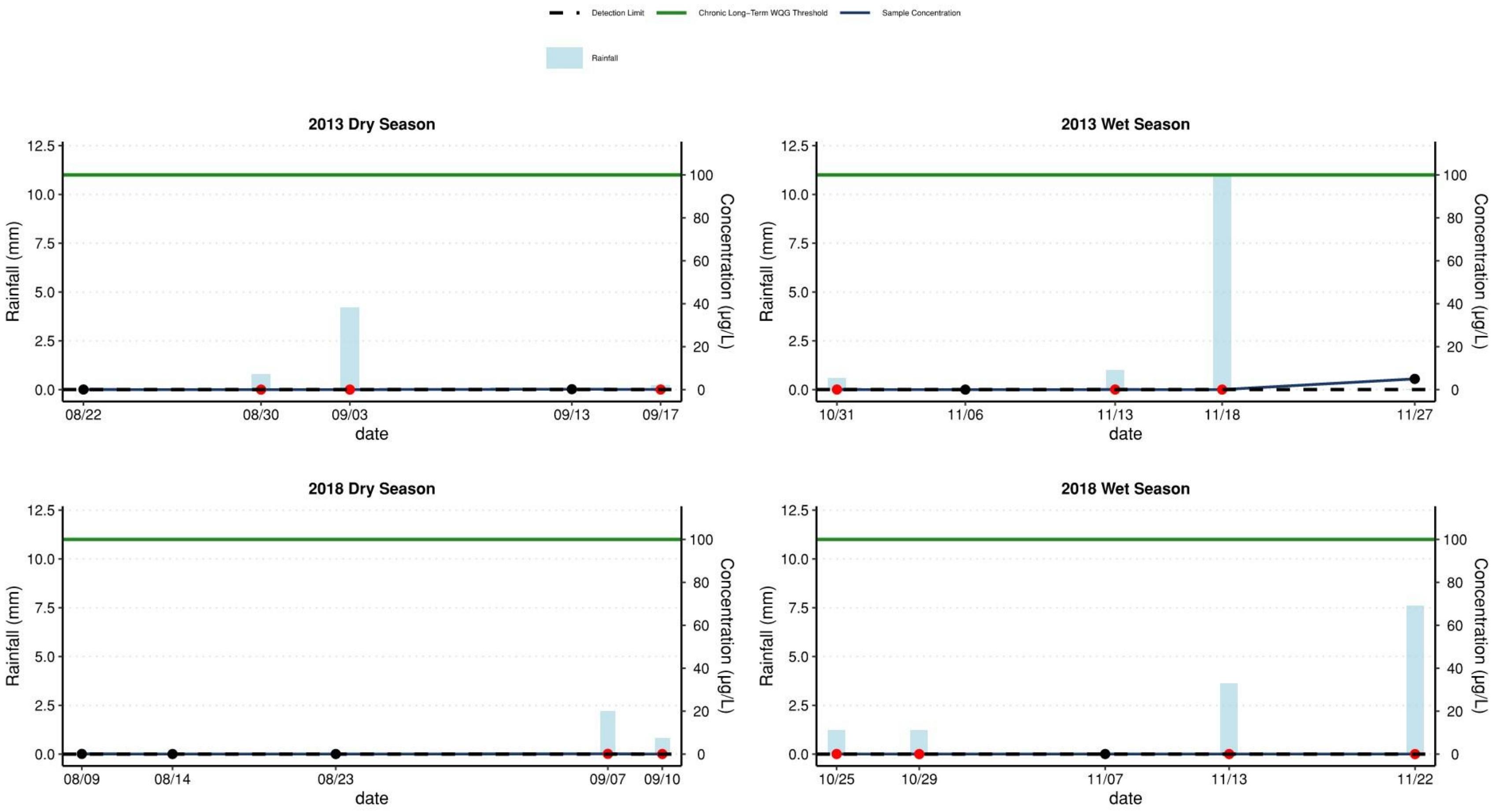
Arsenic (Metals – Metalloid)

Intensive sampling periods with rainfall and water quality guidelines

Note: Multiple samples on the same date have been averaged. All plots use consistent y-axis ranges for fair comparison.

Beryllium (Metals – Alkaline earth)

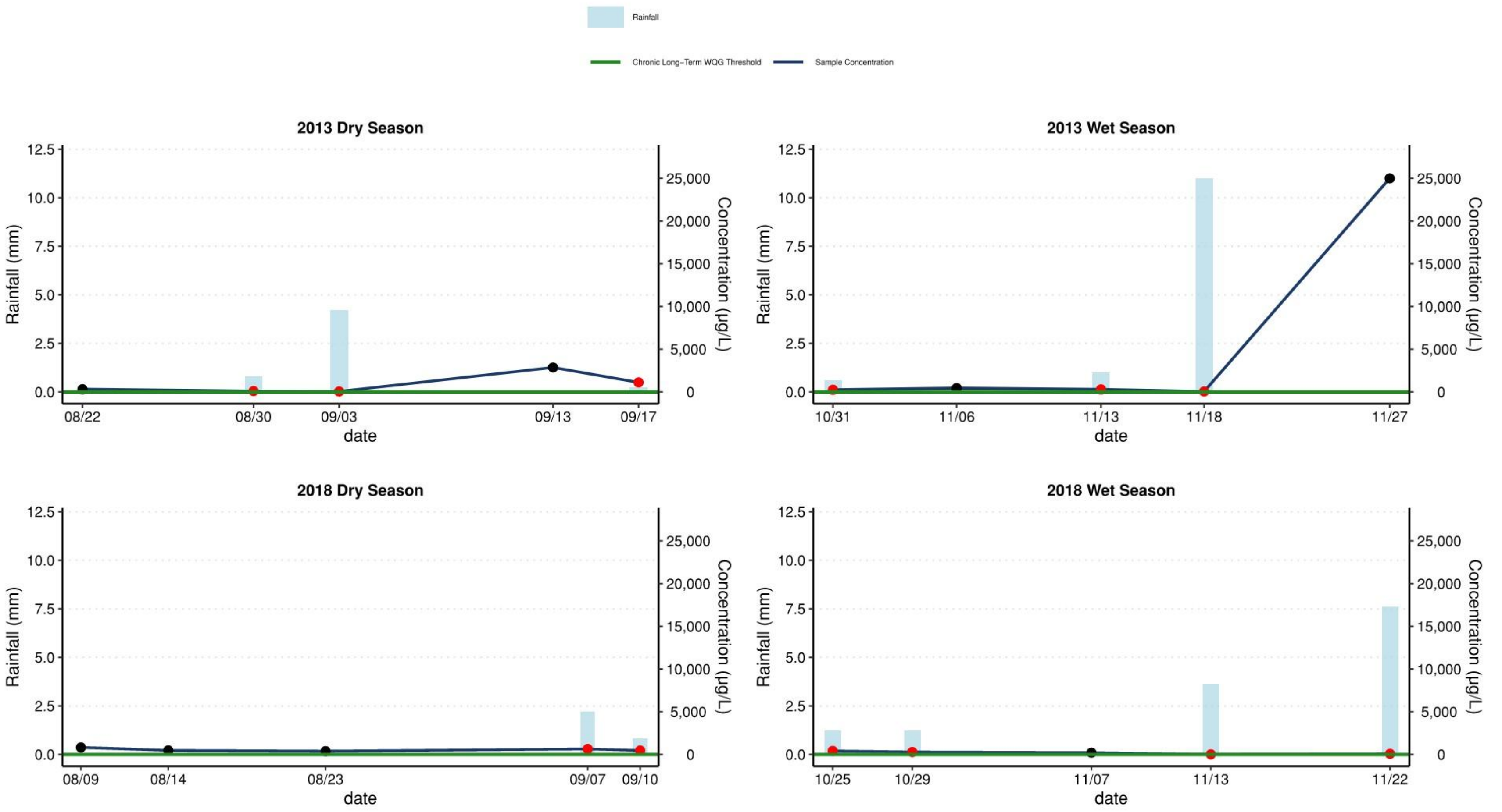
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y−axis ranges for fair comparison.

Boron (Metals – Metalloid)

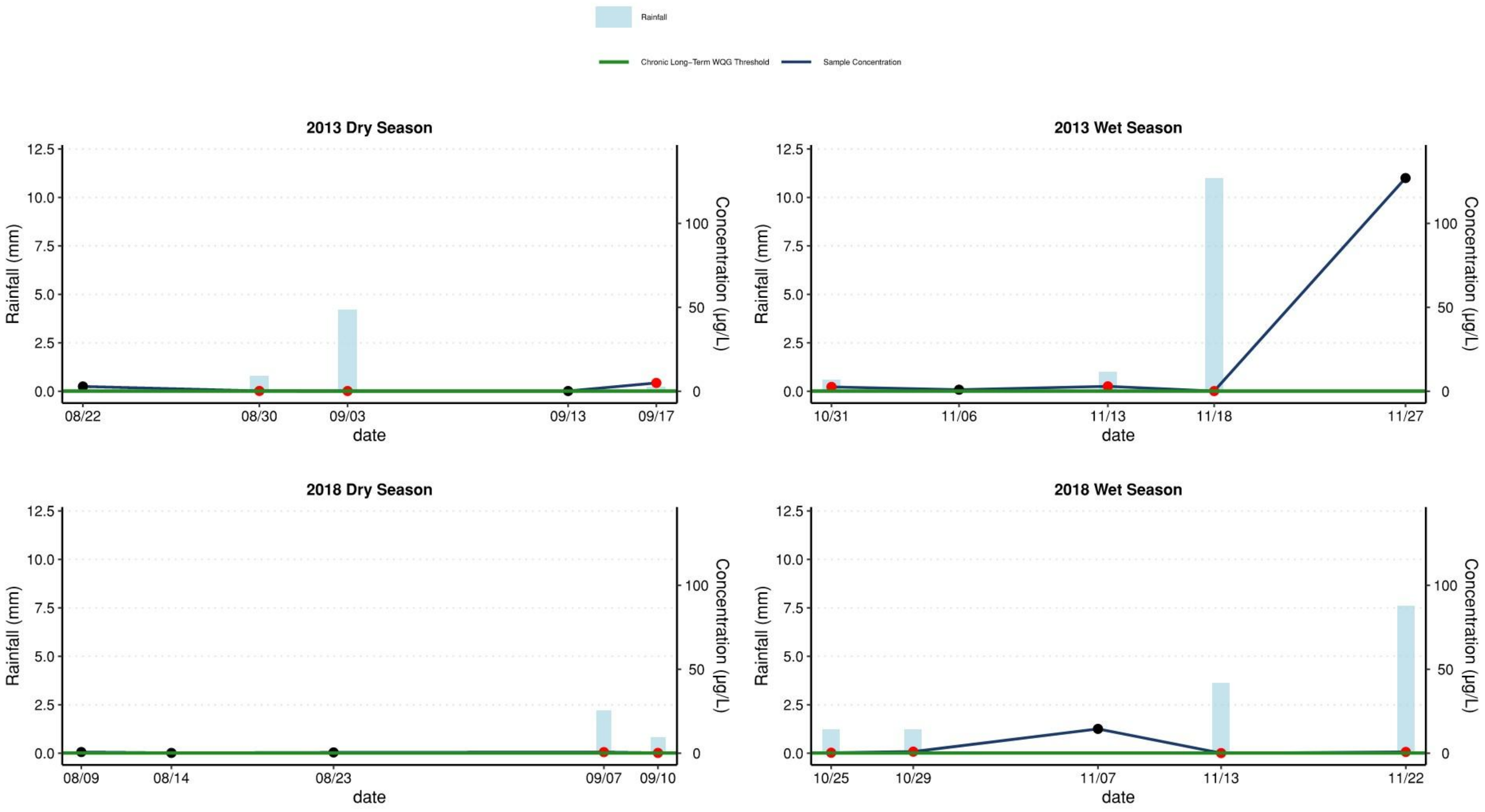
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Cadmium (Metals – Transition)

