UNIVERSITY OF PENNSYLVANIA · PECI

Philadelphia Emerging Contaminants Initiative

Tracking PFAS, microplastics, and toxic elements from source water to the tap across Philadelphia's rivers, tributaries, and built environment.

A community-engaged water monitoring study spanning fourteen tributary sites and twenty-eight built-environment locations, examining three classes of emerging contaminants across the same sampling network, in the same city, during the same winter window.

Workshop hosts: Dr. Derek Ho & Dr. Samantha McBride, MEAM / CBE · The Water Center at Penn · CEET, Perelman School of Medicine

PFAS • MICROPLASTICS • TOXIC ELEMENTS • LAND USE • SOCIAL VULNERABILITY • SOURCE-TO-TAP

Contents

A study of emerging contaminants in Philadelphia's drinking water

THE TEAM

Who We Are

The PECI community fellows: Victoria Valdivia, Tess Vu, Pawan Khanal, and Prajwal Poonacha.

Victoria Valdivia

BIOENGINEERING · SEAS

An undergraduate majoring in Bioengineering and minoring in Legal Studies and History at the University of Pennsylvania. Her passion lies at the intersection of science, law, and policy; she is currently leading a policy-memo working group to advocate for greater PFAS protections at the state level. She hopes to work as a toxic tort lawyer after working in the cancer-engineering field.

Tess Vu

MUSA CANDIDATE 2026 · STUART WEITZMAN SCHOOL OF DESIGN

A geospatial engineer and GeoAI researcher interested in exploring spatial ML systems that make infrastructure inequity legible at city scale. Her specialization sits at the intersection of computer vision, remote sensing, and spatiotemporal modeling — applied to climate science, environmental health, urban heat, and physical utility networks. She is PECI's Esri technology and open-source geospatial expert.

Pawan Khanal

MES CANDIDATE 2027 · LPS

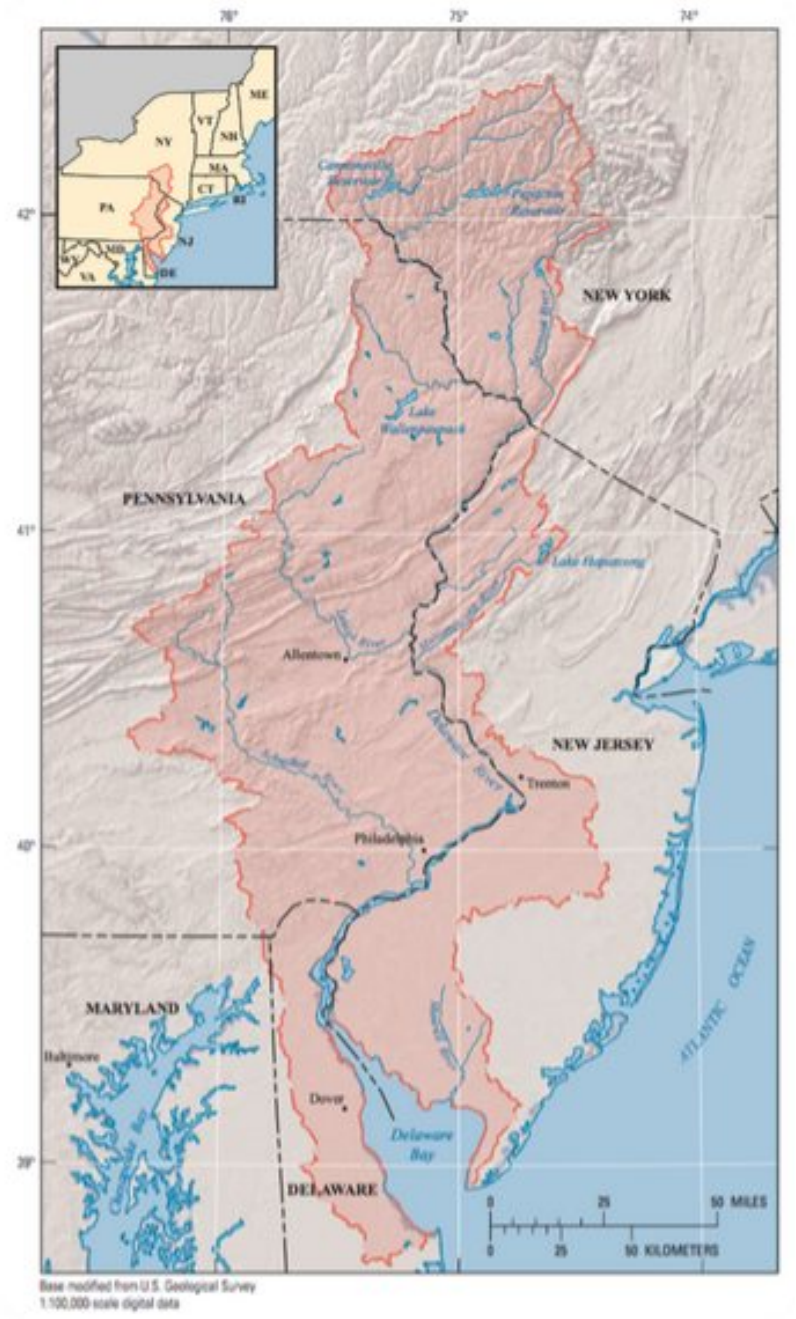
A graduate student studying Environmental Studies. His broader interests are in water resources, spatial analysis, and data-driven environmental work. He hopes to work at the intersection of data, maps, and environmental problem-solving, especially around water-resources development and management.

Prajwal Poonacha

MECHANICAL ENGINEERING AND APPLIED MECHANICS · SEAS

BACKGROUND

Why This Matters



USGS Delaware River Basin.

Across the United States, emerging contaminants are being detected in drinking-water systems that were never designed to remove them. The EPA's most recent national monitoring effort, the Fifth Unregulated Contaminant Monitoring Rule (UCMR 5), confirmed PFAS detections in public water systems serving more than 100 million Americans. In 2024, the agency finalized the first-

ever national drinking-water standard for six PFAS compounds, setting enforceable maximum contaminant levels at single-digit parts per trillion. At the same time, federal investment in chemical-safety infrastructure faces uncertainty as the administration's fiscal-year-2026 budget proposed eliminating the Chemical Safety and Hazard Investigation Board entirely, though Congress ultimately maintained its funding.

For Philadelphia, however, the story is not abstract — it runs through the rivers that supply the city's drinking water.

Contamination Already Upstream

Twenty miles north of Philadelphia, the former Naval Air Station Joint Reserve Base Willow Grove and the adjacent Horsham Air Guard Station in Montgomery County used aqueous film-forming foam (AFFF) — which contains PFAS — for decades of fire-training exercises. Groundwater monitoring at those sites has detected PFAS concentrations orders of magnitude above the new federal limits; on-site groundwater at Willow Grove has been measured at over 300,000 parts per trillion, compared to the EPA's 4 ppt maximum contaminant level (MCL) for PFOS. Contaminated groundwater plumes have migrated into local wells and surface streams across Bucks and Montgomery Counties, affecting an estimated 85,000 residents.

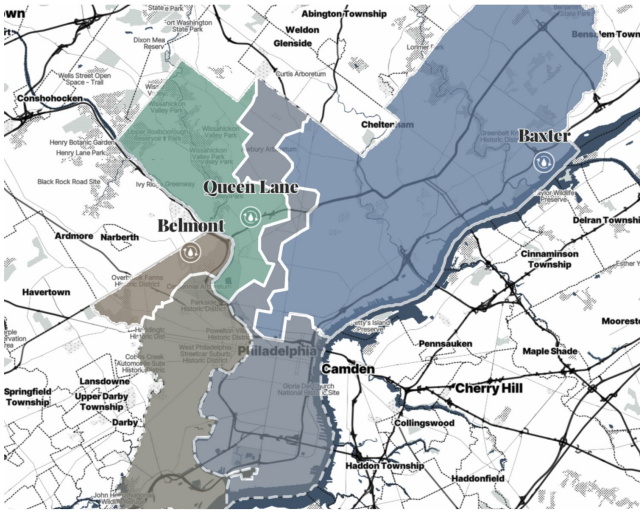
Public water systems in Warminster, Warrington, and Horsham Townships have installed granular activated-carbon treatment specifically to remove PFAS from their supplies. The broader Delaware and Schuylkill watershed network connects these contaminated areas to the same river systems from which Philadelphia draws its supply.

Closer to home, Philadelphia experienced its own acute contamination event on March 24, 2023, when an equipment failure at the Trinseo Altuglas facility in Bristol Township, Bucks County, released approximately 8,100 gallons of a latex-emulsion solution into Otter Creek, which flows into the Delaware River roughly 13 miles upstream of the Baxter Water Treatment Plant. PWD shut the Baxter intakes as a precaution, issued a tap-water advisory, and residents across the city cleared store shelves of bottled water within hours. Subsequent testing detected no contaminants in the treated supply, and the advisory was lifted within days — but the event demonstrated how quickly public confidence can erode when contamination enters the source-water conversation.

Philadelphia's System and Exposure

Outflow along Cobbs Creek near a sampling site.

Philadelphia is one of the largest cities in the country that relies entirely on surface water for its drinking supply — no groundwater backup and no aquifer reserve. What enters the Schuylkill and Delaware Rivers upstream is what arrives at the intakes of the city's three treatment plants: Baxter, Queen Lane, and Belmont.



Treatment-plant service areas: Baxter, Queen Lane, and Belmont.

Finished drinking water at the tap.

PWD's own UCMR 5 monitoring results, reported in 2024, confirmed detectable concentrations of multiple PFAS compounds in finished water leaving all three treatment plants. These concentrations were below the new federal MCLs — so the question is not whether these contaminants are present in Philadelphia's water system, as the monitoring record has already answered that.

Three classes of emerging contaminants of particular concern in urban watersheds

Per- and Polyfluoroalkyl Substances (PFAS) are a family of synthetic chemicals used in non-stick coatings, food packaging, and firefighting foams. Their carbon–fluorine bonds resist environmental degradation, earning them the name "forever chemicals." PFAS have been associated with immunological, endocrine, and carcinogenic effects at parts-per-trillion concentrations. Philadelphia's source waters receive PFAS inputs from upstream industrial discharge, wastewater-treatment effluent, and legacy military sites.

Microplastics (MP) are synthetic polymer fragments smaller than 5 millimeters, which enter waterways through stormwater runoff, textile-fiber shedding, and the breakdown of larger plastic debris. In a combined sewer system like Philadelphia's, storm events flush accumulated surface debris directly into waterways, potentially spiking microplastic loads in receiving streams. These particles also act as vectors, adsorbing heavy metals and organic pollutants onto their surfaces and transporting them through aquatic systems.

Toxic Elements — including lead, cadmium, arsenic, and copper — originate from industrial discharge, legacy contamination in soils, and aging infrastructure. Philadelphia's water-distribution network includes sections of pipe dating to the early 20th century, and lead service lines remain present in portions of the system. At elevated concentrations, these metals pose acute and chronic risks to neurological, renal, and developmental health. Unlike PFAS, which primarily

enter through source water, metals can also be introduced after treatment through corrosion and leaching within the distribution network itself.

THE SHARED CHARACTERISTIC: PERSISTENCE

Despite their differences and internal diversity, these three contaminant classes do not readily degrade, and they accumulate in sediments, organisms, and infrastructure over time. What distinguishes this project is that it examines all three simultaneously, across the same sampling network, in the same city, during the same time window.

FRAMING

Three Questions

Philadelphia's drinking water begins as surface water.

The Delaware and Schuylkill Rivers, along with a network of tributaries — Cobbs Creek, Wissahickon Creek, Darby Creek, Indian Creek — collect runoff from over 140 square miles of urbanized landscape before reaching the city's treatment intakes. What these waterways carry depends on what the land around them holds.

1. Does the type of land surrounding a waterway serve as an indicator of what contaminants it carries?

Industrial sites generate different chemical signatures than residential neighborhoods, which differ from open green spaces. Philadelphia's variety of land uses serves as a spatial proxy for the types of contaminants likely to enter adjacent waterways. Industrial-adjacent sites may show elevated metal concentrations; sites downstream of dense residential development may carry higher microplastic loads. PFAS, given their diverse consumer-product origins, may distribute more broadly — but sites near known point sources like fire-training facilities, landfills, or wastewater outfalls may show distinct species profiles.

