

INVESTIGATION OF DIFFUSE PFAS CONTAMINATION IN URBAN AREAS AND THE RISK TO GROUNDWATER

NORDROCS
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Katerina Tsitonaki, WSP Denmark

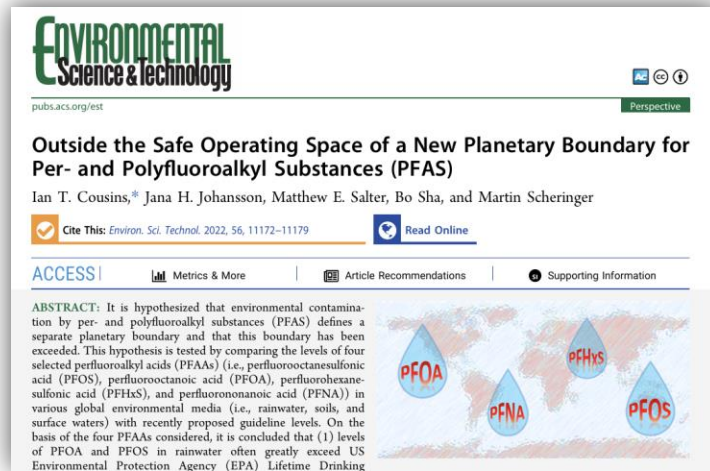
Co-authors

Karen Andreasen (former WSP), Paul Hurst and Katrine Smith, WSP
Ditte Lykkesborg Schrøder and Maria Hag, Capital Region of Denmark



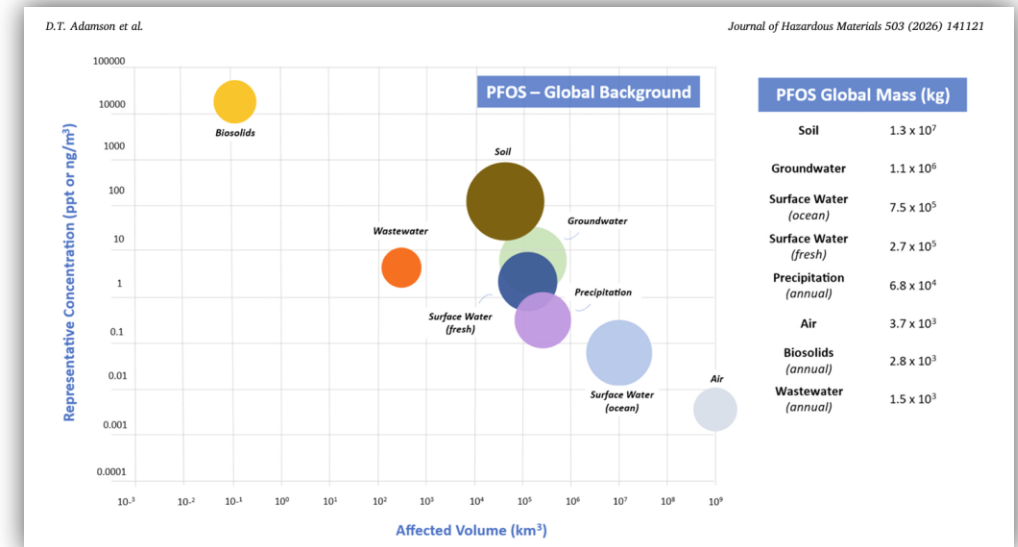
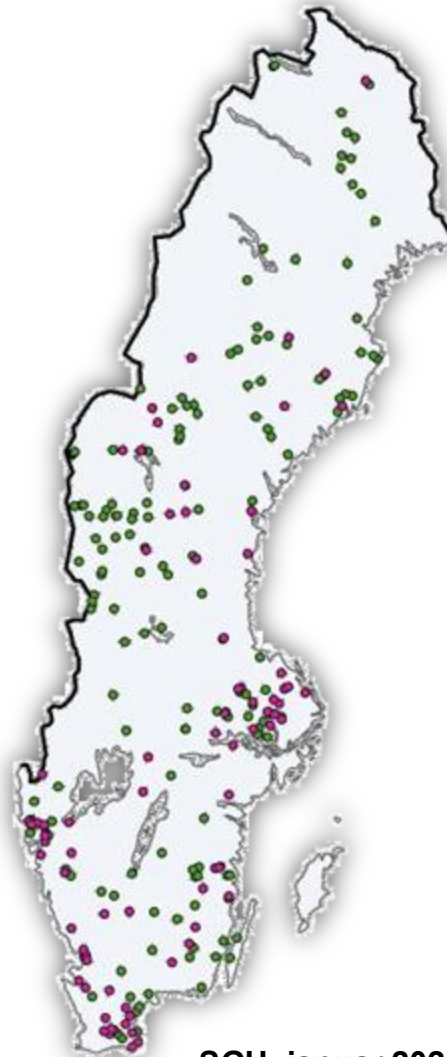
WSP Anthropogenic background levels of PFAS