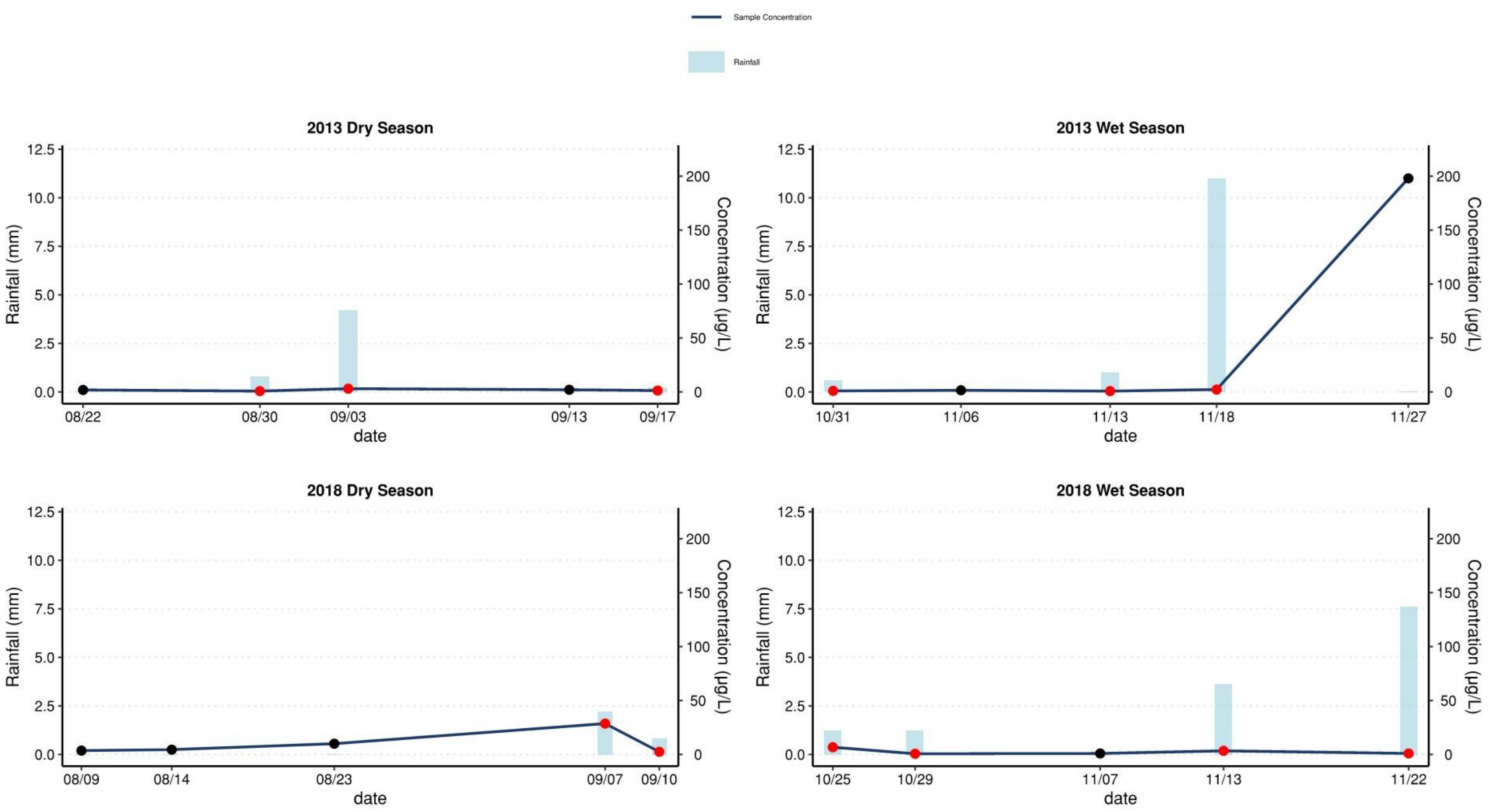
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Chromium (Metals – Transition)

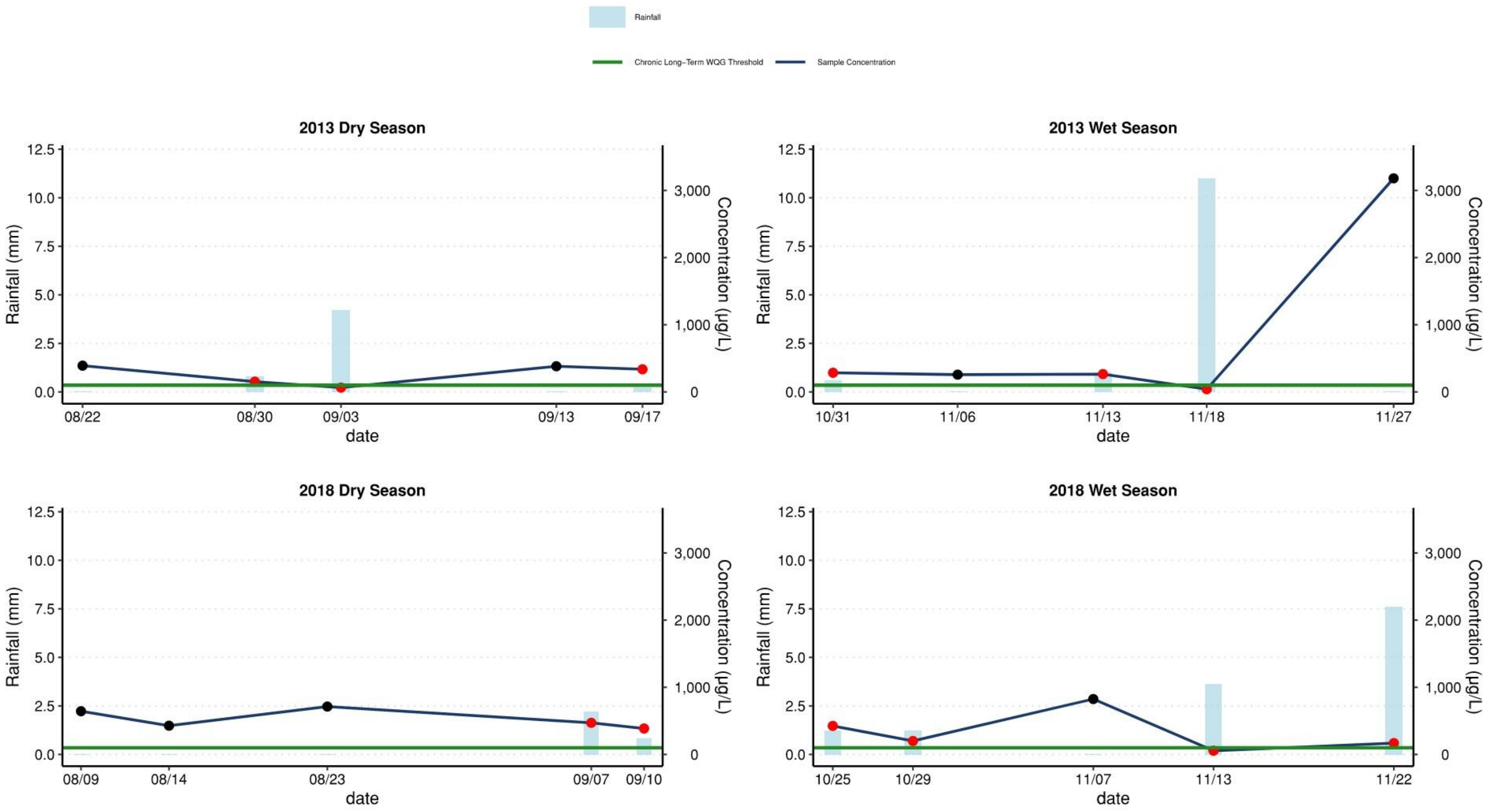
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Manganese (Metals – Transition)

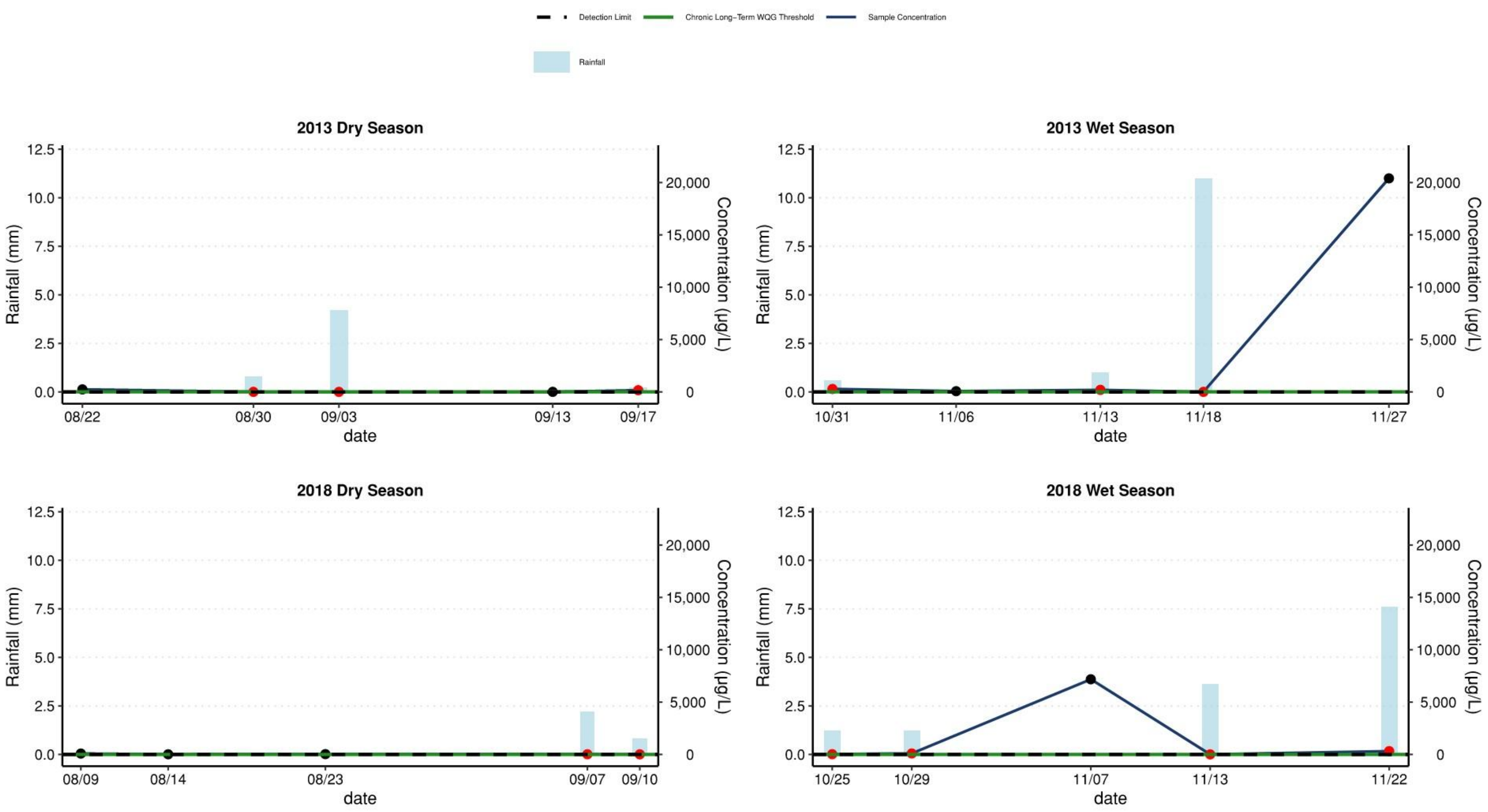
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Nickel (Metals – Transition)