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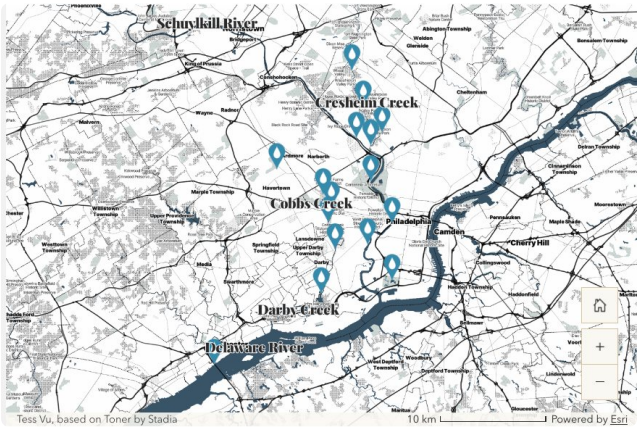
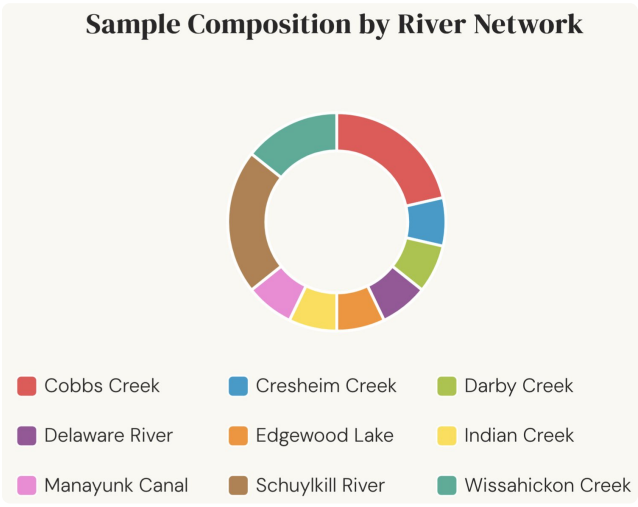
TRIBUTARY SITES SAMPLED	WATERWAYS ACROSS A ZONING GRADIENT	TREATMENT PLANTS STUDIED



Tributary sampling sites across the waterway network.



Sample composition by river network.

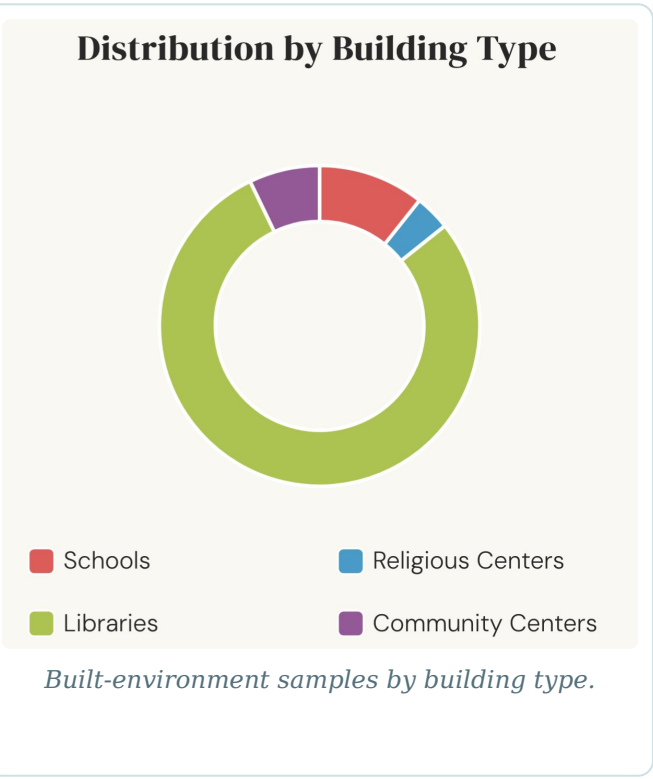
Philadelphia's drinking water is processed by three primary treatment facilities: the Samuel S. Baxter plant on the Delaware River, the Queen Lane plant on the Schuylkill, and the Belmont plant, also on the Schuylkill. Each plant serves a defined geographic area — Northeast

Philadelphia receives Baxter water, parts of North and Northwest Philadelphia are served by Queen Lane, and West and Southwest Philadelphia fall under Belmont. Two additional zones receive blended water. These service-area boundaries represent the physical network of mains, valves, and pumping stations that route water from a specific plant to a specific set of addresses, so a resident's exposure to any contaminant that survives treatment is, in part, a function of which plant processed their water.

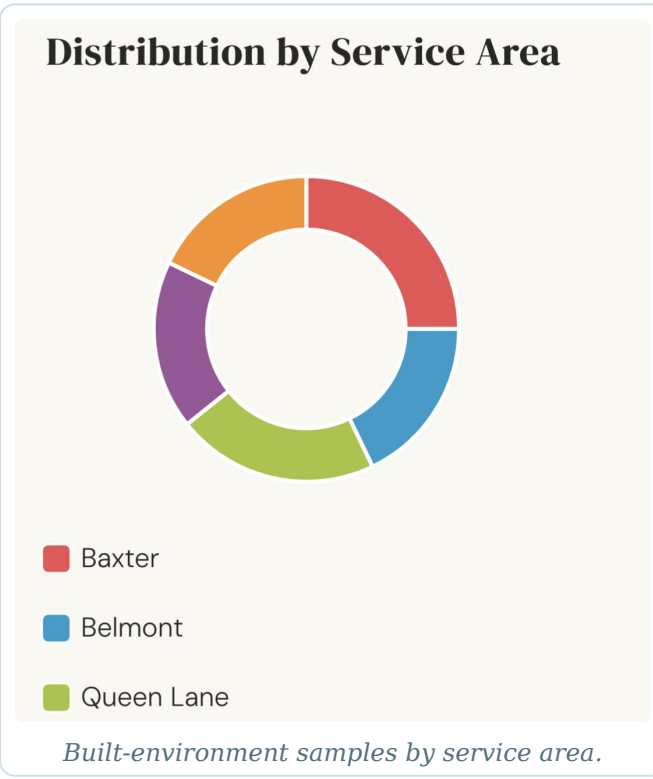
2. How do heavy metals, PFAS, and microplastics change from source to tap?

A great deal of research has examined how elements arise in our environment, the pathways they take into drinking water, and how to treat them before release into the system. Yet there is sparse research on how these chemicals interact with the distribution network. Do they increase or decrease in concentration? Do they remain inert? PWD performs extensive work before water leaves the plant — settling, disinfection, coagulation, flocculation, sedimentation, filtration, and final chemical treatment. But the story may not end there: after treatment, water travels through pipes, storage tanks, and service areas, where it can mix, sit, react with pipe materials, or pick up particles and metals through corrosion and leaching.

28	4	5+
BUILT-ENVIRONMENT LOCATIONS SAMPLED	SERVICE ZONES (BAXTER, QUEEN LANE, BELMONT, MIXED)	PUBLIC-FACING SITE TYPES



Built-environment samples by building type.



Built-environment samples by service area.

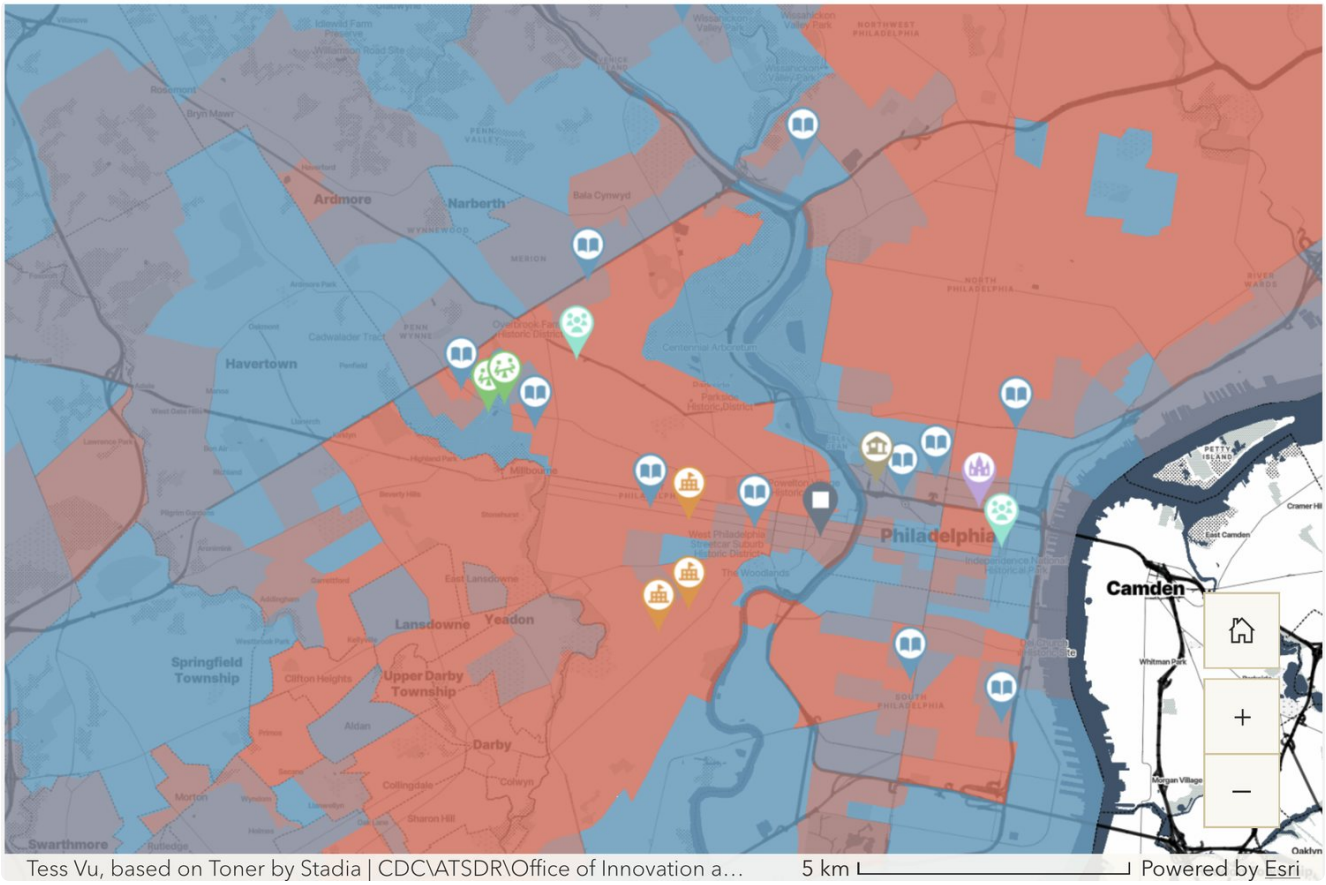
To compare water from source to tap, sampling was organized around Philadelphia's water service regions, with each tap linked back to the treatment plant most likely serving that area.

Samples were drawn from public-facing sites — libraries, churches, schools, recreation centers, and other community spaces — to reflect places where people actually encounter drinking water.

3. Are communities with higher social-vulnerability indices disproportionately exposed to contaminants?

Nationally, communities with higher social vulnerability — as measured by indices such as the CDC's Social Vulnerability Index (SVI) — tend to be disproportionately exposed to environmental hazards, including degraded water quality. The Cobbs Creek watershed in West Philadelphia drains through census tracts with elevated SVI scores (higher poverty, older housing stock, greater proportions of minority residents), while the Wissahickon Creek watershed in Northwest Philadelphia drains through tracts with comparatively lower scores.

Twenty-eight built-environment sites were distributed across a range of SVI tracts, balanced across service areas. This is not a question about blame or causation, but a spatial observation that assesses whether the geography of contamination aligns with the geography of vulnerability. Because contaminants are often more prevalent in cheaper consumer products, the team wanted to see whether that trend extended into the distribution of contaminants in drinking water — an imbalance that, if present, would be purely utility-driven rather than a result of residents' own actions, and would therefore necessitate government action.



CDC Social Vulnerability Index across Philadelphia, with sampling sites overlaid.

FIELDWORK

What We Did

A winter sampling campaign bracketing a major rain event.

January 7

Environmental sampling. Moderate winter temperatures (53°F), variable light winds (3 mph), low humidity (45%), mostly cloudy skies. No precipitation in the preceding 48 hours.

January 10 — Rain event

A significant rain event delivered 0.97 inches of precipitation to the region, beginning around 12:30 PM and continuing through the evening. This mobilized surface contaminants, flushed stormwater systems, and altered flow regimes across the watershed.