Fynd av PFAS exkl. ultrakorta substanser



”PFOA and PFOS in rainwater often exceed the Danish drinking water limit values.”

”Atmospheric deposition leads to global soils being ubiquitously contaminated”





Typical concentrations of PFAS*

**mostly Danish data*

PFAS 4 ng/l
PFAS 22 ng/l

Fire-fighting training grounds

NOTE! Only regions DK
80% percentile groundwater
1100 / 2600

Rain (ng/l): **0.74 / 2.7, Danish EPA**

Danish EPA: Sea foam,
West Jutland

Up to 17,000-250,000 ng/l!

Porewater under
sludge-treated
fields (ng/l)
2.8 / 6.5

Contaminated sites

Danish regions data
80% percentile groundwater ng/l
51 / 110
80% percentile soil (µg/kg DM)
33 / 74

Drainage water from artificial turf
pitches (ng/l)

3/8:



DANVA: Wastewater
inlet to treatment plant
4.1 / 11



When it comes to risk assessment of contaminated sites

How can we assess and distinguish:

- Significant contributions from contaminated sites sources
- Minor contributions from registered contaminated sites
- Anthropogenic background from other activities

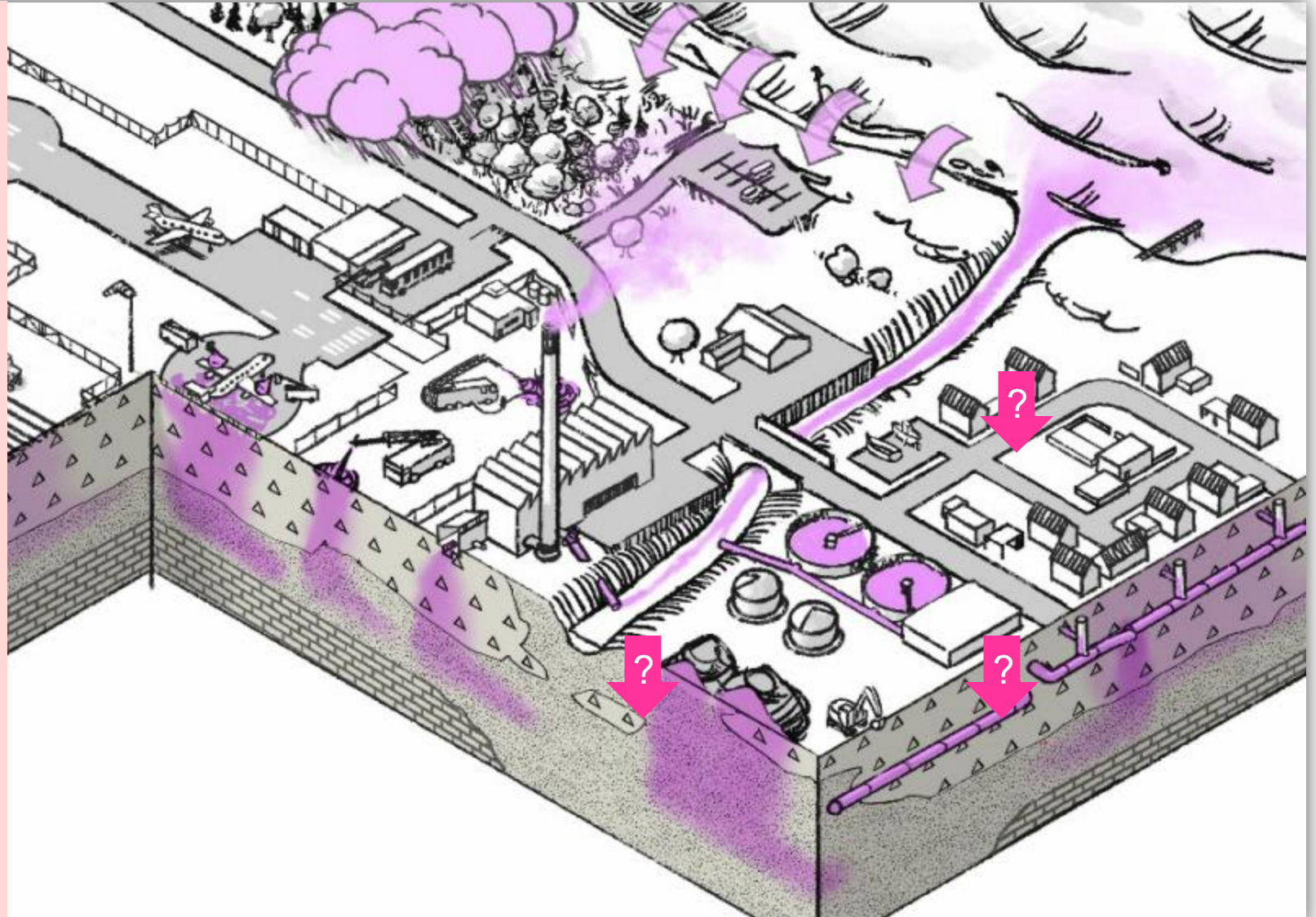
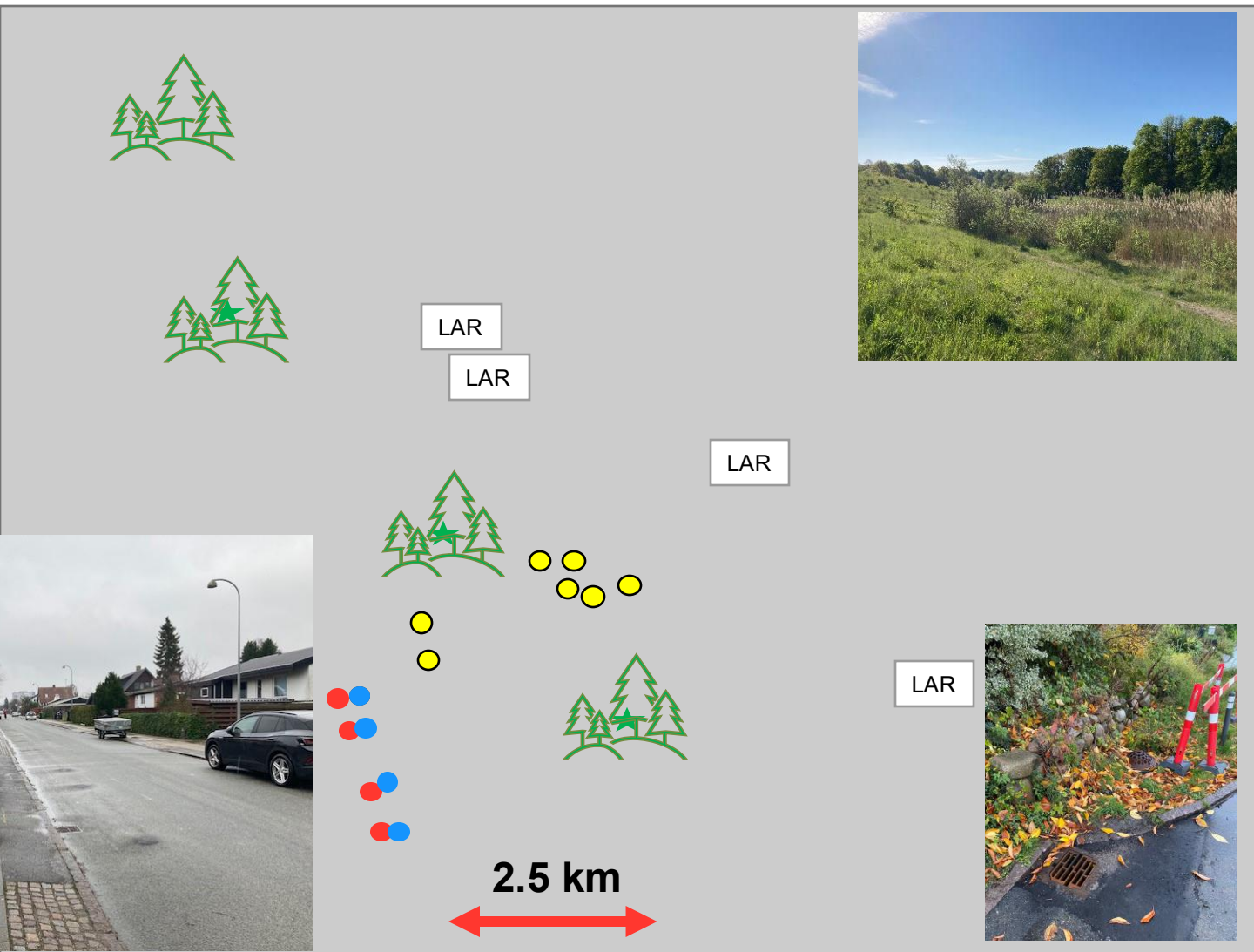