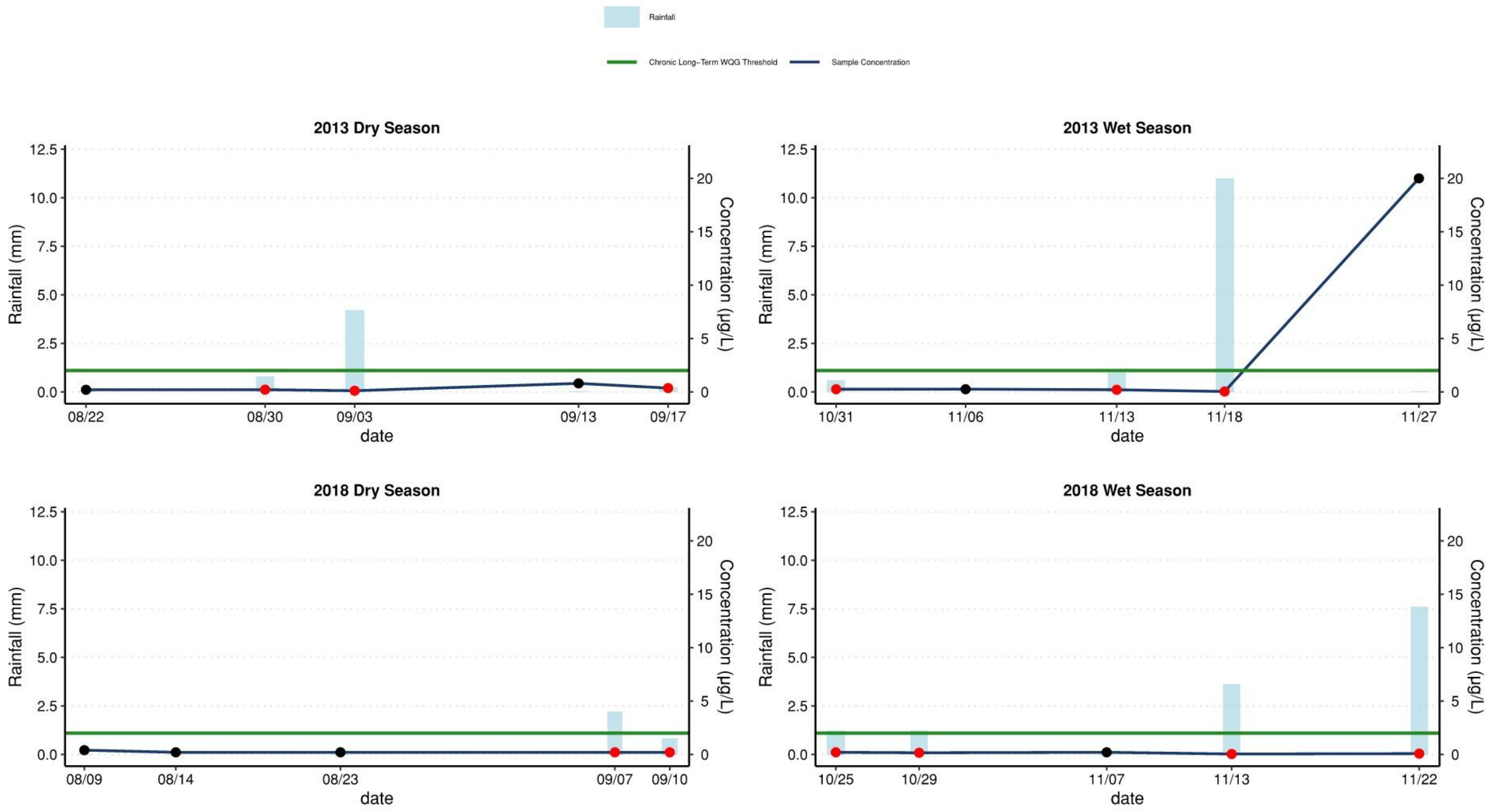
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y−axis ranges for fair comparison.

Selenium (Metals – Reactive non metal)

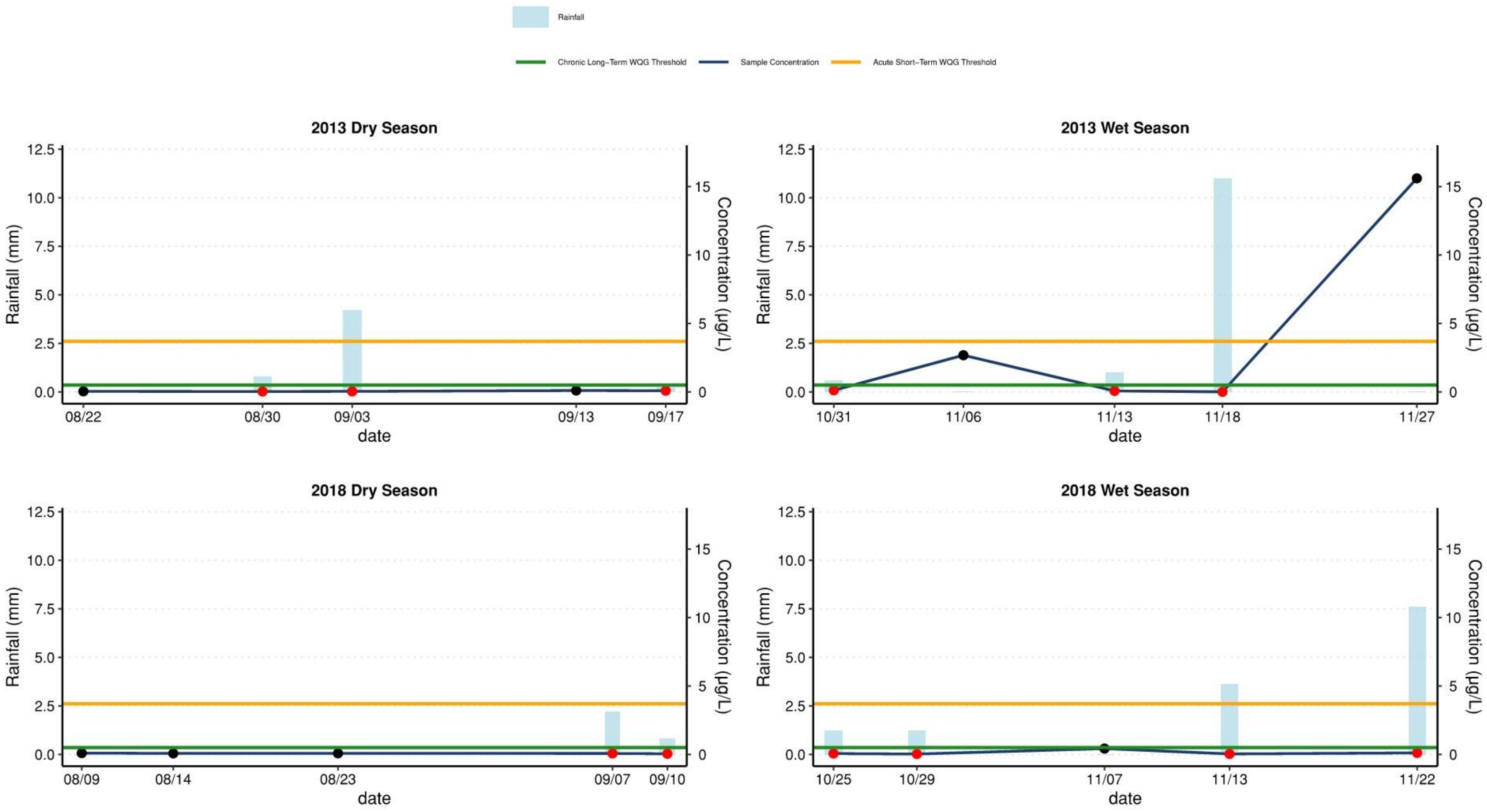
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

Silver (Metals – Transition)

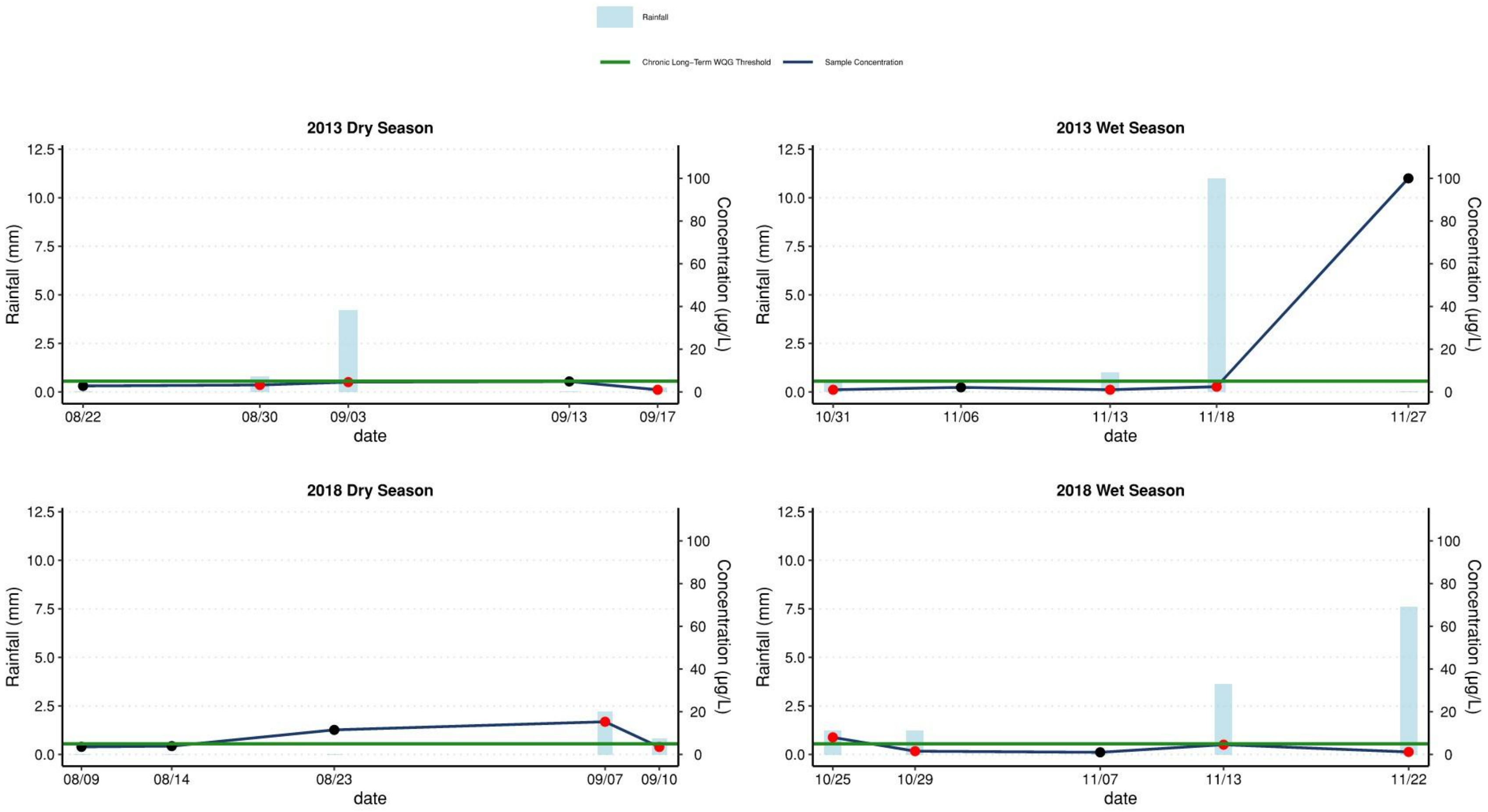
Intensive sampling periods with rainfall and water quality guidelines



Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

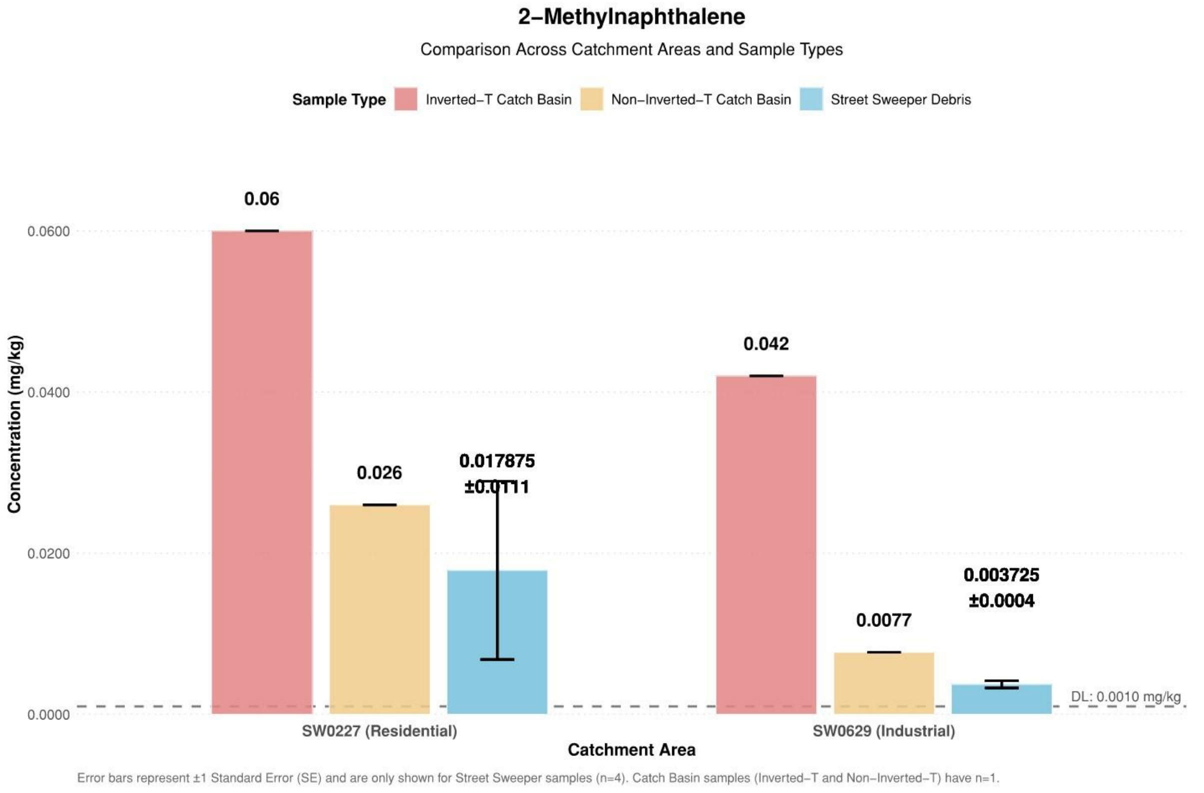
Vanadium (Metals – Transition)

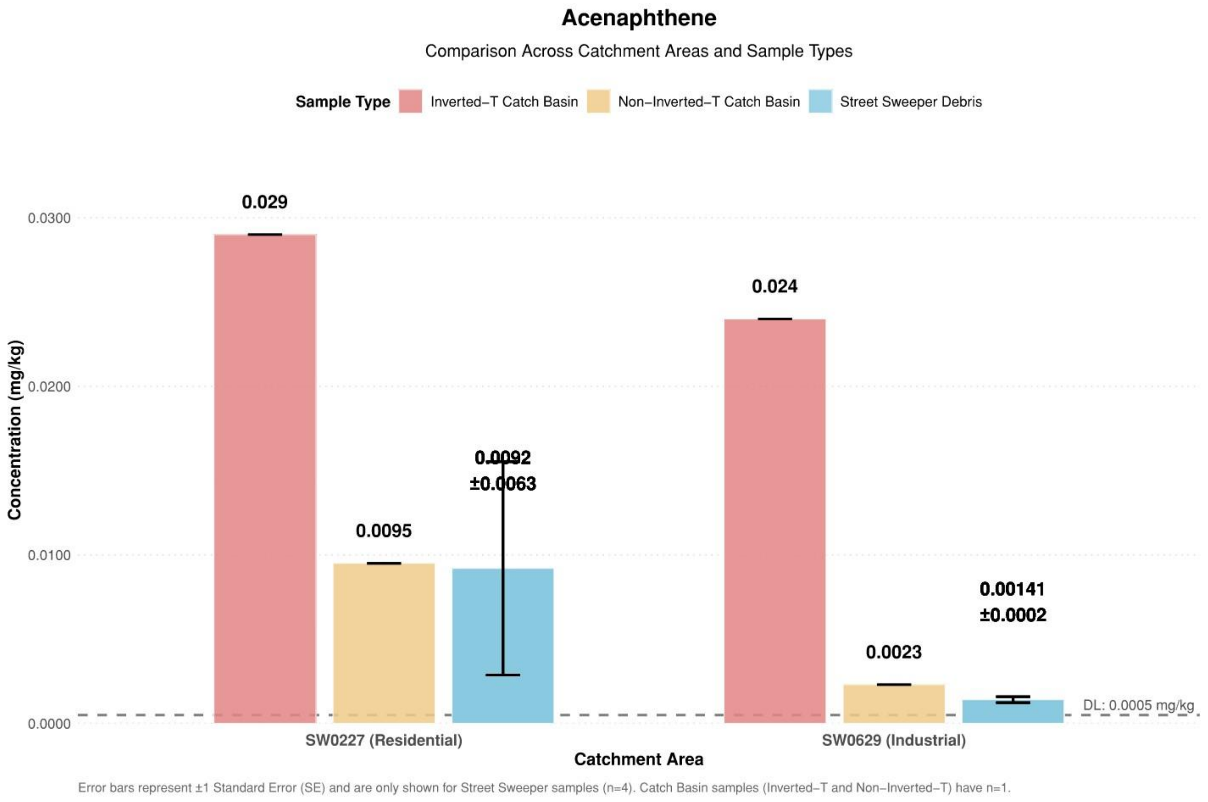
Intensive sampling periods with rainfall and water quality guidelines

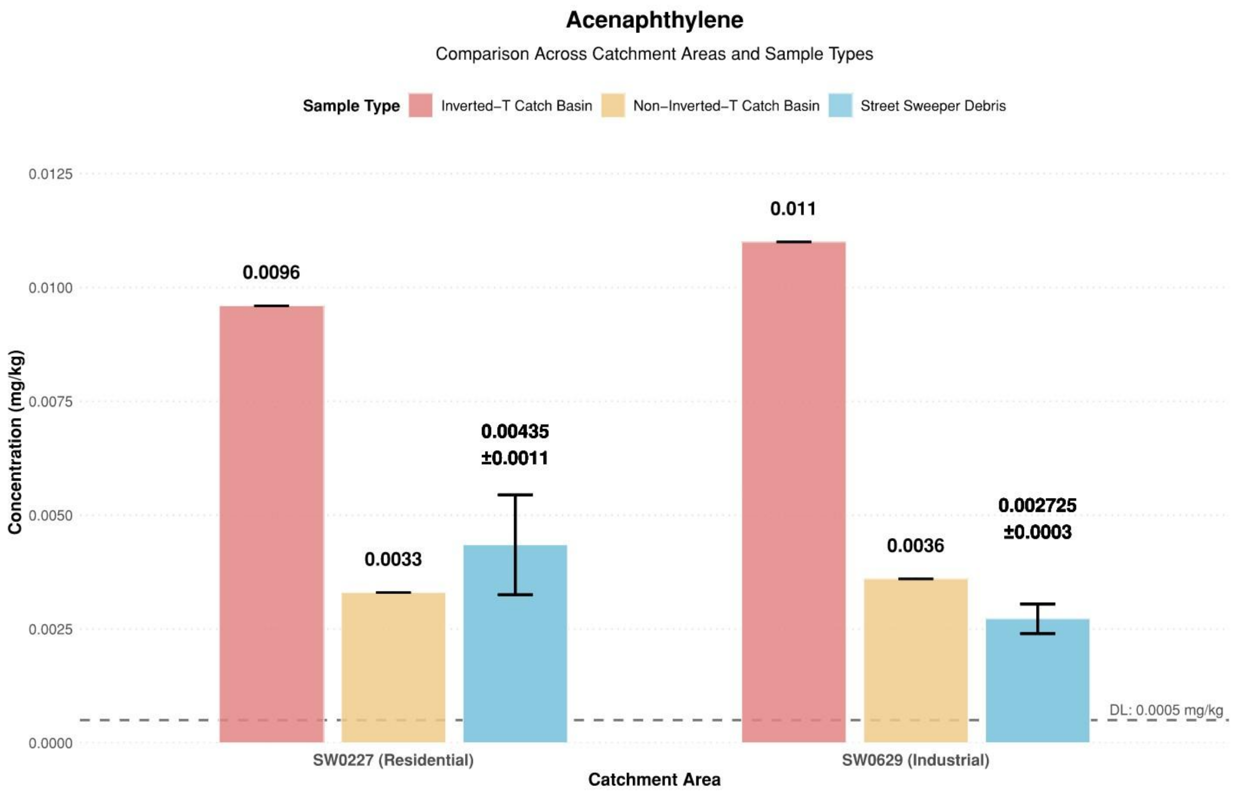


Note: Multiple samples on the same date have been averaged. All plots use consistent y–axis ranges for fair comparison.