January 12 & 14

Environmental sampling under similar pre-rain weather conditions along the Wissahickon, Schuylkill, and Darby waterways.

February 6

First batch of built-environment sampling.

February 20

Second batch of built-environment sampling.

February 27

Third batch of built-environment sampling.

March 4

Fourth batch of built-environment sampling.

In the field

Environmental sampling along a tributary.

Collecting and transferring a field sample.

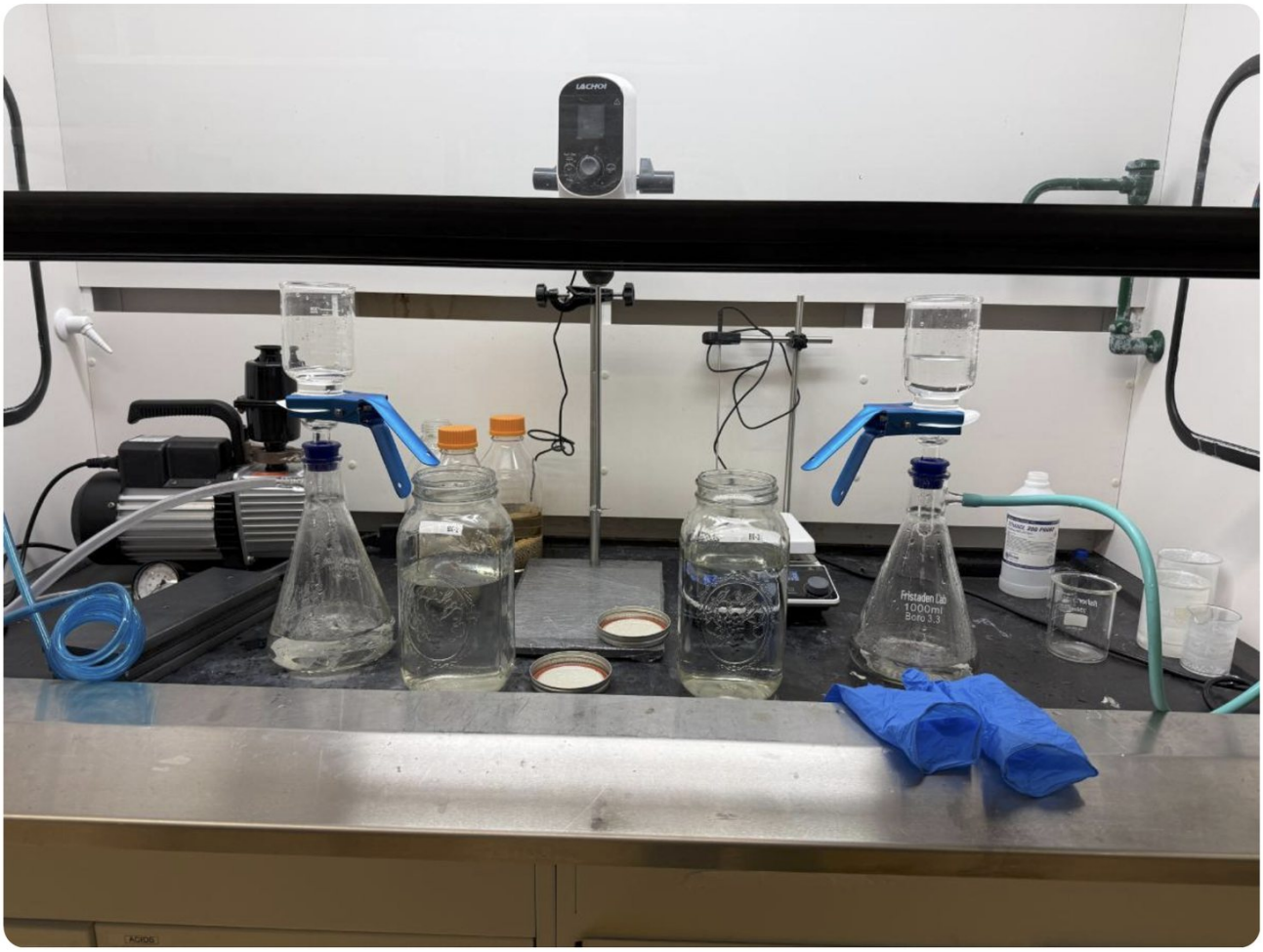
Sampling at a lake edge with an extension pole.

Built-environment sampling at a public library.

METHODS · MICROPLASTICS

Microplastics Sample Preparation

Fluorescence imaging, preceded by chemical preparation to make suspected plastic particles easier to see.



Vacuum filtration setup for microplastic samples (2.5 µm filters).

1. **Filtration.** Each water sample was filtered through a 2.5 µm filter, which acts like a fine sieve: water passes through, but suspended particles above 2.5 µm — including suspected microplastics — are trapped on the filter surface.

2. **Fenton digestion.** A chemical cleanup step using iron and hydrogen peroxide to generate highly reactive molecules that break down natural organic matter (biological material, dust, fibers, debris) while leaving plastic particles relatively intact.

3. **Nile Red staining.** Particles were stained with Nile Red dye, which attaches to oily or hydrophobic materials. Many plastics share that surface chemistry, so stained particles glow under the right light during fluorescence imaging, distinguishing them from the background.

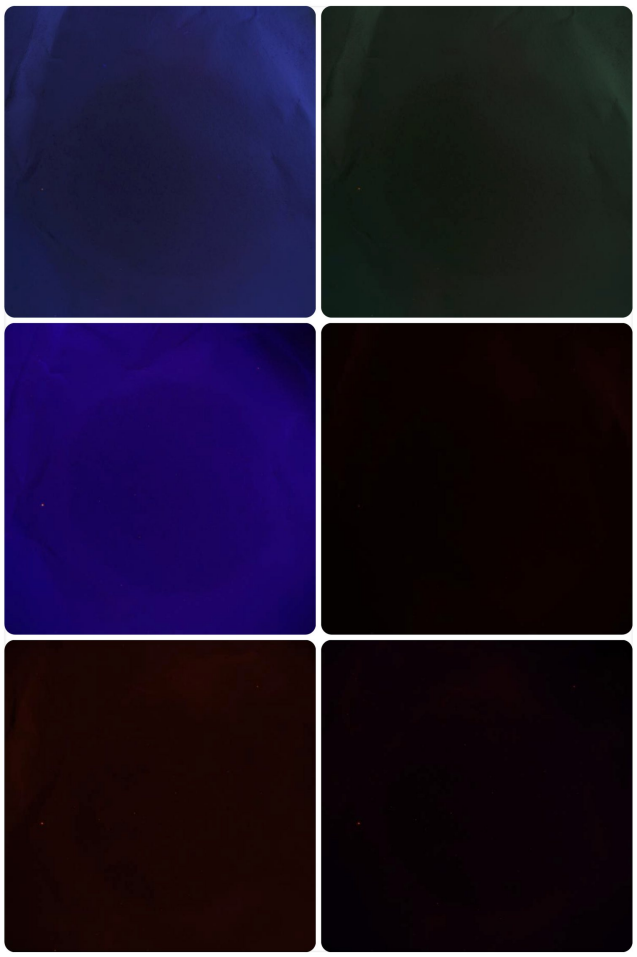
4 **Warm water bath.** Samples were placed in a 65°C bath for 30 minutes to keep digestion and staining consistent across samples, giving the peroxide reaction and Nile Red dye enough time and energy to work effectively.

Particle staining (left) and Nile Red dye with Fenton (right).

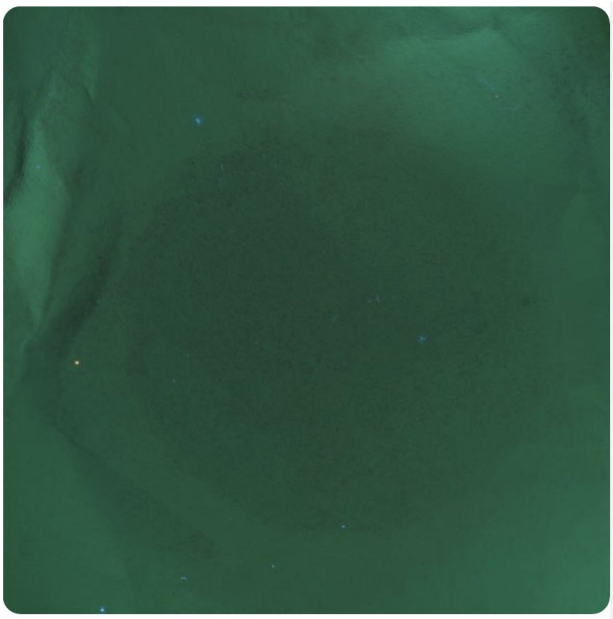
Labeled sample trays post-staining, ready for imaging.

5 **Focusing the camera.** Before imaging, the camera had to be focused on the filter paper for each sample. Because refocusing was needed every time the filter paper changed, the workflow switched from autofocus to manual focus, briefly back to autofocus to find the filter surface, and finally back to manual to lock focus while capturing images.

6 **Spectral imaging (FIMAP).** After testing several excitation/emission combinations, the Yellow filter at 365 nm (UV-A excitation) was selected as the primary imaging condition. Under this setting, suspected microplastic particles fluoresce in red-to-yellow tones after Nile Red staining, while organic material such as cotton fibers appears blue — allowing more confident discrimination between synthetic polymer particles and natural organic debris.



L5 sample (Library of Accessible Media for PA) imaged at different wavelengths.



L5 image: microplastics (red) and cotton (blue).

7 **Particle counting (ImageJ).** Suspected particles were counted using ImageJ with rules set for color, brightness, size, and shape: size 3–infinity (ignoring tiny specks likely to be noise), circularity 0–1 (allowing many shapes), hue 0–50 and saturation 0–255 (focusing on reddish/orange stained particles), and brightness 81–255 (removing darker background).

IN SUMMARY

The Nile Red stain helped the particles glow, the fluorescence images helped the team see them, and ImageJ helped count them more consistently — a practical way to screen for suspected microplastics in tap-water samples.

Metals Sample Preparation

Acidification and contamination-controlled storage, followed by ICP-MS.

Because trace metals can easily be contaminated or lost to the walls of their storage containers, all chemical handling and cleaning — except filtration — was performed under a fume hood.

Toxic-elements acidification and pipette-preparation station.

Pipette preparation and acidification

1. **Cleaning pipettes.** Under the fume hood, pipettes drew up a 5% hydrochloric acid (HCl) solution once, then a 2% HCl solution twice, disposing of liquid into a waste container after each cycle, then rinsed three times with ultra-pure water. If a tip touched any surface outside the required HCl after cleaning, it was discarded and the process restarted — ensuring the integrity of trace-element measurements.

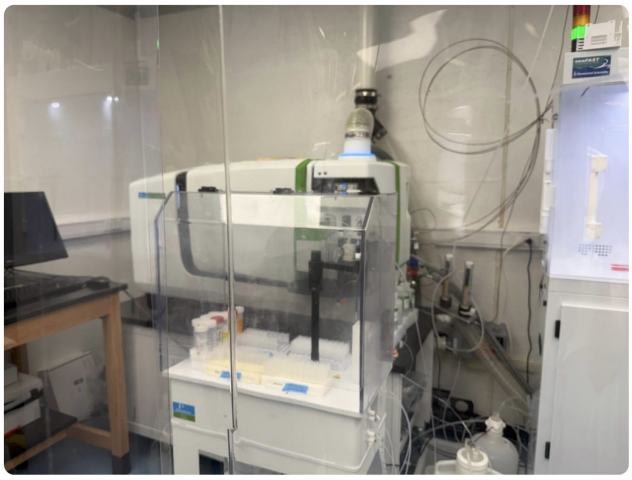
2 **Acidification (preservation).** Adding acid lowers the pH, keeping dissolved metals suspended and preventing adsorption to the bottle walls. For 30 mL Nalgene bottles (trace metals only), a 100 µL pipette added 60 µL of HCl. For larger 150 mL amber bottles, a 500 µL pipette scaled the HCl volume to maintain a consistent 0.2% HCl concentration. Bottles were inverted to mix, bagged, and frozen; tips were discarded immediately afterward.

Samples in Nalgene bottles before acidification (left) and frozen samples in amber bottles (right).