Figure modified from Morsing et al., 2025

Sampled several areas in a suburban area in the Capital Region of Denmark



REGION Hovedstaden



Pore water and soil samples from green areas
PFAS 73; PFAS 73 + TOP



Known contaminated sites
PFAS 73; PFAS 73 + TOP



Boreholes near leaking sewers
PFAS 73; PFAS 35 (TOP)



Wastewater from a residential area
PFAS 41; PFAS 30 TOP

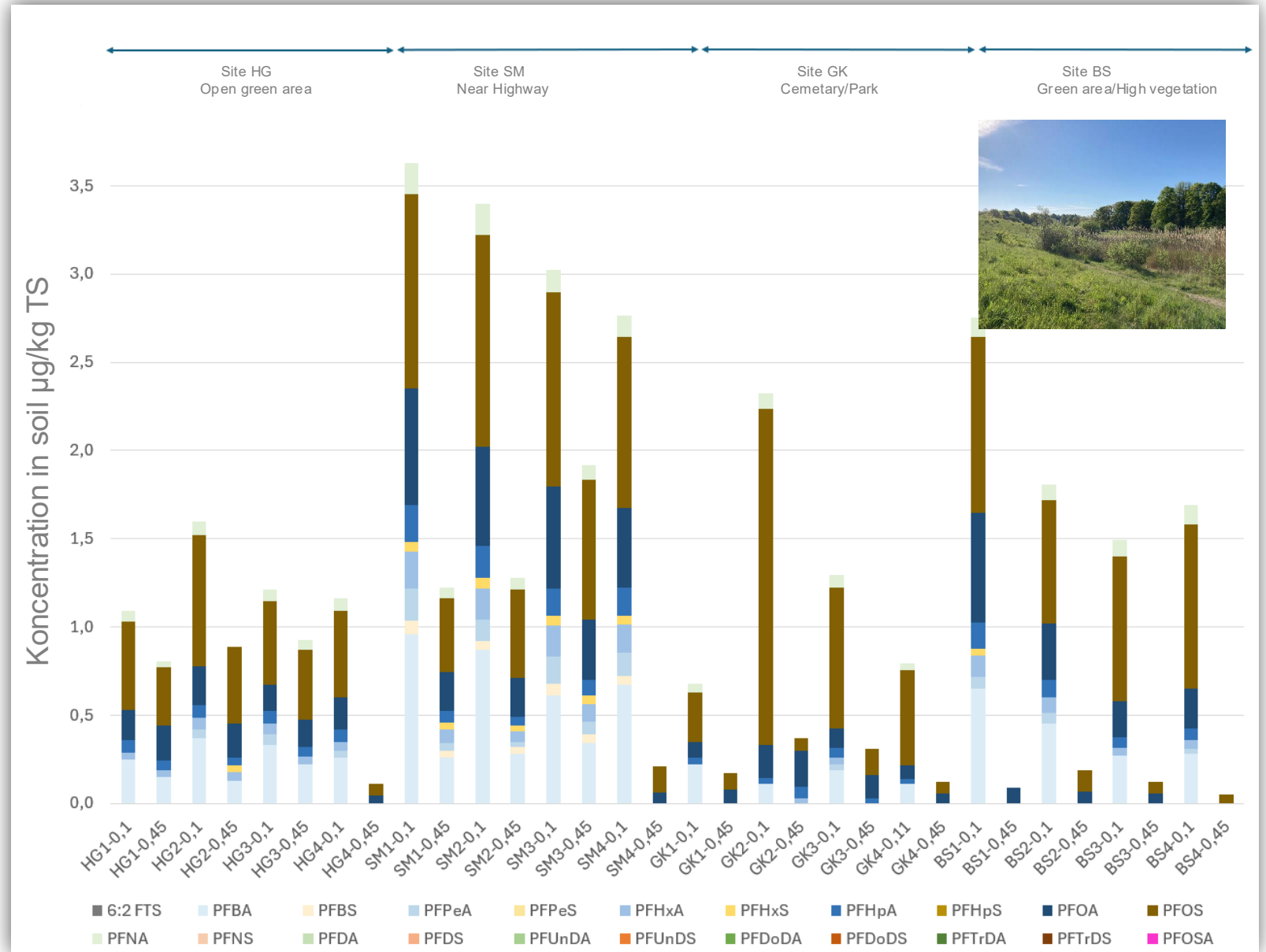
LAR

Stormwater Infiltration Systems
PFAS 73; PFAS 35 (TOP)