STREET SWEEPING AND CATCH BASIN RESULTS FOR CATCHMENTS 227 AND 629

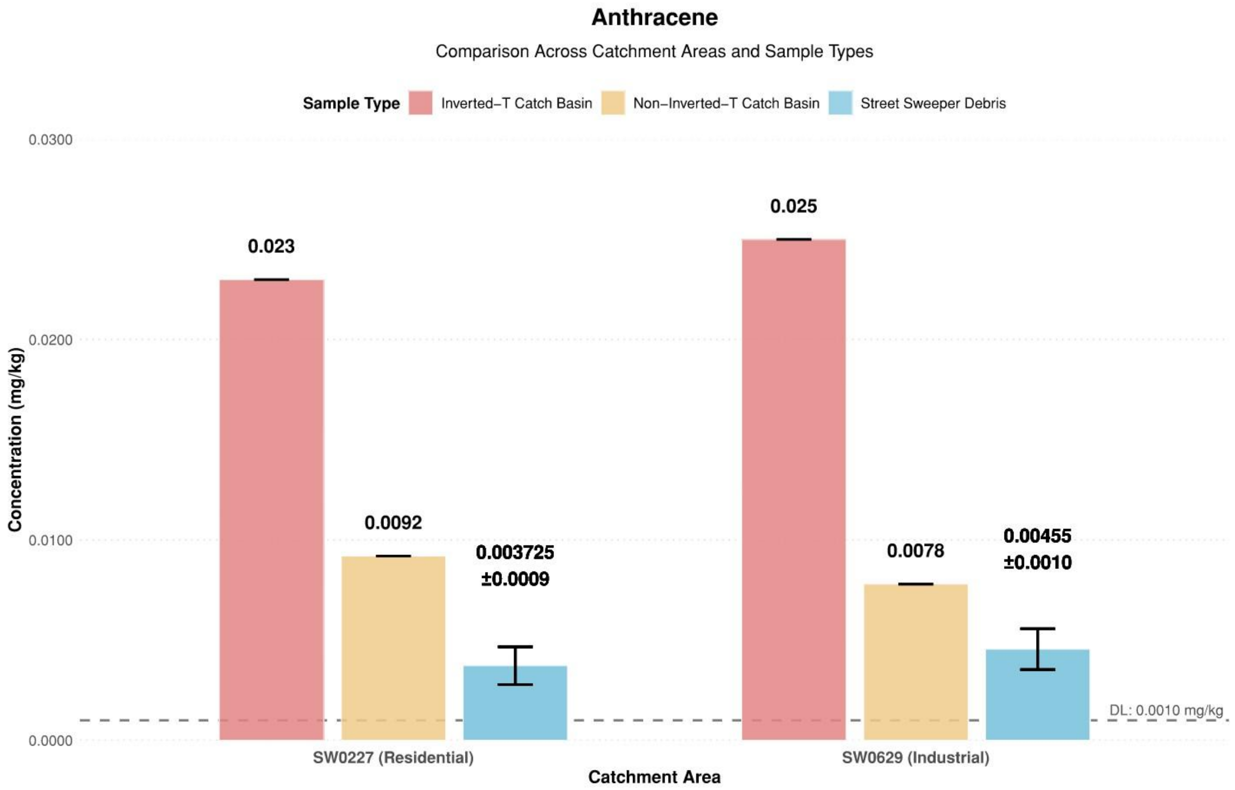





Acenaphthylene

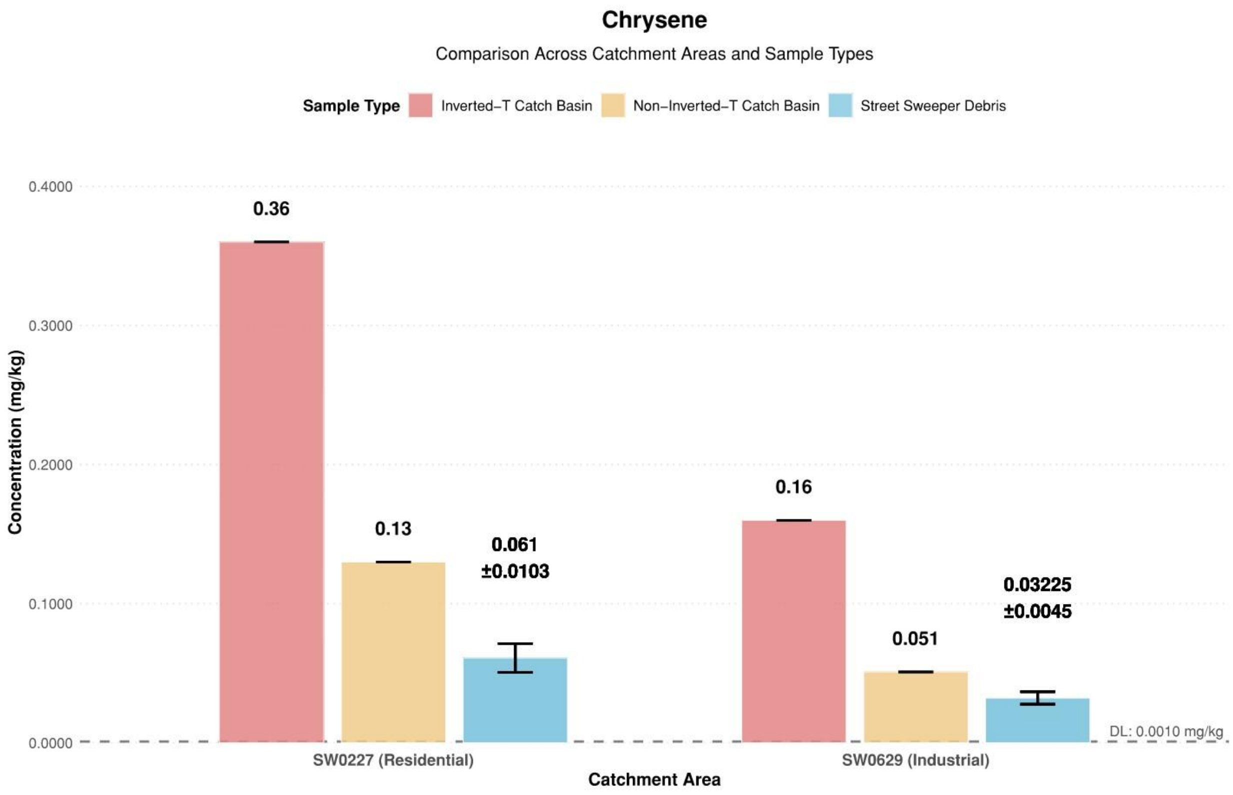
Comparison Across Catchment Areas and Sample Types

Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.

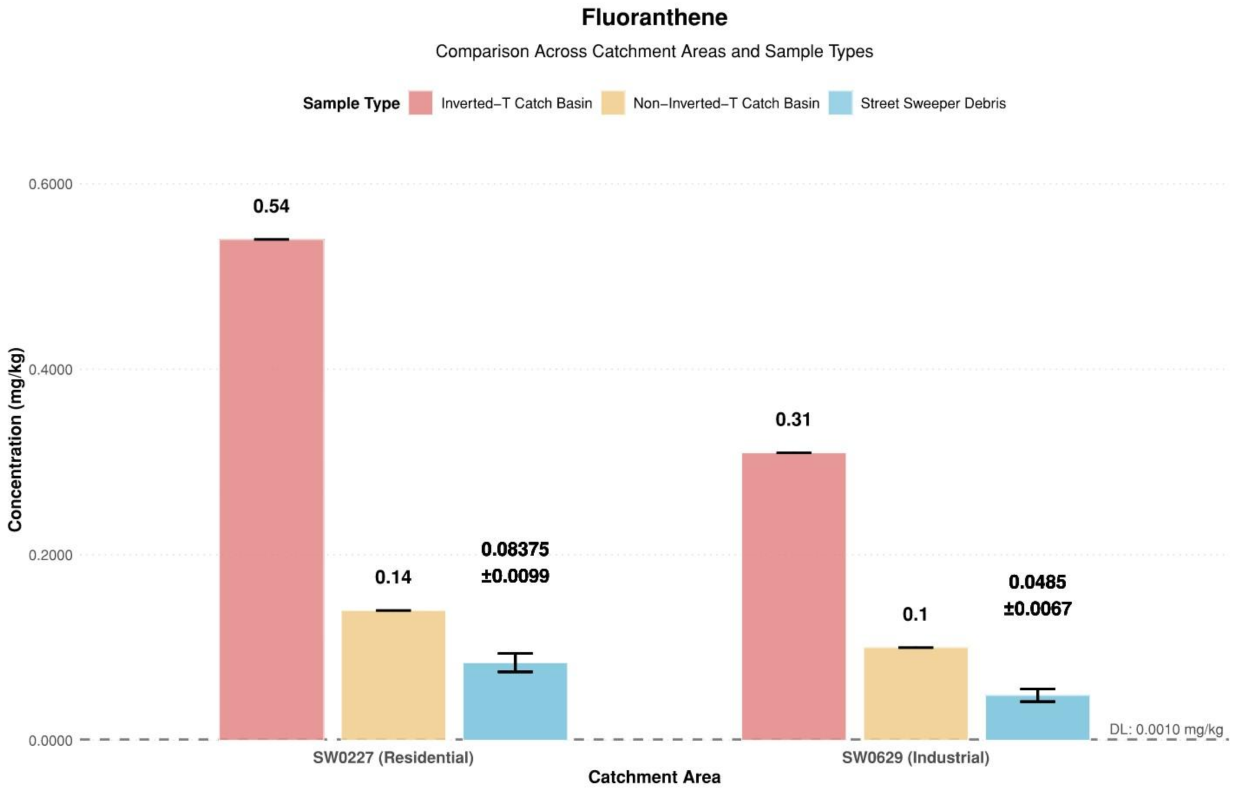

Anthracene

Comparison Across Catchment Areas and Sample Types

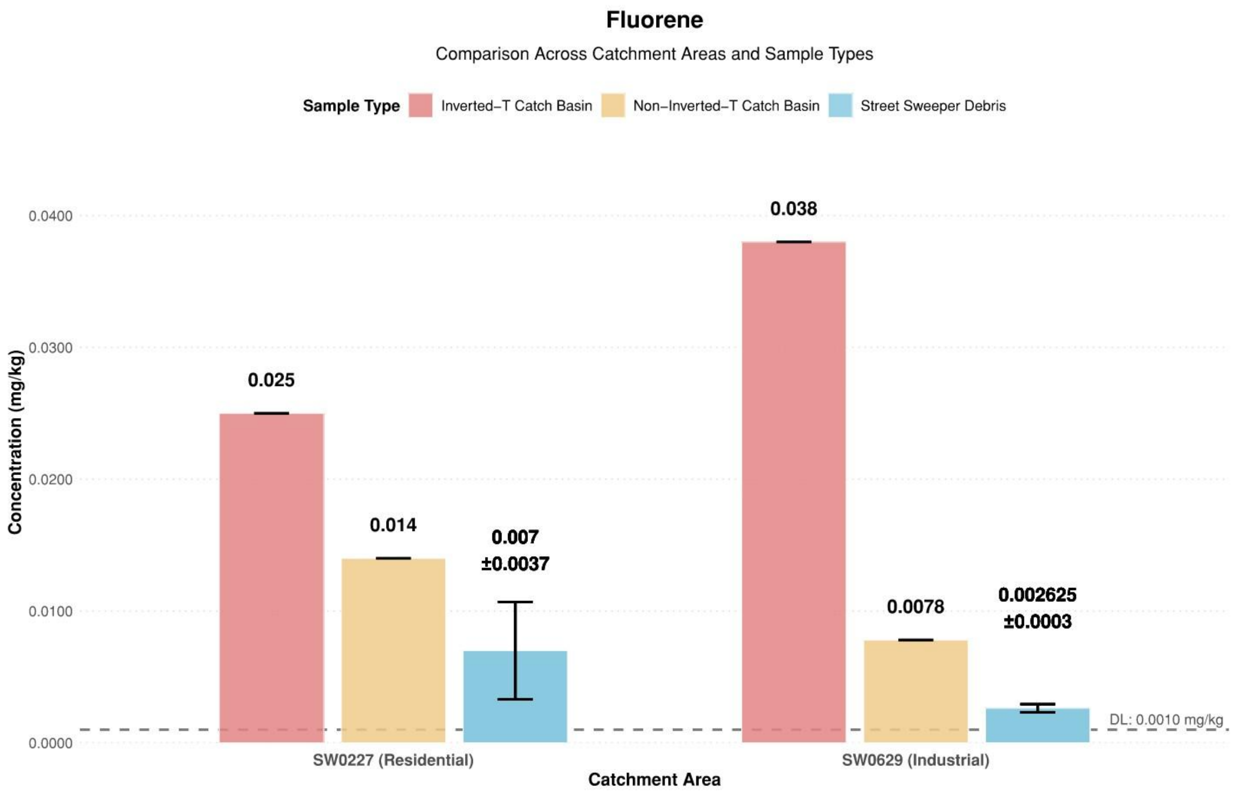
Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.



Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted–T and Non–Inverted–T) have n=1.



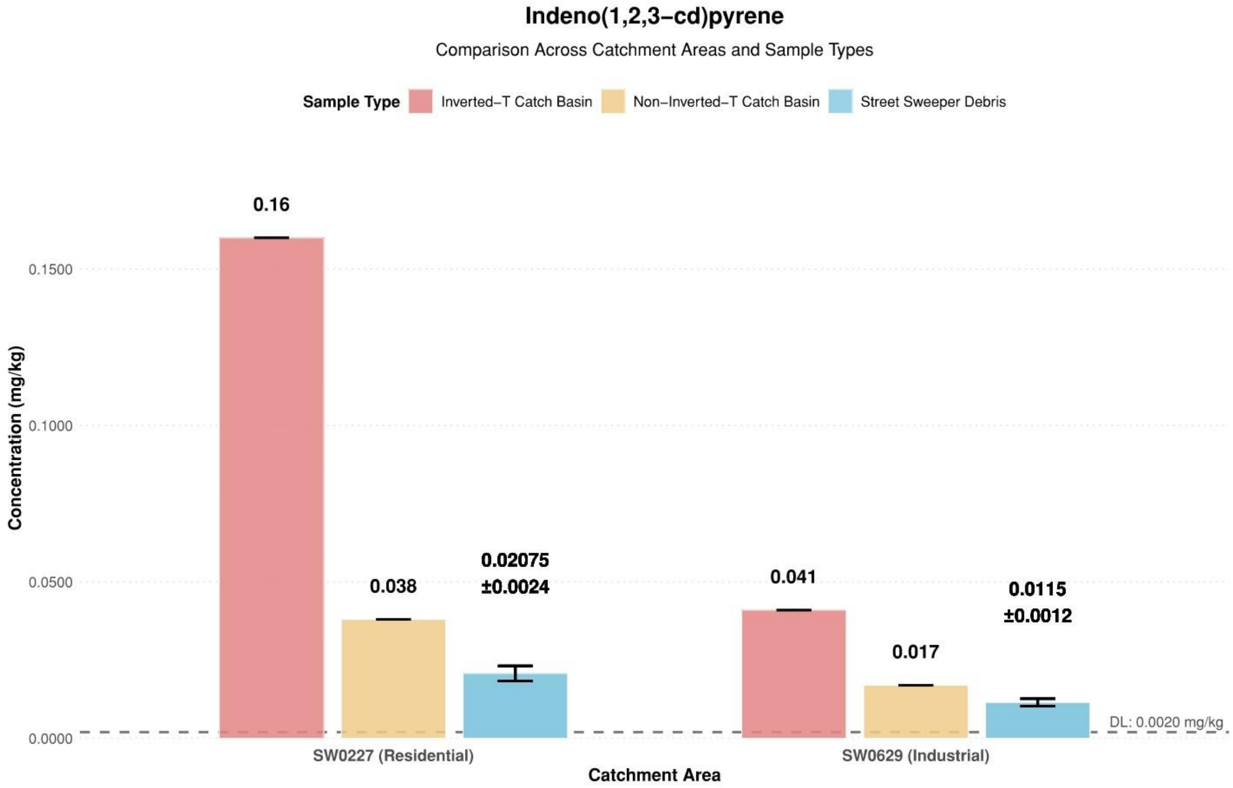
Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted–T and Non–Inverted–T) have n=1.