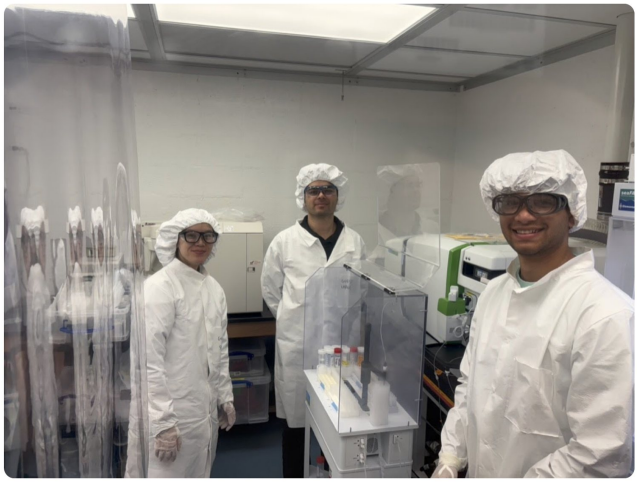
Lab logistics and communication

3 **Inventory logging.** The team emailed Dr. Hawkings a detailed inventory of stored samples — total count, sample types (petri dishes, amber bottles), ownership, arbitrary labels (e.g. T1, T2), and origins (e.g. Wissahickon coordinates). The 0.2% HCl concentration stabilized the metals in solution, the PES membrane captured suspended solids, and strict administrative logging ensured the integrity of the sample library.

A portion of the stored, labeled sample library.



ICP-MS machine in the Bi-Cycles Lab clean room.



ICP-MS demonstration (left to right): Tess, Younes, and Prajwal.

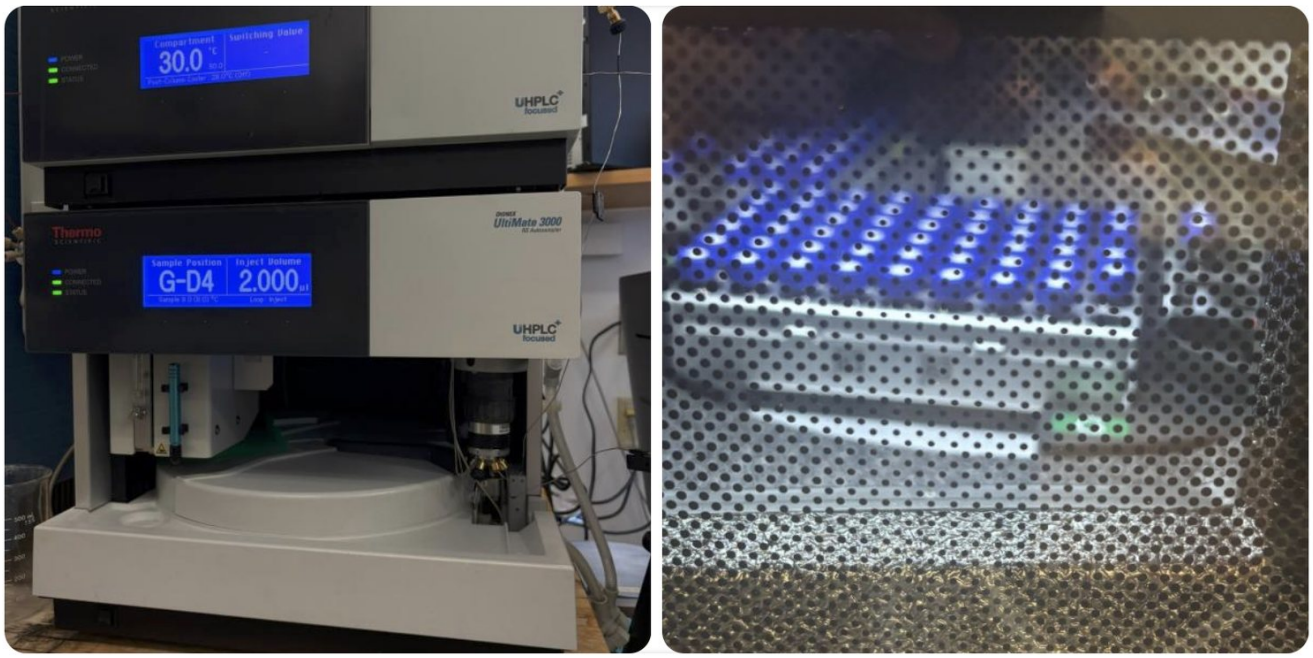
ICP-MS after sample preparation

1. **Raw signal.** Results emerged as counts per second (cps) — signal strength for each element, not yet a concentration. Because samples ran in five batches, each batch had its own blank and standards. Blanks accounted for background signal; standards provided a known reference. The 1643 standard (trace elements in drinking water) and the SLRS standard (a river-water reference) were used.

2 **Calibration.** CPS values were converted to concentration using a one-point calibration: for each sample, the blank signal was subtracted, then the corrected sample signal was compared to the corrected standard signal — done batch by batch to keep concentrations tied to the specific instrument conditions of each batch.

PFAS Sample Preparation

Analysis via LC-MS/MS, exploiting PFAS ions' unique mass-to-charge ratios.



LC-MS/MS machinery: an older model (left) and sample trays from a newer model (right).

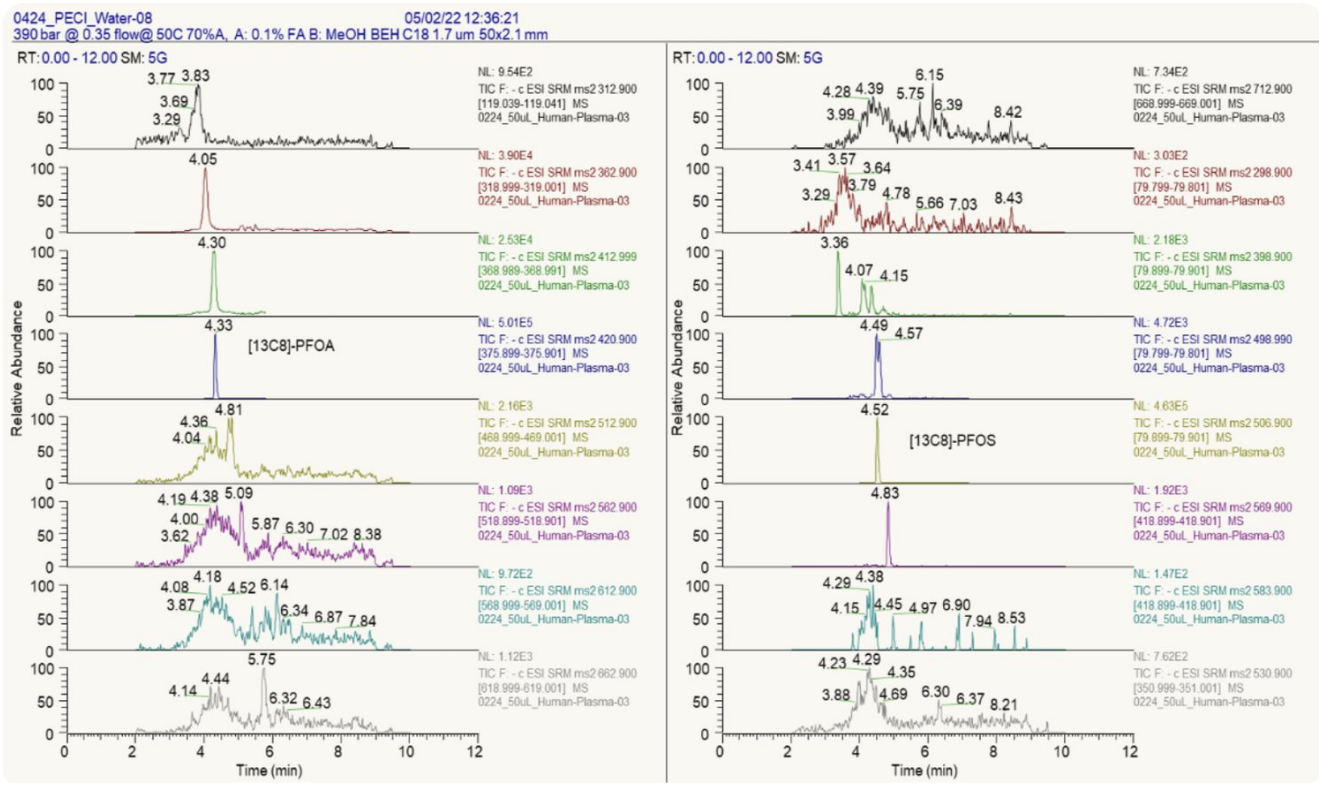
1. **Collection & spiking.** Water samples (100–250 mL) were spiked with isotopically labeled standards ($^{13}C_8$-PFOA & $^{13}C_8$-PFOS) before any preparation, to improve quantification accuracy and confidence.

2. **Solid-phase extraction.** SPE cartridges with polystyrene-divinylbenzene (SDVB) were prepared by washing with methanol (MeOH) and metal-free water. Samples were passed through under high vacuum to extract and concentrate the compounds.

3. **Quality control.** Five 100 mL metal-free water samples were processed as technical replicates; calibration standards were prepared in 1 mL of metal-free water for instrument calibration and quantification.

4. **Elution & storage.** PFAS were eluted from the cartridges using methanol, dried under a nitrogen stream, and stored at −80°C until analysis. Samples were reconstituted in 1 mL of 96% methanol in water prior to instrument analysis.

5. **LC-MS/MS injection.** A 2 µL aliquot of each sample was injected into the LC-MS/MS system equipped with a C18 column. Liquid chromatography separated PFAS by chemical properties, allowing less-abundant PFAS to be detected more clearly. As compounds exit the column, they are ionized and introduced into the mass spectrometer.



Representative LC-MS/MS chromatogram.

6 **Calibration curves.** Area ratios were collected for each sample, and standards (0.00–20 ng) for each PFAS type were used to plot an area-ratio-vs.-amount calibration curve. Back-calculating the specified amount yielded a percent accuracy used to determine the limit of detection for each PFAS, aiming to stay below a 15% difference between the known amount and the curve's estimate.

PFAS detection limits.

PFAS Type	Limit of Detection (ng/mL)	# Samples > LOD / Total
PFOS	0.160	32 / 32
PFOA	0.160	29 / 32
PFNA	0.160	9 / 32
PFHxS	0.310	7 / 32
PFBS	5.000	0 / 32

NOTE ON PFBS & THE HAZARD INDEX

From a regulatory standpoint, PFBS is not evaluated by its individual concentration alone. Instead it is included in the EPA's Hazard Index, which considers the combined presence of several PFAS compounds. Each PFAS concentration is divided by the EPA's reference value for that compound, and those fractions are summed.

$$\text{Hazard Index (H.I.)} = \Sigma_i \left(\text{Concentration}_i \div \text{Reference Value}_i\right)$$

The "# Samples > LOD" column reports the number of samples whose back-calculated concentration exceeded the method's limit of detection. The LC-MS/MS instrument registered a chromatographic signal for all samples for PFOS, PFOA, PFNA, and PFHxS, and for 28 of 32 samples for PFBS. However, a detectable signal does not guarantee the concentration is reliably quantifiable above the LOD.