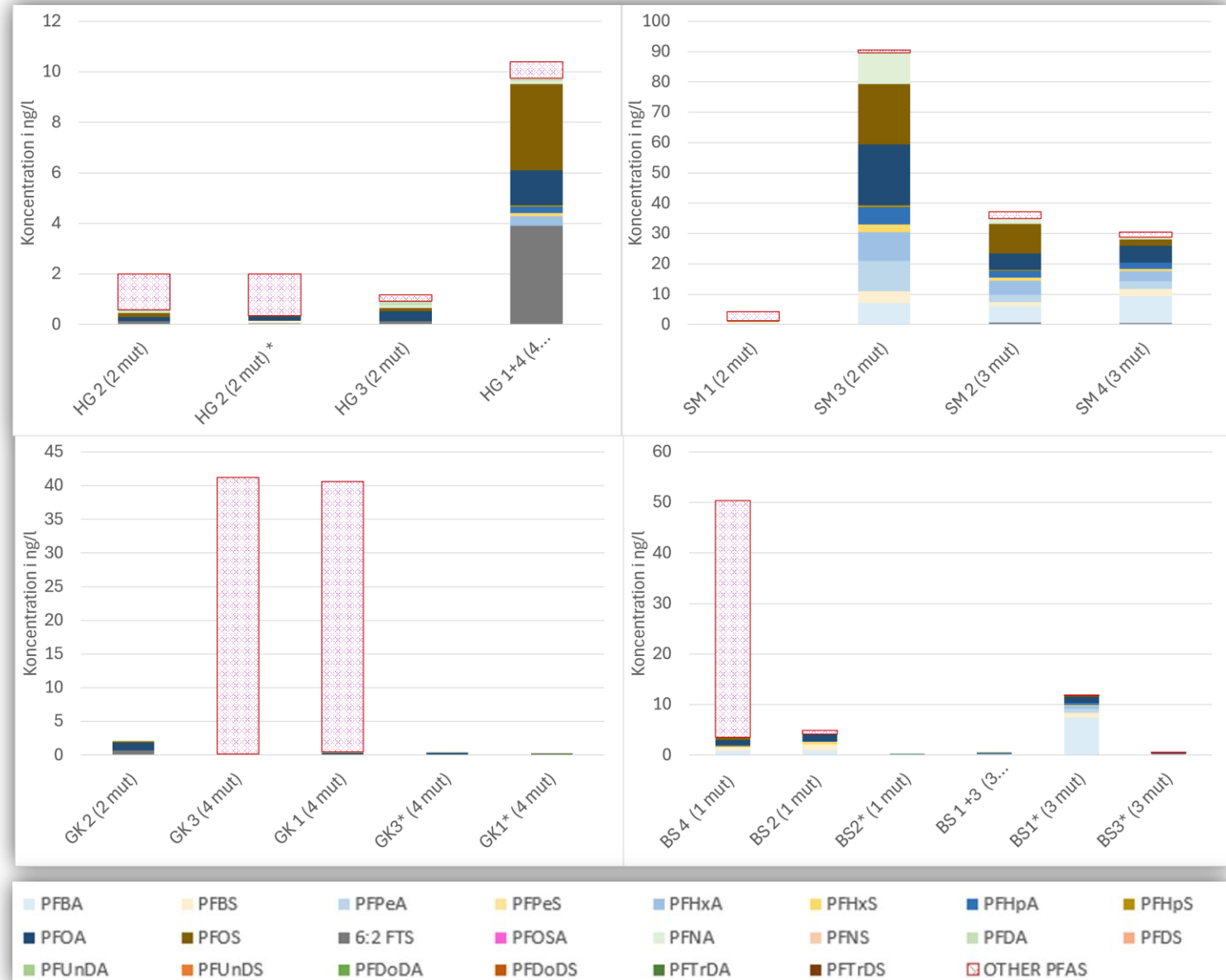
PFAS in soil from green areas

- Only PFAS 22 detected, and highest in the surface soil (approx. 0.5-4 µg/kg DM)
- Replicates from the same area agree well
- Composition differs slightly at SM, next to the motorway and a stormwater outlets
- Soil impact is concentrated in the top 10 cm.
- PFAS4: 1.25 ± 0.55 µg/kg DM
- PFAS22: 1.92 ± 0.91 µg/kg DM