Fluorene

Comparison Across Catchment Areas and Sample Types

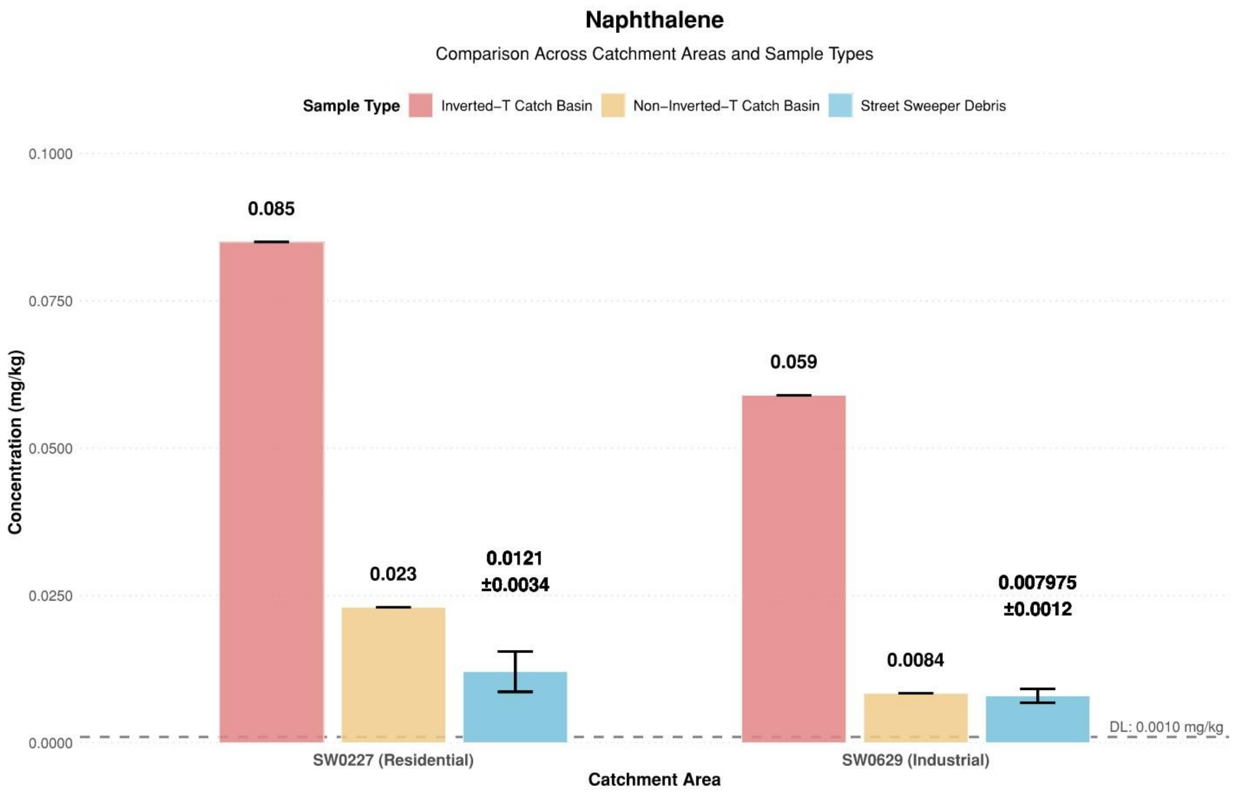
Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.



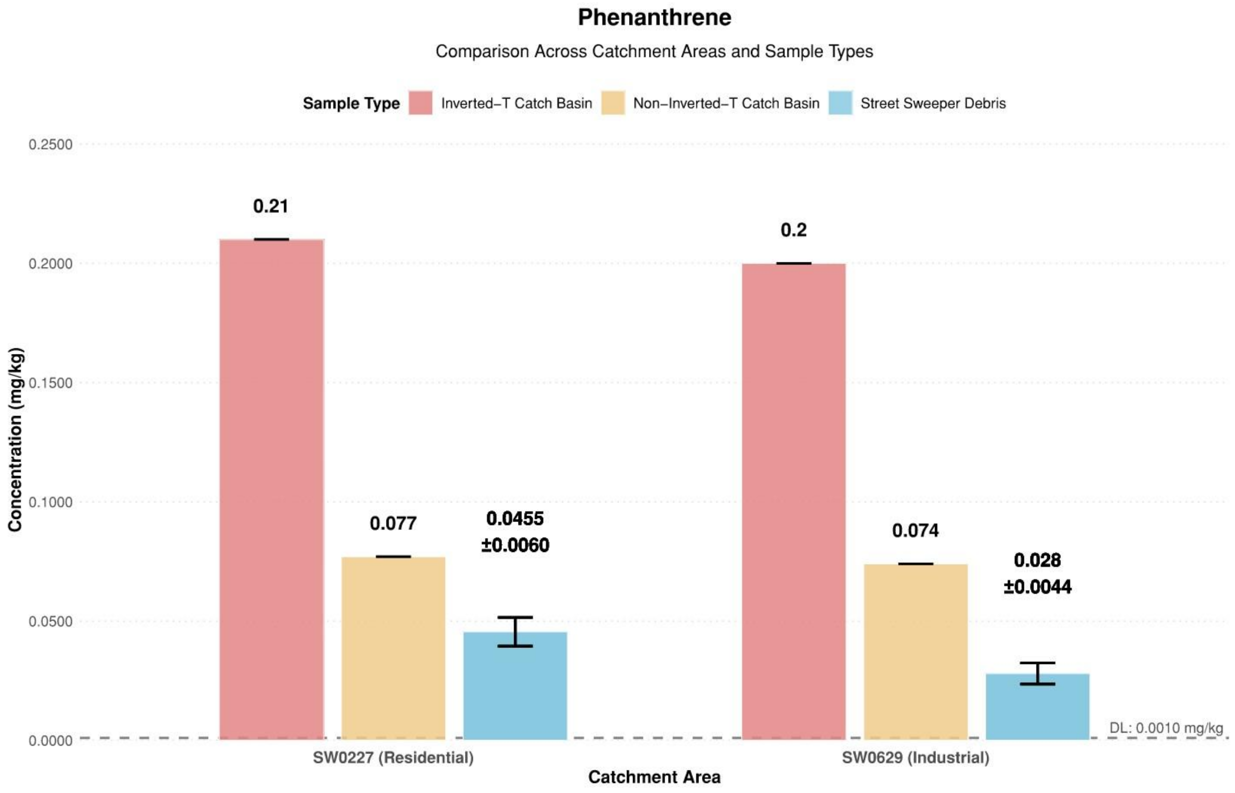
Indeno(1,2,3−cd)pyrene

Comparison Across Catchment Areas and Sample Types

Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.



Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.



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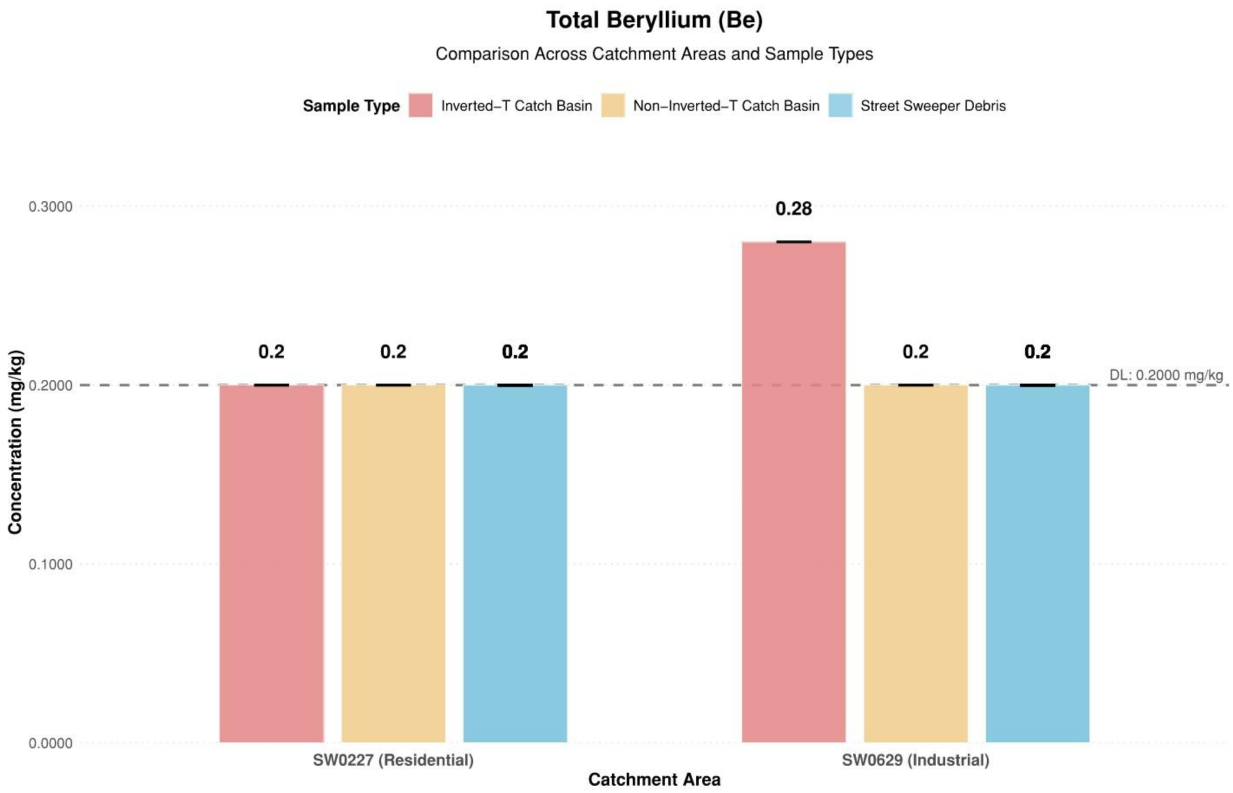