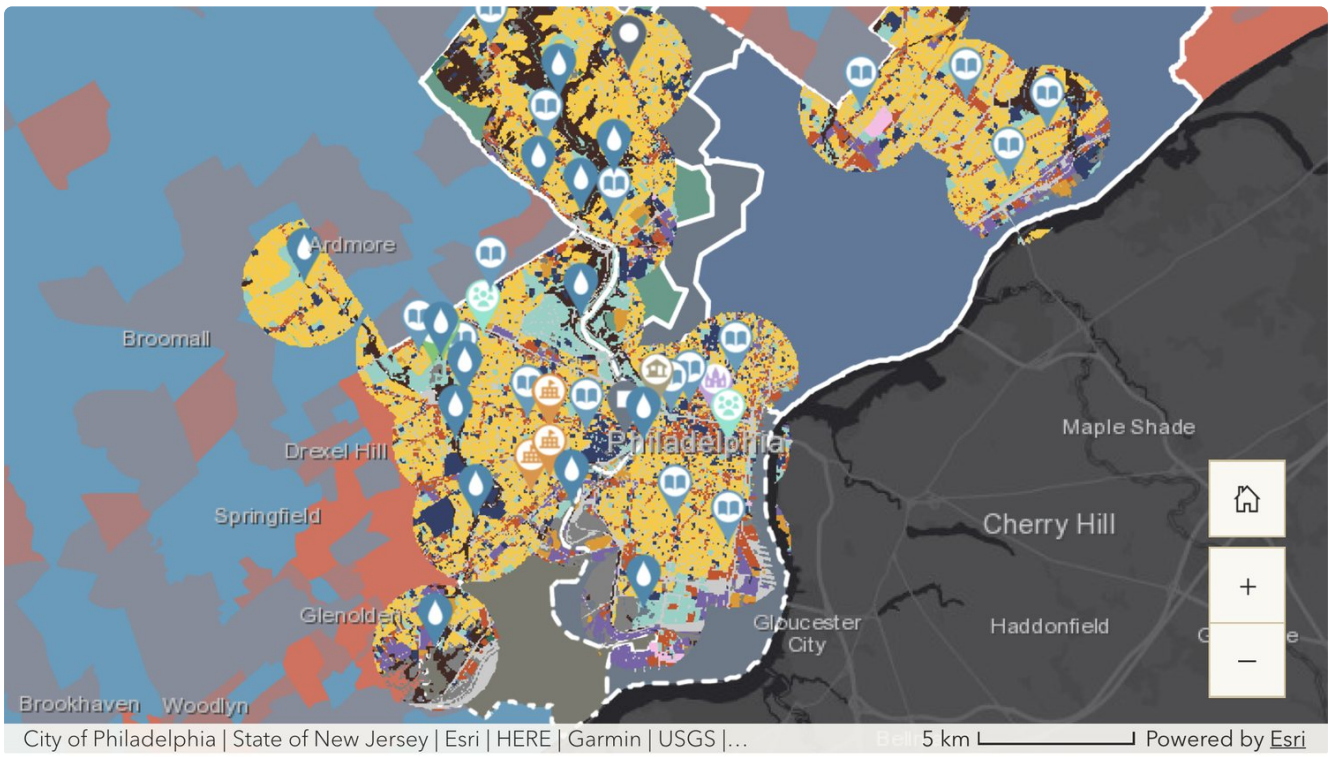
7 **Final concentrations.** The calibration curve and area ratios were used to estimate the amount of PFAS in each sample; sample concentrations were found by dividing the calculated amounts (ng) by the sample volumes.

FINDINGS

Results & Key Findings

Patterns across three contaminant classes, the same network, the same winter window.

The following sections present results from the three contaminant classes sampled across Philadelphia's tributaries and built environment, each addressing the spatial questions framed earlier: how contaminants relate to land use, whether concentrations change from source to tap across service areas, and whether exposure patterns align with social vulnerability.



PECI interactive map (static view). Powered by Esri | HERE | Garmin | USGS | EPA | NPS | CDC/ATSDR GRASP.

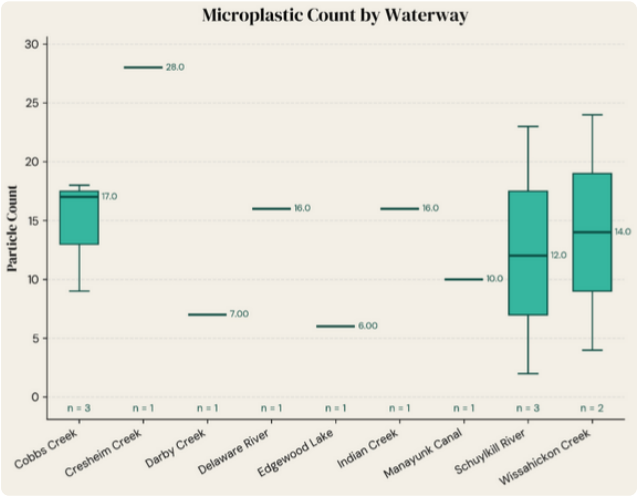
Key Findings

- Microplastic counts were higher in tributaries (median 14) than at the tap (median 8), but distributions overlap substantially — one tap site, S1 (West Philadelphia High School), exceeded all tributary values at 45 particles.
- PFOS concentrations ranged from 1.23 to 12.18 ppt (median 3.51 ppt); 11 of 28 sites exceeded the EPA MCL of 4 ppt. PFOA ranged from 0.60 to 5.14 ppt (median 1.31 ppt), with two sites above 4 ppt.

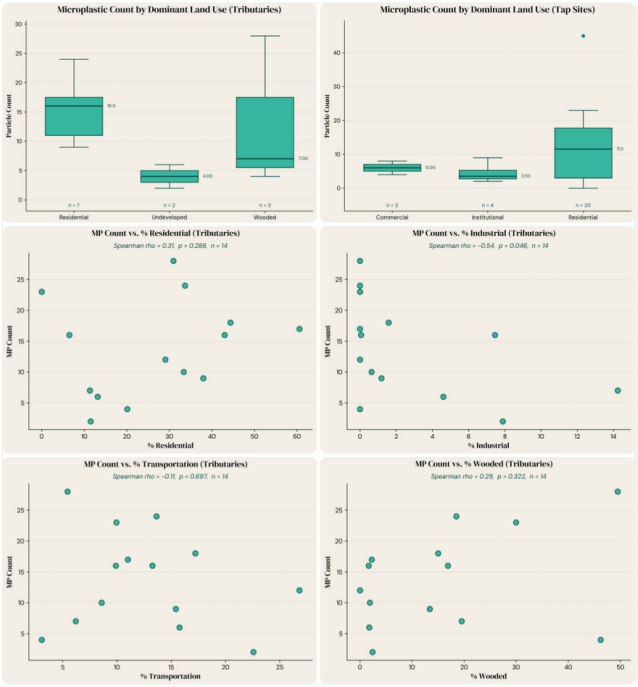
- The strongest land-use-to-contaminant signal was Percent Industrial vs. Lead at the 500 m buffer (rho = 0.72, p = 0.005, n = 13), decaying with buffer size.
- Cadmium was the only contaminant with a statistically significant SVI association (rho = +0.46, p = 0.014), though concentrations remain far below the MCL.
- No PFAS analyte showed a significant SVI correlation, consistent with centralized treatment delivering equitable exposure.

Microplastics

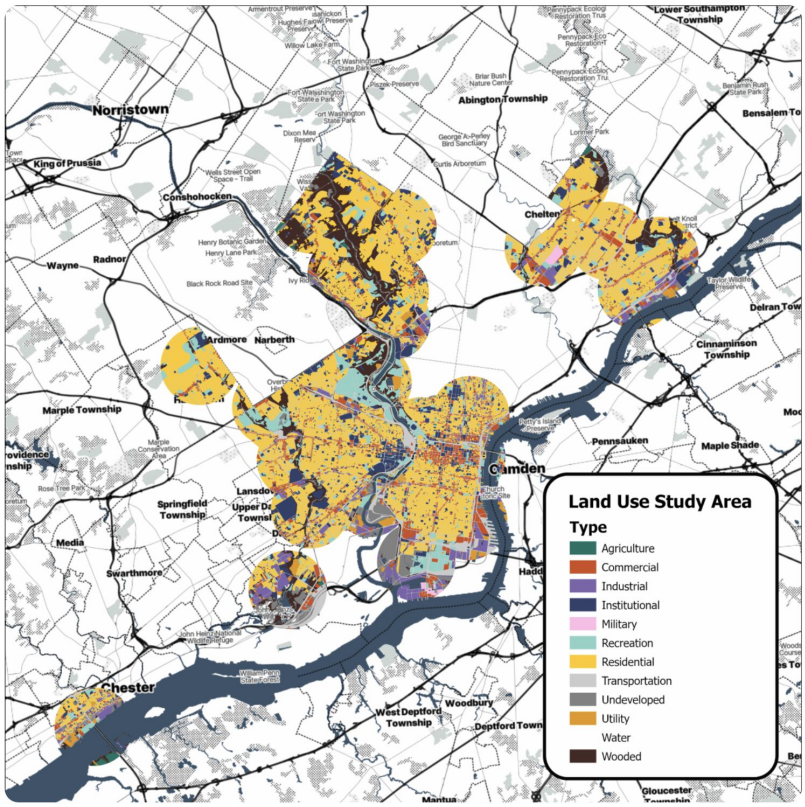
Does land use correlate to microplastic loading?



Microplastic count by waterway.



Microplastic count by dominant land use, with land-use correlation scatters.



DVRPC land-use study area. Euclidean 500/1000/2000 m buffers were drawn around each sample; watershed-based delineation would be more hydrologically accurate in future iterations.

METHODOLOGICAL NOTE

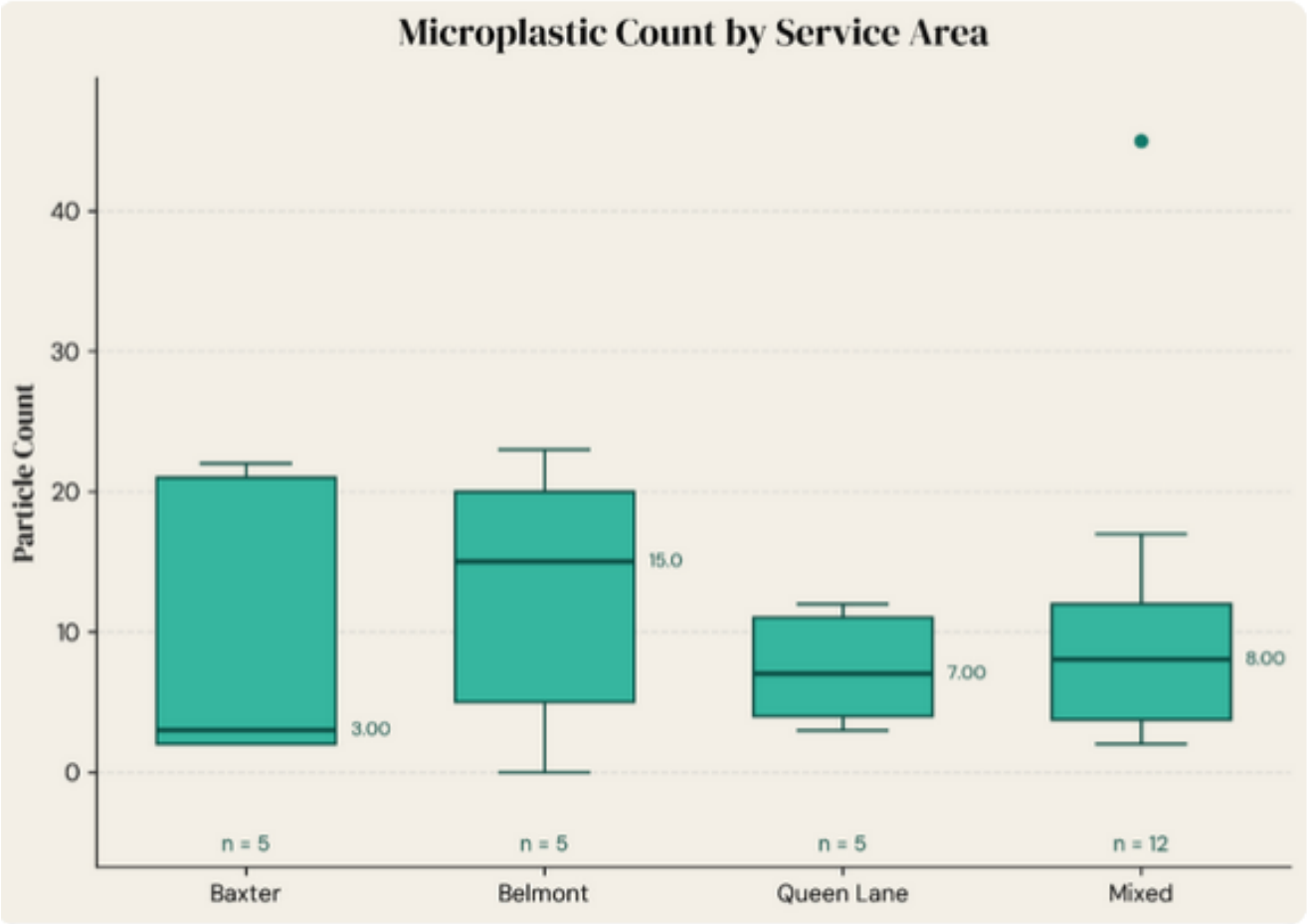
Euclidean buffers are a geometric approximation — a known limitation. Upstream watershed-based delineation would be more hydrologically accurate for future iterations.

Among tributary sites, the strongest land-use-to-contaminant association was Percent Undeveloped vs. MP Count (rho = −0.55, p = 0.04, n = 14). A nearly equivalent negative correlation appeared for Percent Industrial vs. MP Count (rho = −0.54, p = 0.046, n = 14), suggesting industrial-adjacent tributary sites also carried fewer microplastics — though some collinearity between industrial and undeveloped land-use percentages may partly account for this. The most positively associated class was Percent Residential vs. MP Count (rho = 0.31, p = 0.29, n = 14). The small tributary sample size limits statistical power, so non-significant rho values should be read as inconclusive rather than as evidence of no association.