PFAS in porewater from green areas

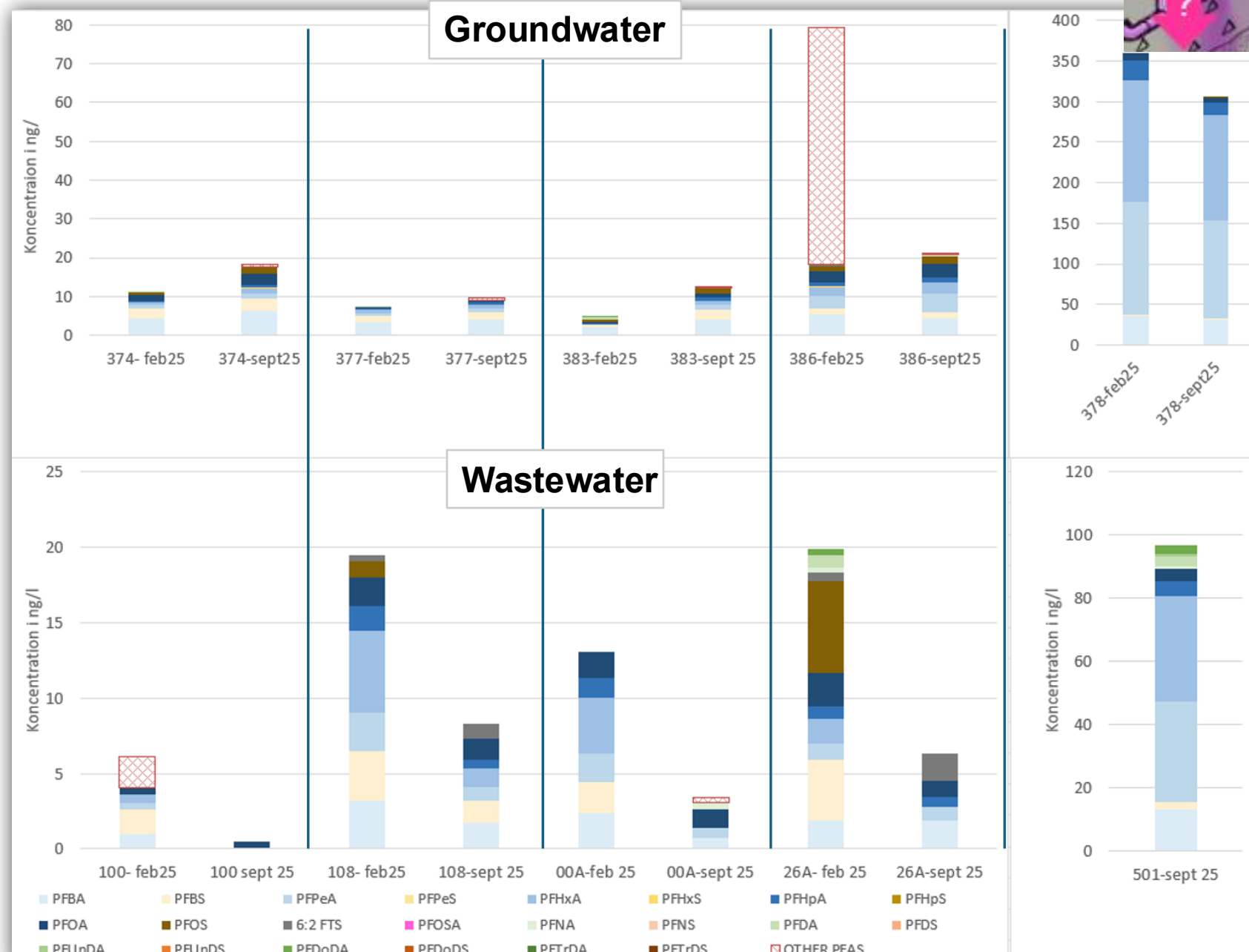
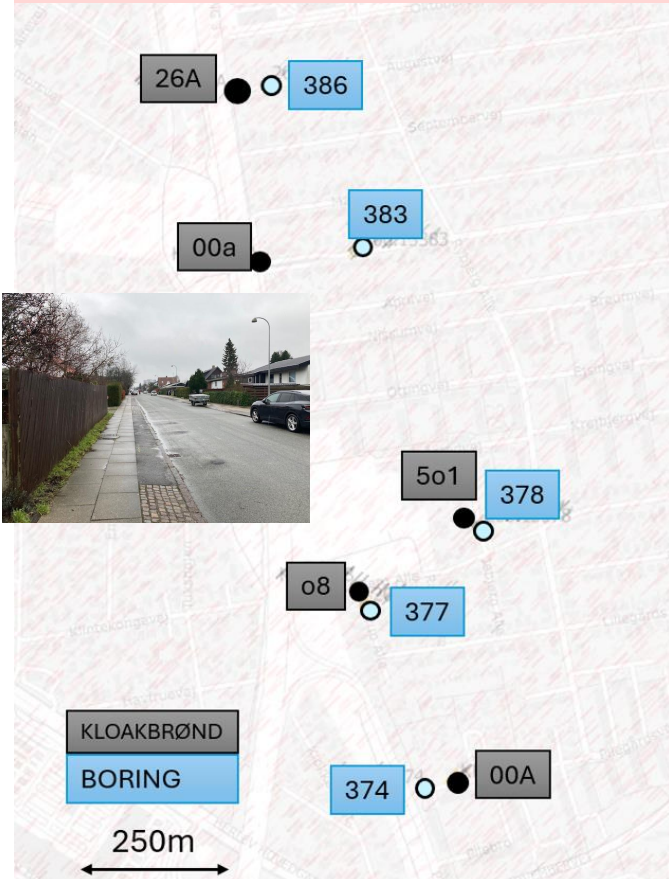
- PFAS4: 0,5 – 19,8 ng/l
 - PFAS22: 0,8-37,8 ng/l
 - PFAS detected in all four green areas
 - Several compounds beyond PFAS 22 were detected,:
- ⑩ Perfluoro(perfluoroethyl)-cyclohexanesulfonic acid (9/19 samples, <0.5 ng/l)
 - ⑩ 5:3, 6:2 and 7:3 FTCA.