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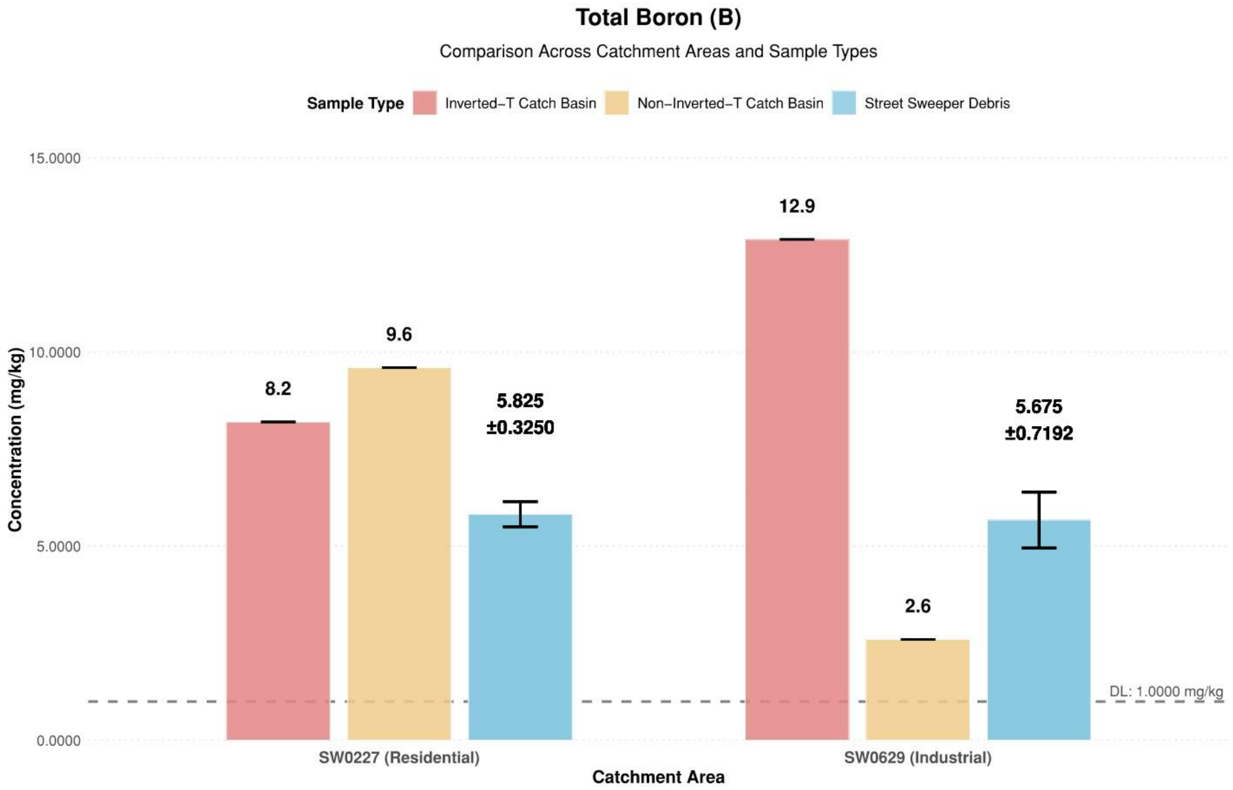

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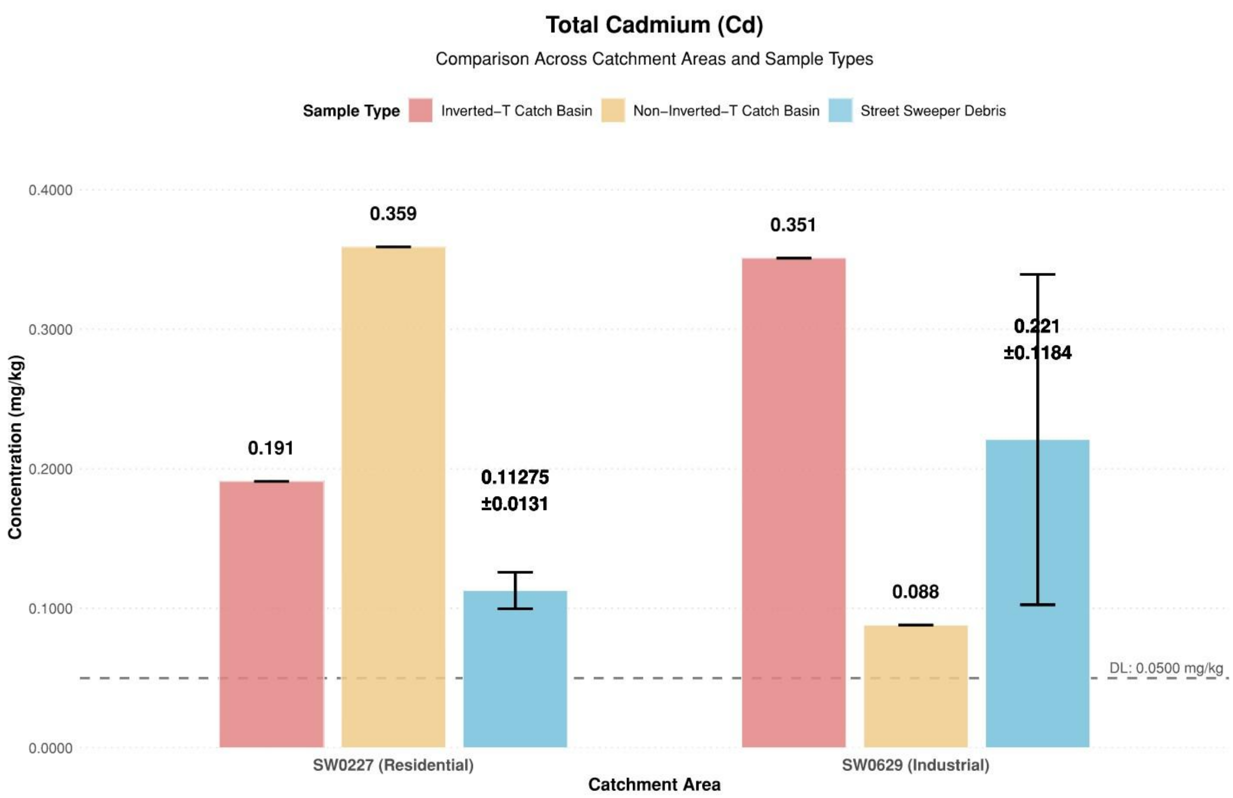
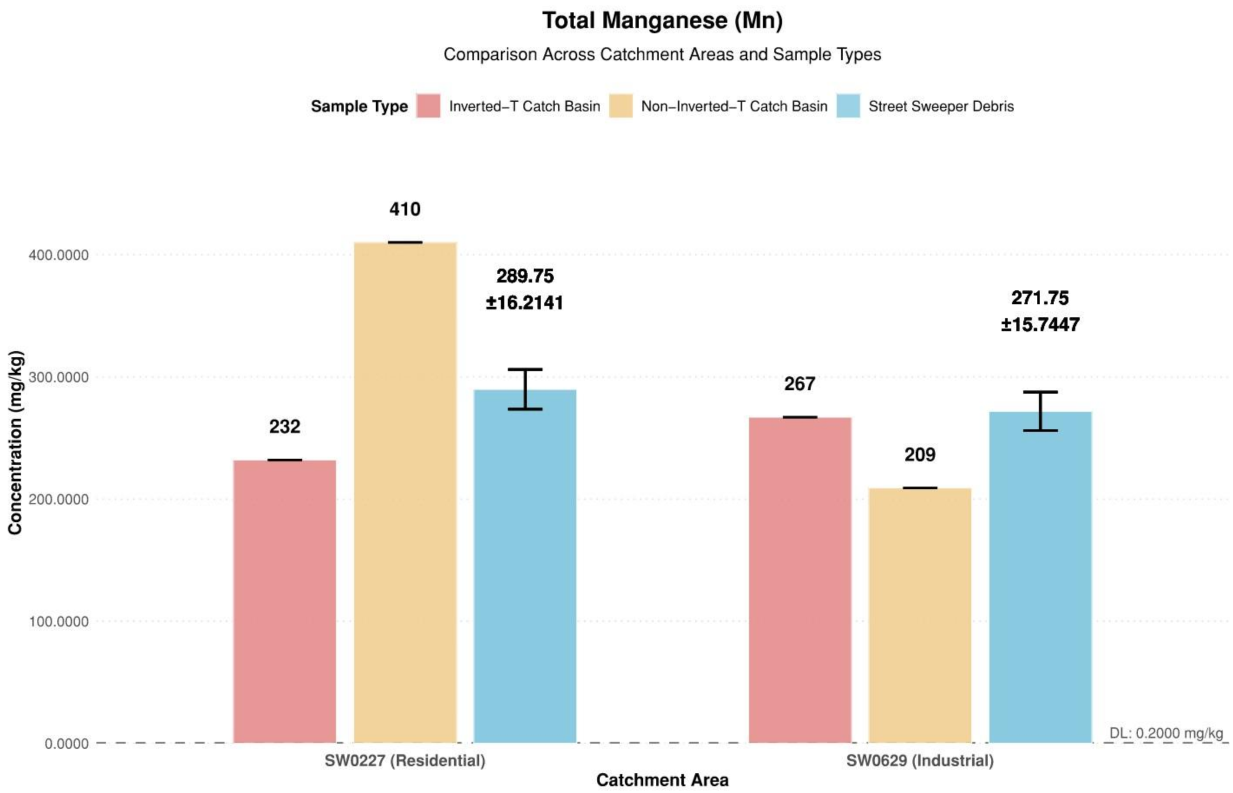


Total Cadmium (Cd)

Comparison Across Catchment Areas and Sample Types

Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.



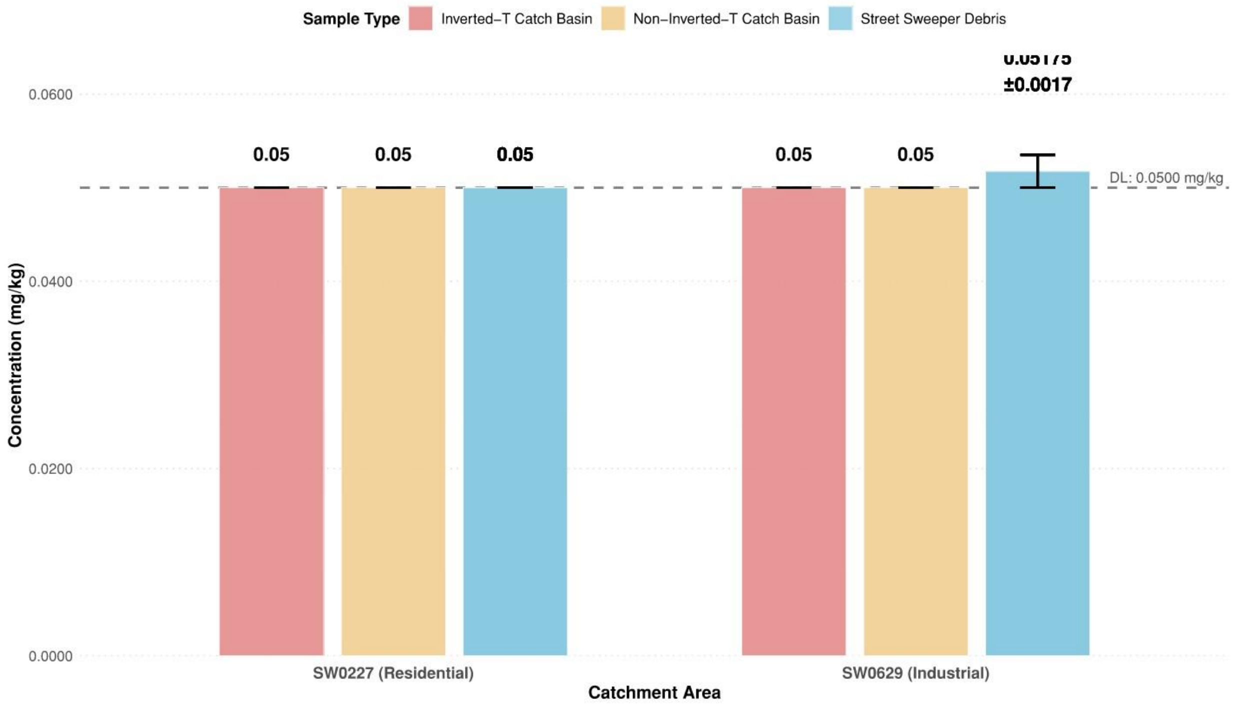
Total Manganese (Mn)

Comparison Across Catchment Areas and Sample Types

Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.