Among built-environment (tap) sites, only a single land-use-to-contaminant correlation reached $p < 0.05$, contradicting the initial hypothesis: Percent Residential vs. MP Count (rho = 0.42, p = 0.02, n = 29). Kruskal–Wallis tests across dominant class groups showed no significant differences in median concentrations — consistent with tap water being delivered from centralized plants rather than reflecting the land use immediately surrounding each tap. Pooling tributary and tap sites yielded zero correlations at $p < 0.05$ (versus two in the tributary-only set and one in the built-environment-only set); because the two site types measure fundamentally different

exposure pathways, pooled associations should be interpreted with site-type stratification in mind.

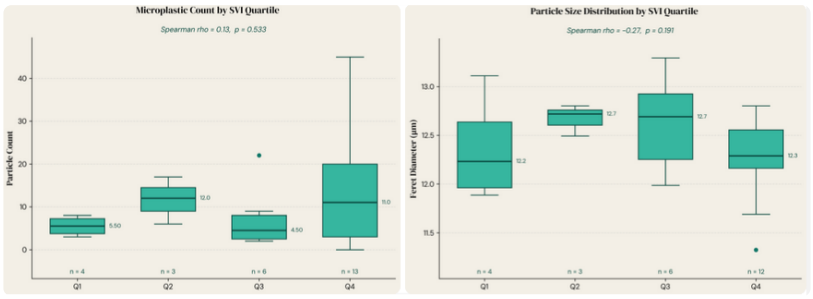
Do microplastic counts change from source to tap?



Microplastic count by treatment-plant service area.

Tributary samples had a median count of 14 versus 8 for tap samples, suggesting a modest reduction in microplastic load between source water and point of use. Both distributions overlap substantially: tributary counts ranged from 2 to 28 while tap counts ranged from 0 to 45, with at least one tap site (S1, West Philadelphia High School) exceeding all tributary values. Service-area medians varied from 3 particles at Baxter to 15 at Belmont and 7 at Queen Lane, though small per-group sample sizes (n = 5 each) and overlapping interquartile ranges limit interpretability. The data are best read as showing that conventional treatment does not fully eliminate microplastics but may reduce their abundance to some degree; additional paired source-to-tap sampling with standardized volumes would be needed to confirm the magnitude of reduction.

Are higher-SVI communities disproportionately exposed to microplastics?



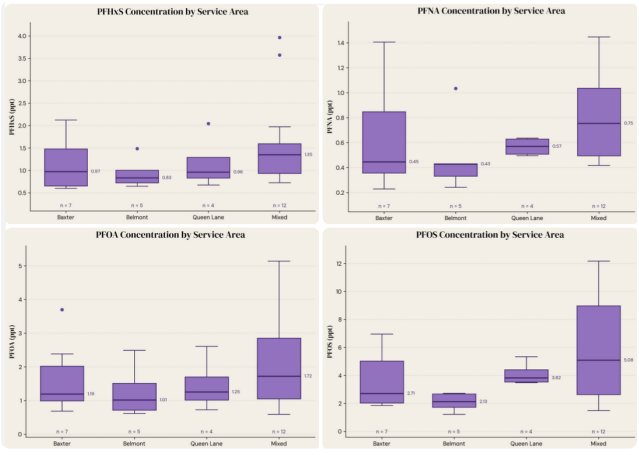
Microplastic count and particle size by SVI quantile.

The SVI-quartile box plot for microplastic count shows no clear monotonic trend — Q1 and Q4 have similar medians, while Q2 and Q3 show moderate variation without a consistent gradient. The Spearman correlation between raw SVI and particle count is weak and non-significant (rho = +0.13, p = 0.53, n = 26), providing no evidence that social vulnerability is systematically associated with higher microplastic exposure at the tap. Particle size by SVI quartile similarly shows no meaningful gradient (rho = −0.27, p = 0.19).

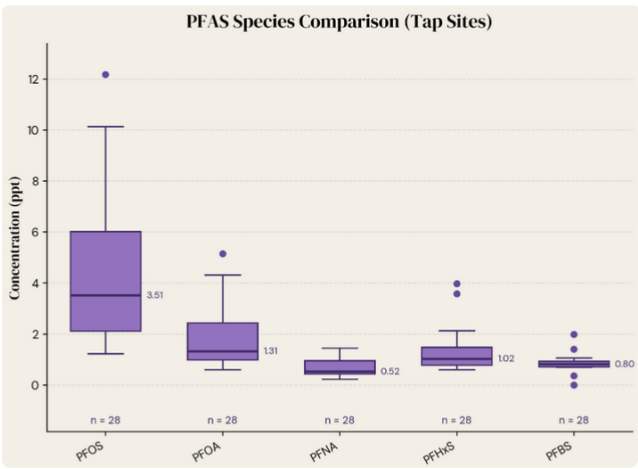
Wide interquartile ranges within each SVI group indicate that site-specific factors (plumbing age, fixture type, flushing history) likely dominate over census-tract-level social determinants for microplastics — consistent with the expectation that microplastic contamination is primarily driven by source-water characteristics and treatment efficacy rather than distribution-system infrastructure. Small per-quartile sample sizes (n = 3 to 12) limit statistical power. Median particle size differed between site types: tributary samples had a median particle area of approximately 49,097 µm^2, compared to approximately 131,323 µm^2 at the tap, suggesting smaller particles may be preferentially removed during treatment or that larger particles accumulate or are introduced within the distribution system. Particle-morphology data (circularity, aspect ratio, Feret diameter) were collected for future polymer-type classification but are not presented here.

PFAS

Do PFAS concentrations change from source to tap?



PFAS concentrations by water-treatment service area.

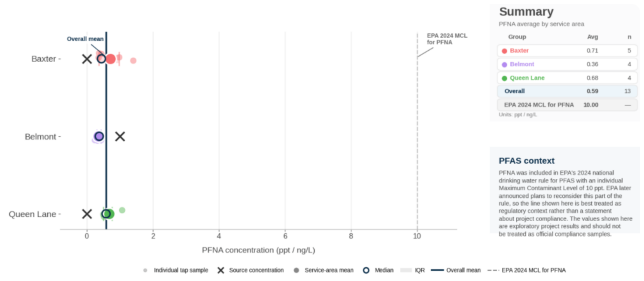


PFAS species comparison.

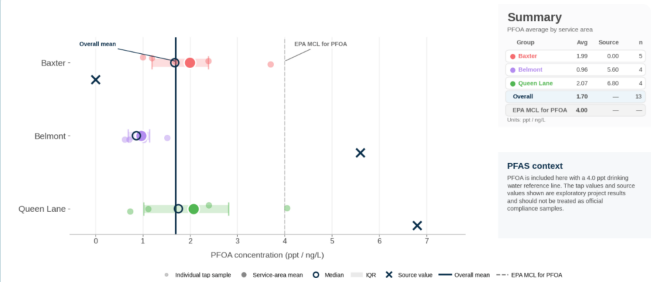
REGULATORY CONTEXT

PFOS is regulated with an enforceable MCL of 4 ppt; PFOA is shown with a 4 ppt reference line. PFHxS and PFNA were included in the EPA's 2024 rule with individual MCLs of 10 ppt, but the EPA later announced plans to reconsider those parts of the rule, so those lines are best treated as context rather than compliance statements. PFBS has no individual MCL and is instead included in the Hazard Index mixture framework with PFHxS, PFNA, and HFPO-DA (GenX).

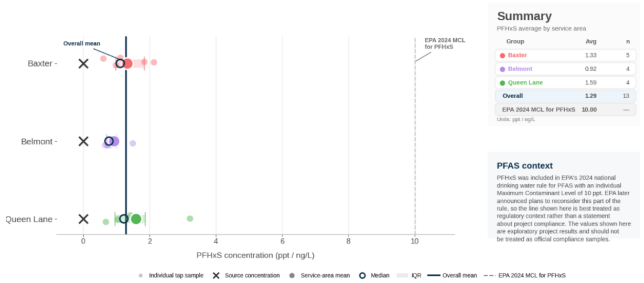
Per-compound concentrations by service area, with drinking-water reference lines



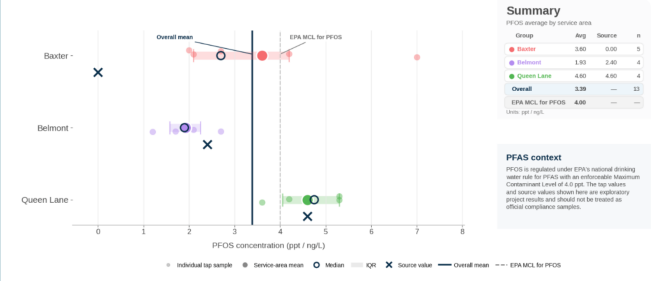
PFOS — enforceable MCL 4 ppt.



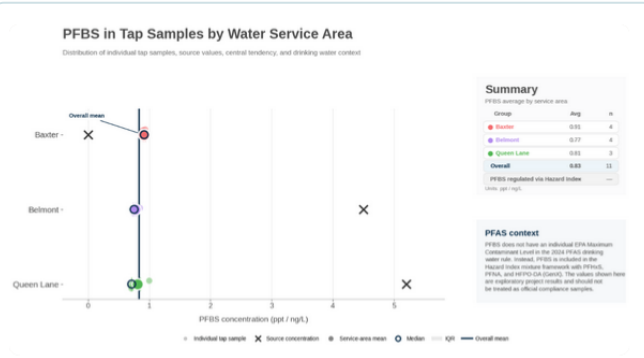
PFOA — shown with a 4 ppt reference line.



PFHxS — 2024 individual MCL 10 ppt (under reconsideration).



PFNA — 2024 individual MCL 10 ppt (under reconsideration).



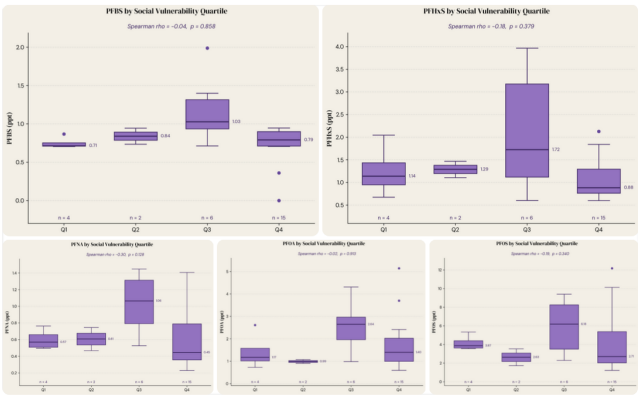
PFBS — no individual MCL; included in the Hazard Index mixture.

The service-area box plots show that shorter-chain PFAS (PFOA, PFHxS, PFBS) have narrow distributions with comparable medians across service areas. PFOS shows wider variability and higher medians in the Mixed and Queen Lane service areas, suggesting PFOS may be more sensitive to source-water composition or treatment differences than other analytes. PFOS ranged

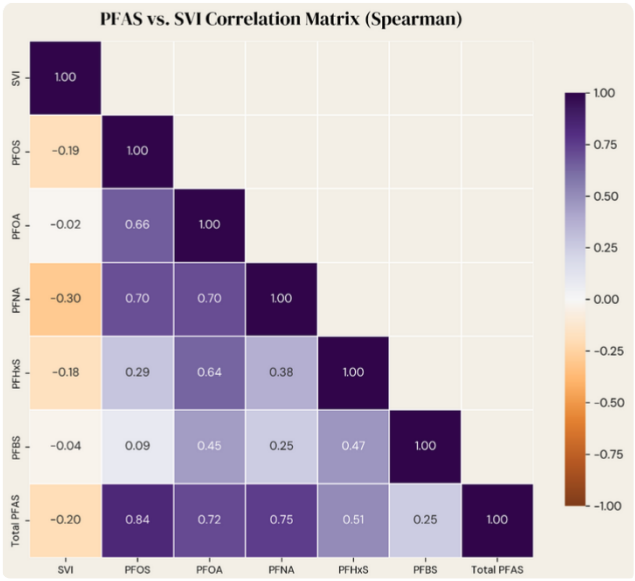
from 1.23 to 12.18 ppt, with service-area medians of 2.13 ppt (Belmont), 2.71 ppt (Baxter), 3.82 ppt (Queen Lane), and 5.08 ppt (Mixed); 11 of 28 sites exceeded the 4 ppt MCL. PFOA ranged from 0.60 to 5.14 ppt (median 1.31 ppt), with two sites above 4 ppt. PFHxS and PFBS were uniformly below 4 ppt across all service areas.

The Mixed service-area median for PFOS (5.08 ppt) exceeded the 4 ppt MCL, and Queen Lane approached it (3.82 ppt), while Baxter and Belmont remained below. For shorter-chain analytes, no service area stood out as systematically elevated — the absence of large source-to-tap changes suggests PFAS neither accumulate in nor are removed by the distribution system itself.

Are higher-SVI communities disproportionately exposed to PFAS?



PFAS concentrations by SVI quantile.



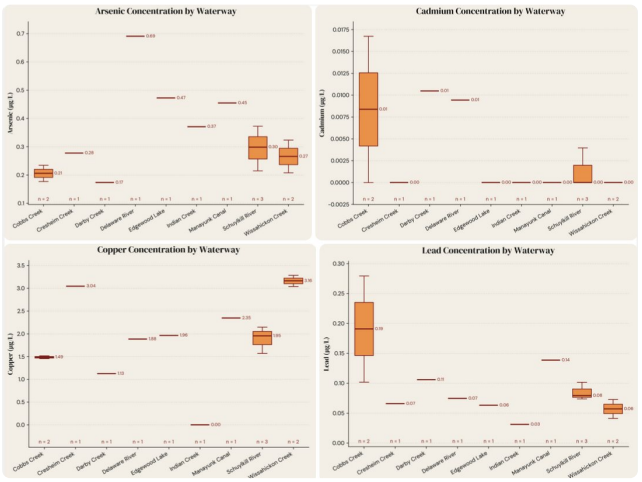
PFAS vs. SVI correlation matrix (Pearson/Spearman).

Spearman correlations between SVI and individual PFAS analytes are uniformly weak and non-significant: PFOS (rho = −0.19, p = 0.34), PFOA (rho = −0.02, p = 0.91), PFNA (rho = −0.30, p = 0.13), PFHxS (rho = −0.18, p = 0.38), and PFBS (rho = −0.04, p = 0.86). None reach significance, providing no evidence of disproportionate PFAS exposure in higher-SVI communities. If anything, the direction for most analytes is weakly negative — higher-SVI areas trend toward slightly lower PFAS concentrations — though far too weak to be meaningful given the sample size. The total PFAS correlation (rho = −0.20, p = 0.33) is likewise negligible. This pattern is consistent with PFAS exposure being driven by treatment-plant source water and process chemistry rather than distribution-system or neighborhood-level factors, suggesting Philadelphia's centralized treatment delivers relatively equitable PFAS exposure regardless of community socioeconomic status. Across all tap sites, total PFAS ranged from 16.5 to 55.7 ppt (median 21.7 ppt).

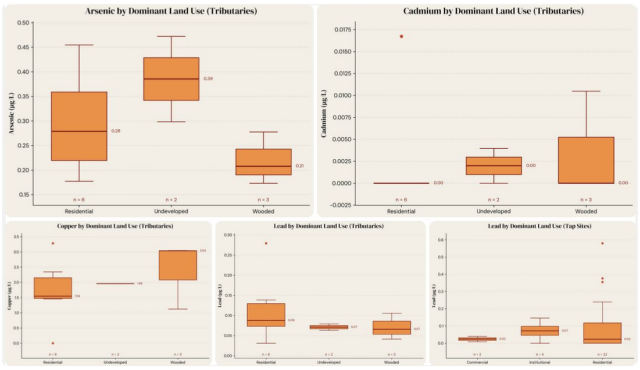
PFAS samples were collected for environmental tributary data but had not been processed as of publishing this StoryMap.

Metals

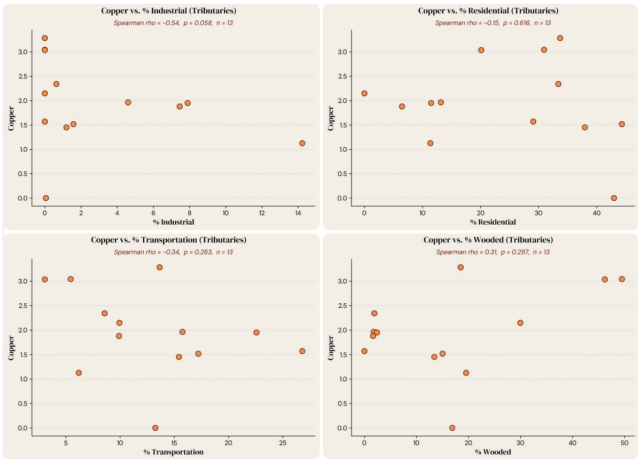
Does land use correlate to metal concentrations?



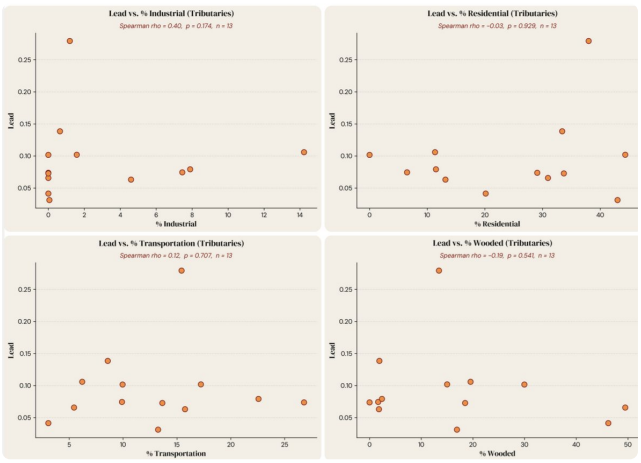
Environmental waterway toxic-element concentrations.



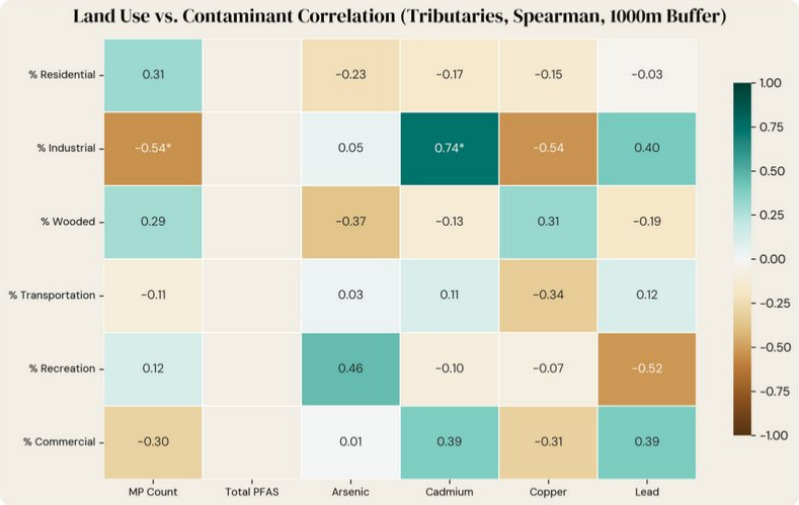
Toxic elements from tributary and tap sites by dominant land use.



Copper vs. land-use fraction (tributary scatter).



Lead vs. land-use fraction (tributary scatter).



Contaminants vs. DVRPC land-use correlation matrix, tributaries, 1000 m buffer (Spearman).

PROXY NOTE

Any metals statement below uses raw blank-clipped CPS as a relative proxy, so direction and rank are meaningful but absolute magnitude is not.

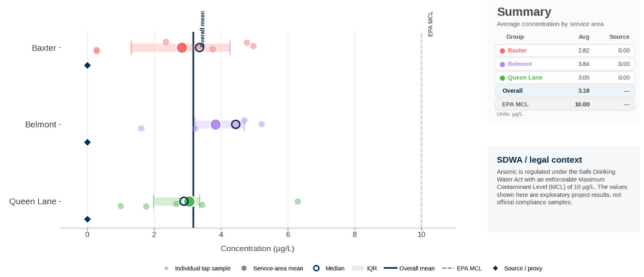
For tributary sites, a buffer-sensitivity analysis computed Percent Industrial vs. Lead (Pb) across three buffers (n = 13):

Percent Industrial vs. Lead, by buffer radius.

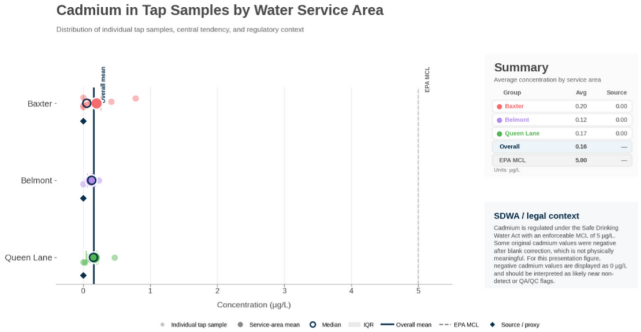
Buffer (meters)	rho	p
500 m	0.72	0.005
1000 m	0.40	0.17
2000 m	0.30	0.32

This is the land-use-to-metal signal in the dataset: a strong, statistically significant positive association between local industrial land area and tributary lead, strongest at the tightest 500 m buffer and decaying with buffer size. That decay pattern is what would be expected from a nearby point-source-like contribution rather than a regional one. In the tributaries, more local industrial land correlates with higher lead, whereas at the tap metals do not track land use — consistent with corrosion-driven exposure that varies with infrastructure and plumbing. Land-use buffers are derived from DVRPC zoning polygons describing permitted or designated land use, so buffer percentages are a coarse proxy for pollution-source intensity and may misrepresent sites near smaller point sources especially.

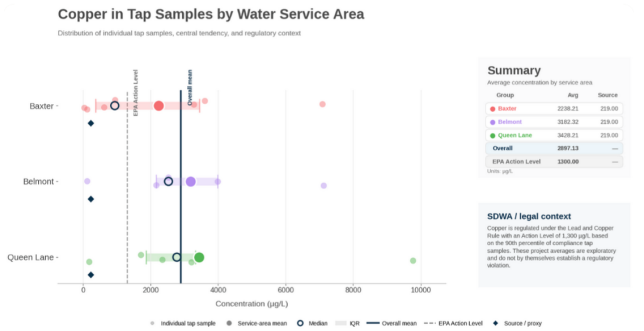
Do metal concentrations change from source to tap?



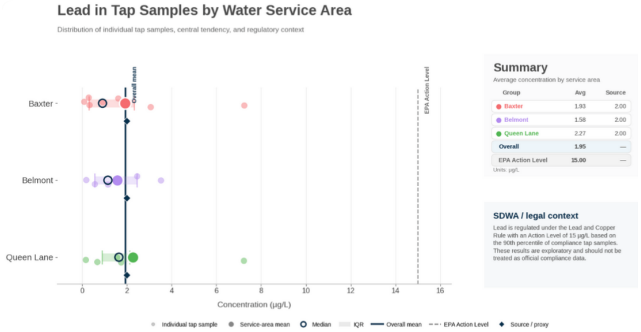
Arsenic in tap samples by service area (MCL 10 µg/L).



Cadmium in tap samples by service area (MCL 5 µg/L).



Copper in tap samples by service area (action level 1,300 µg/L).



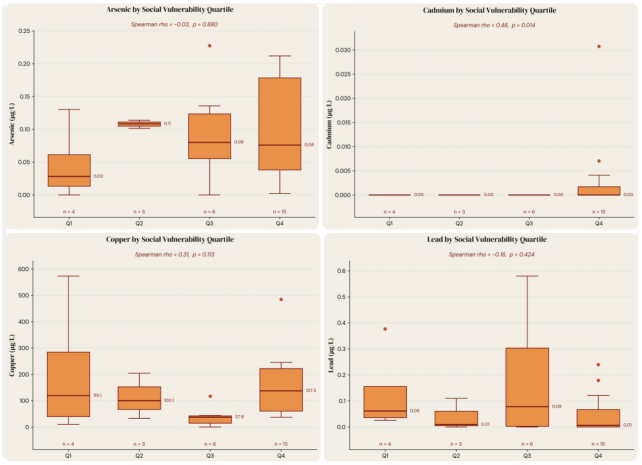
Lead in tap samples by service area (action level 15 µg/L).