Total Mercury (Hg)

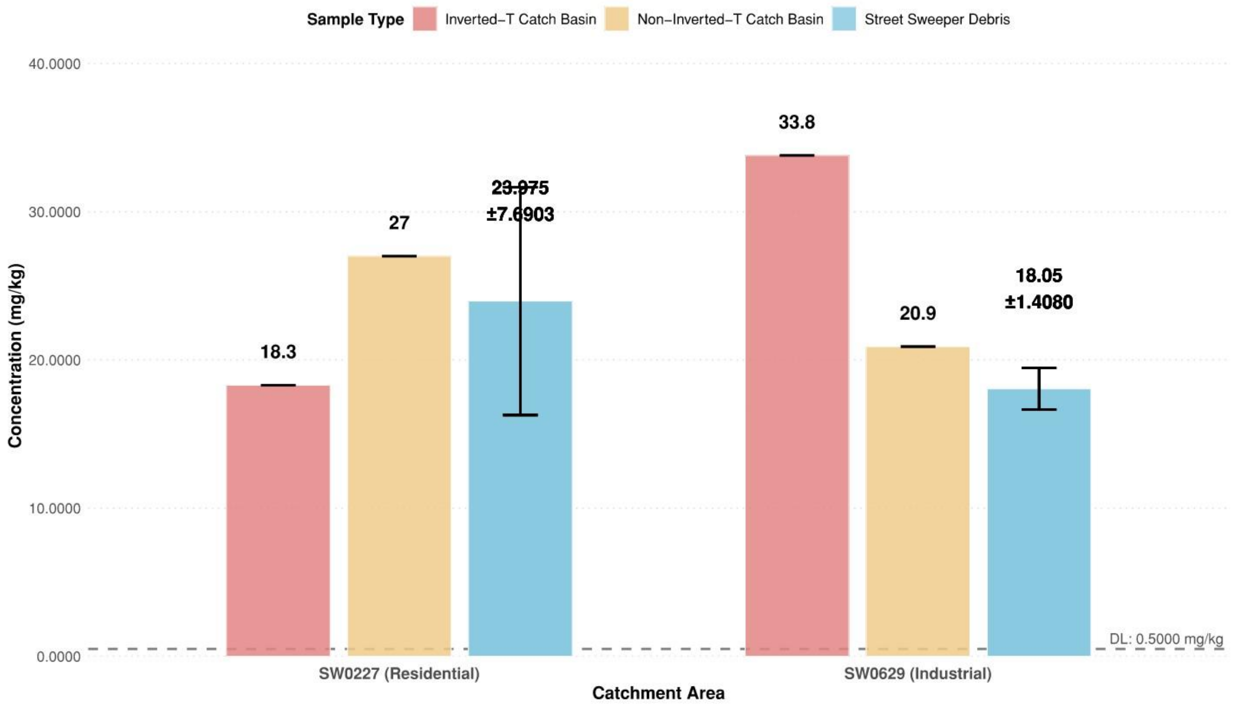
Comparison Across Catchment Areas and Sample Types



Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.

Total Nickel (Ni)

Comparison Across Catchment Areas and Sample Types



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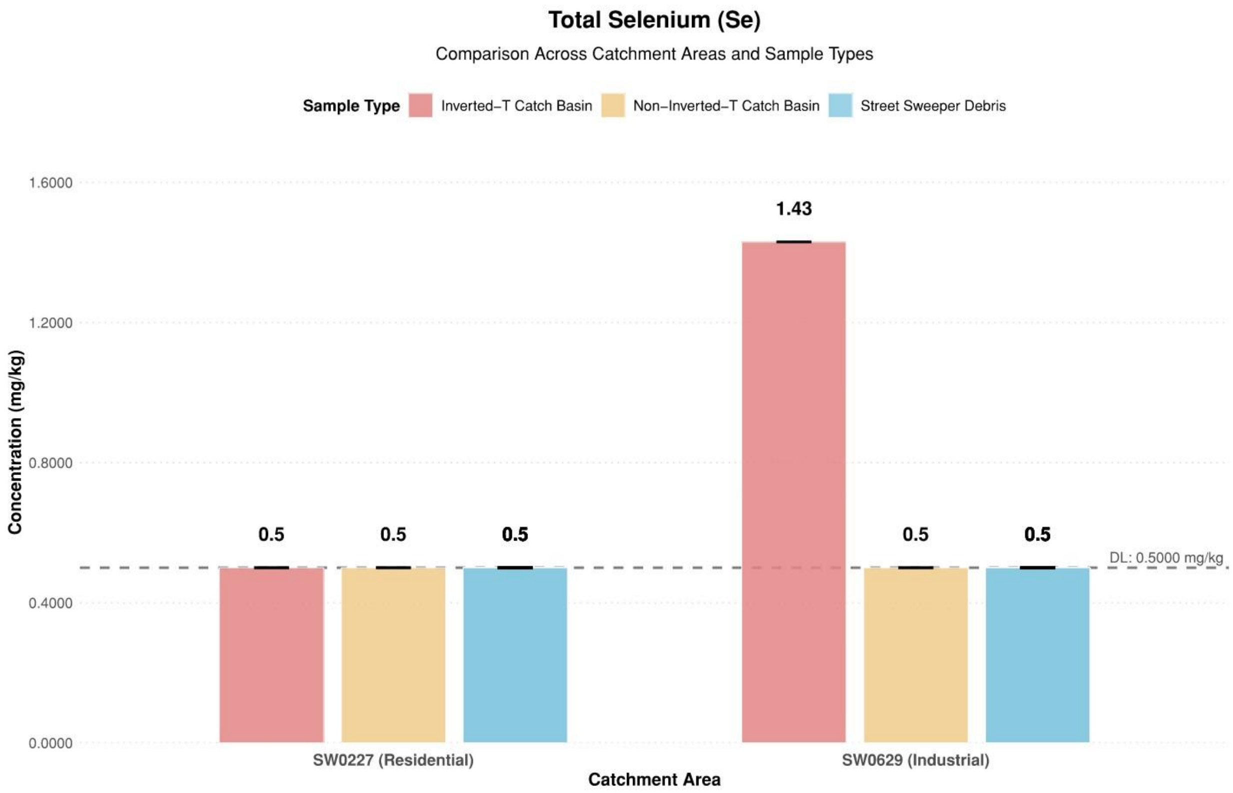
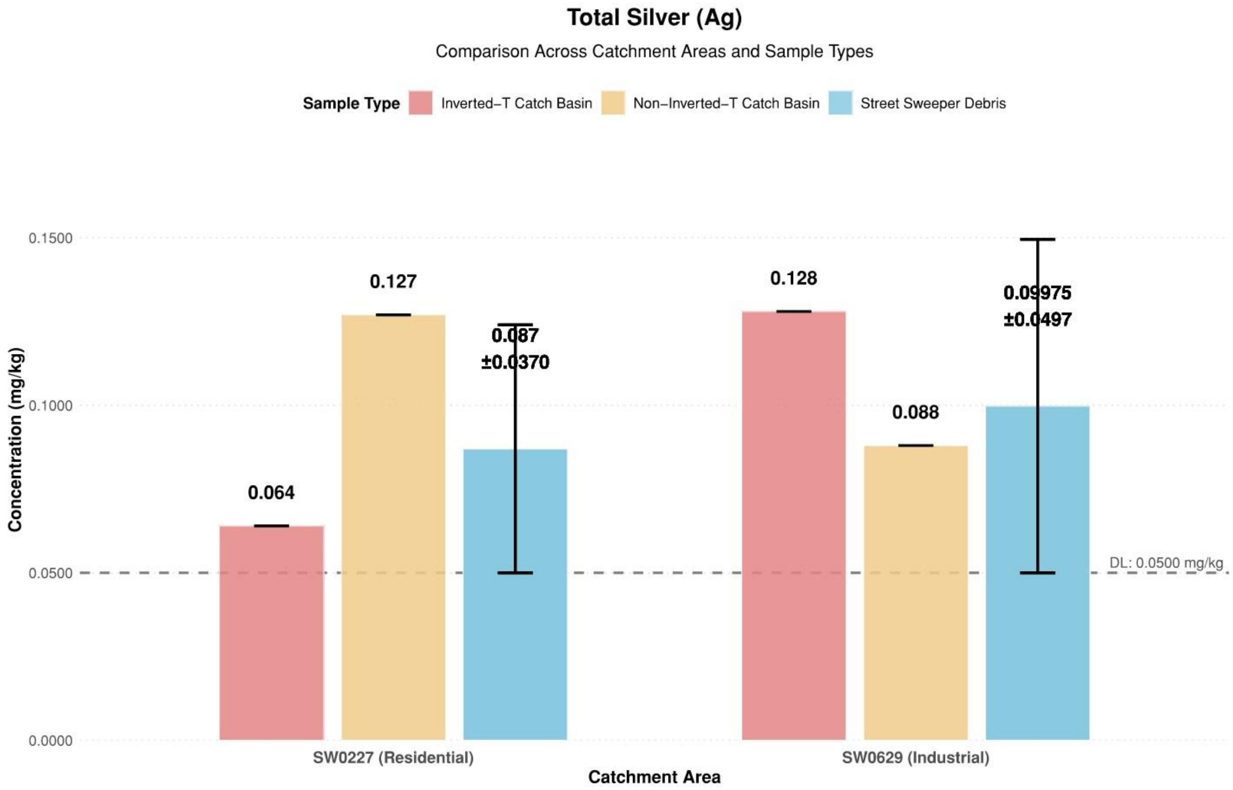


Total Selenium (Se)

Comparison Across Catchment Areas and Sample Types

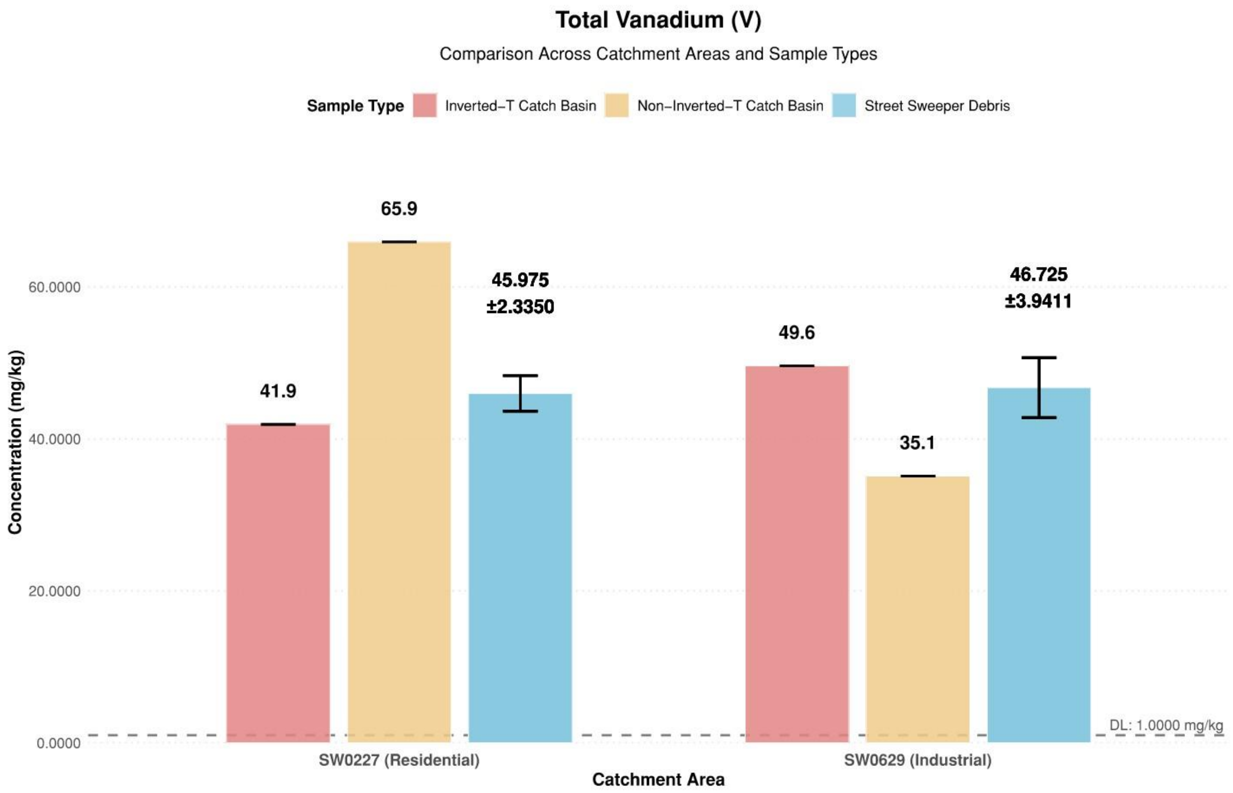
Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted–T and Non–Inverted–T) have n=1.



Total Silver (Ag)

Comparison Across Catchment Areas and Sample Types

Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted–T and Non–Inverted–T) have n=1.



Error bars represent ±1 Standard Error (SE) and are only shown for Street Sweeper samples (n=4). Catch Basin samples (Inverted−T and Non−Inverted−T) have n=1.