REGULATORY THRESHOLDS (SAFE DRINKING WATER ACT)

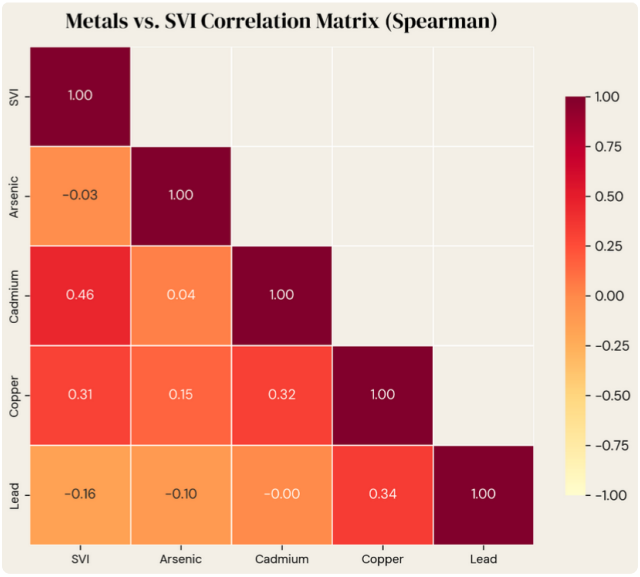
Arsenic MCL 10 µg/L; cadmium MCL 5 µg/L; copper action level 1,300 µg/L (90th percentile); lead action level 15 µg/L (90th percentile). Some cadmium values were negative after blank correction (not physically meaningful); negatives are displayed as 0 µg/L and should be read as near non-detect or QA/QC flags.

The box plots for arsenic and cadmium show uniformly low concentrations across all built-environment sites, far below their respective MCLs. Copper and lead show more variability across tap sites, as expected, because these metals enter drinking water primarily through corrosion of building plumbing (lead service lines, copper pipes, brass fittings) rather than from the treatment plant. All measured lead values are far below the 15 µg/L action level, and copper values are well below the 1,300 µg/L action level. Greater tap-side variability for lead and copper is a well-documented phenomenon nationwide, reflecting building-age and plumbing-material heterogeneity rather than anything unique to Philadelphia.

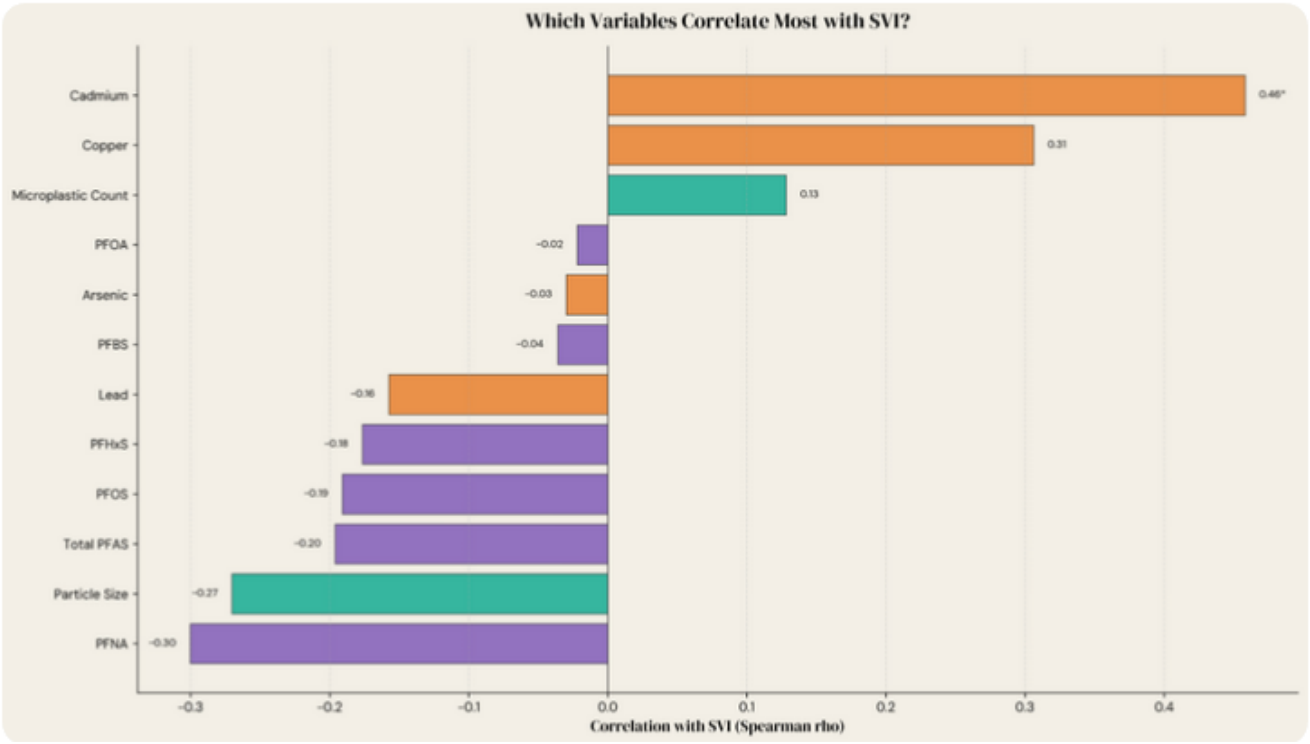
Are higher-SVI communities disproportionately exposed to metals?



As, Cd, Pb, Cu by SVI quantile (box & whisker).



Metals vs. SVI correlation matrix (Pearson).



Which variables correlate most with SVI, ranked by absolute correlation strength.

The most notable finding is cadmium, which shows the only statistically significant correlation in the entire dataset: rho = +0.46, p = 0.014 (n = 28). This positive association suggests higher-SVI neighborhoods have modestly elevated cadmium at the tap, though absolute concentrations remain far below the MCL of 5 µg/L. Copper shows a weak positive association (rho = +0.31, p = 0.11) that does not reach significance. Lead, perhaps surprisingly, shows a weakly negative relationship (rho = −0.16, p = 0.42) — counter to the commonly expected environmental-justice

pattern. A possible explanation is that Philadelphia's targeted lead-service-line replacement and corrosion-control optimization may have preferentially reduced lead exposure in higher-SVI tracts, or that the small sample captures idiosyncratic plumbing configurations rather than systematic neighborhood-level trends. Arsenic shows essentially no SVI relationship (rho = −0.03, p = 0.88), consistent with its source-water origin and effective removal during treatment.

Moran's I Spatial Autocorrelation

Moran's I — Tributary samples (N = 16, K = 3).

Variable	Moran's I	Expected I	Z-Score	P-Value	Observation
Microplastics	−0.1512	−0.0667	−0.5108	0.6095	Random
Copper (CPS proxy)	0.1429	−0.0667	1.2664	0.2054	Random
Lead (CPS proxy)	−0.0915	−0.0667	−0.183	0.8548	Random
Arsenic (CPS proxy)	−0.1349	−0.0667	−0.4302	0.6671	Random
Cadmium (CPS proxy)	−0.1918	−0.0667	−0.771	0.4407	Random

Moran's I — Tap samples (N = 33, K = 4).

Variable	Moran's I	Expected I	Z-Score	P-Value	Observation
Microplastics	−0.0043	−0.0312	0.2636	0.7921	Random
Total PFAS	0.1392	−0.0312	1.5772	0.1147	Random
PFOS (ppt)	0.0289	−0.0312	0.5729	0.5667	Random
PFOA (ppt)	0.2132	−0.0312	2.3435	0.0191	Clustered
Copper (CPS proxy)	−0.0616	−0.0312	−0.2935	0.7692	Random
Lead (CPS proxy)	−0.0314	−0.0312	−0.0014	0.9989	Random
Arsenic (CPS proxy)	−0.0193	−0.0312	0.1096	0.9128	Random
Cadmium (CPS proxy)	−0.1147	−0.0312	−0.8209	0.4117	Random

Global Moran's I was computed for 8 contaminant variables across tap and tributary subsets using K-nearest-neighbors spatial weights (k = 4 for tap, k = 3 for tributary). Of the 13 variable-subset combinations tested, only PFOA at tap sites exhibited statistically significant positive spatial autocorrelation (I = 0.213, z = 2.34, p = 0.019), indicating that nearby tap sites tend to have similar PFOA concentrations. This clustering is consistent with service-area-level differences in PFOA source-water concentrations rather than site-specific factors. Local Moran's I (LISA) analysis with false-discovery-rate correction did not identify significant individual hotspot or cold-spot sites, suggesting the PFOA pattern is a broad gradient across service areas rather than a localized cluster. No other variable showed significant spatial autocorrelation, including PFOS (p = 0.57), total PFAS (p = 0.11), microplastic count (p = 0.79), or any of the four metals

($p > 0.41$). The absence of clustering for metals is consistent with plumbing variability at the individual-building scale; for microplastics, the null result supports treatment efficacy — rather than geographic location within the network — determining tap-water particle counts.

The values shown in the Results are exploratory and should not be treated as official compliance samples.

LESSONS

Trials and Tribulations

Fieldwork and analytical challenges — and the methodological adjustments made in response.

In the field

Trial #1 · Seasonal water stations

Many outdoor water stations in Philadelphia's parks and recreation centers are seasonal, shut down around mid-to-late November to prevent freezing damage. Because sampling occurred in colder weather, many stations were already closed, requiring a large revision of the original sampling plan.

LESSON LEARNED

Conduct sampling outside peak shoulder seasons and winter months (November through early-to-mid March).

Trial #2 · Fountains without bottle fillers

Some water fountains lacked a bottle-filling component, making it difficult to collect enough water for the 1.5-liter microplastic jars. The team improvised by using the metal lid to deflect the low stream at an angle, collecting at least 1 liter.

Improvised collection at a low-stream fountain.

LESSON LEARNED

Bring a clean metal or plastic conduit to guide water into the jar, or carry smaller pre-cleaned transfer bottles. Pair any reusable equipment with a field decontamination kit (deionized water and/or clean wipes) to reduce cross-contamination.

Trial #3 · Unexpected library closures

Some libraries were closed despite their websites indicating otherwise — especially challenging in Belmont-served areas, where sampling options were already limited. Even backup sites were sometimes closed on arrival.

LESSON LEARNED

A single backup plan is not always enough for fieldwork. Build in a second layer of backup locations, especially in service areas where suitable sites are already limited.

Trial #4 · Fractured sampler head

On January 12, the sampler head fractured in the field. A repair was executed on-site using a standard L-joint with universal 3/4-inch threading sourced from a local hardware store; a neoprene collection bottle was secured to the modified head with duct tape. Strict decontamination procedures were maintained throughout.

On-site repair of the fractured sampler head with an L-joint.

LESSON LEARNED

Bring extra sampling poles if available; otherwise, carry DIY repair material as a next-best step.

In analysis

Trial #5 · No public pipe maps

The team wanted to understand how water moves from plants to taps using actual pipe and water-main maps, but detailed distribution-line maps were not publicly available — likely sensitive infrastructure data. The road network was explored as a proxy for the pipe network.

LESSON LEARNED

When direct infrastructure data are unavailable, be clear about what is used as a proxy and what assumptions are made. Road-network routing was explored but not used in the final analysis, since pressurized distribution networks (and many other utilities) are too infrastructurally complex to simplify with road centerlines.

Trial #6 · No plant access

Samples could not be collected directly from the treatment plants, so source water could not be directly compared to tap water using the team's own field data.

LESSON LEARNED

Future source-to-tap studies should plan early for how "source" conditions will be represented if direct plant access is impossible. Here, that meant relying on PWD Drinking Water Quality Reports and EPA UCMR 5 data to approximate conditions near the distribution-system entry point.

Trial #7 · Timing of secondary data

Because source-side data came from secondary sources, timing became a limitation: if tap samples are collected far from official monitoring dates, source-to-tap comparisons become harder to interpret.

LESSON LEARNED

Align tap sampling as closely as possible with official monitoring periods. PWD's UCMR 5 results show Baxter, Queen Lane, and Belmont were sampled quarterly in 2024, but are reported by quarter rather than exact date — so future tap sampling within the same quarter as PWD/EPA monitoring would make comparisons more defensible.

Trial #8 · Exploding frozen jars

Some trace-metal samples lacked large enough air pockets for safe freezing. As a result, several glass mason jars exploded, leaving the team unable to report results for the locations they represented.

A burst frozen sample, bagged after the jar fractured.

LESSON LEARNED

For samples that must be frozen, measuring the minimum air space required should be part of the protocol. It is also important to be cautious in mixed-service areas, where a tap may receive water from more than one plant and is harder to link back to a single source.

Special Thanks

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