PFAS in groundwater near sewers and in wastewater

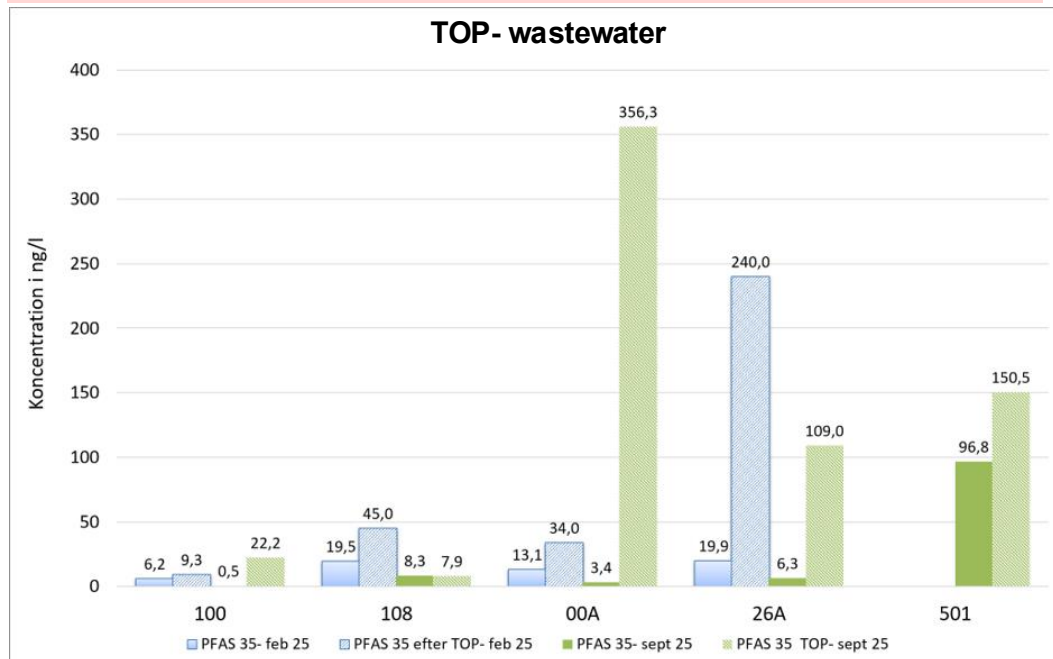
- Primarily PFAS 22 at levels of 10-20 ng/l
- However, VERY high concentrations of 350 ng/l in one of the boreholes!
- Levels were pretty consistent across both monitoring rounds
- FPePA and PFBSA in groundwater



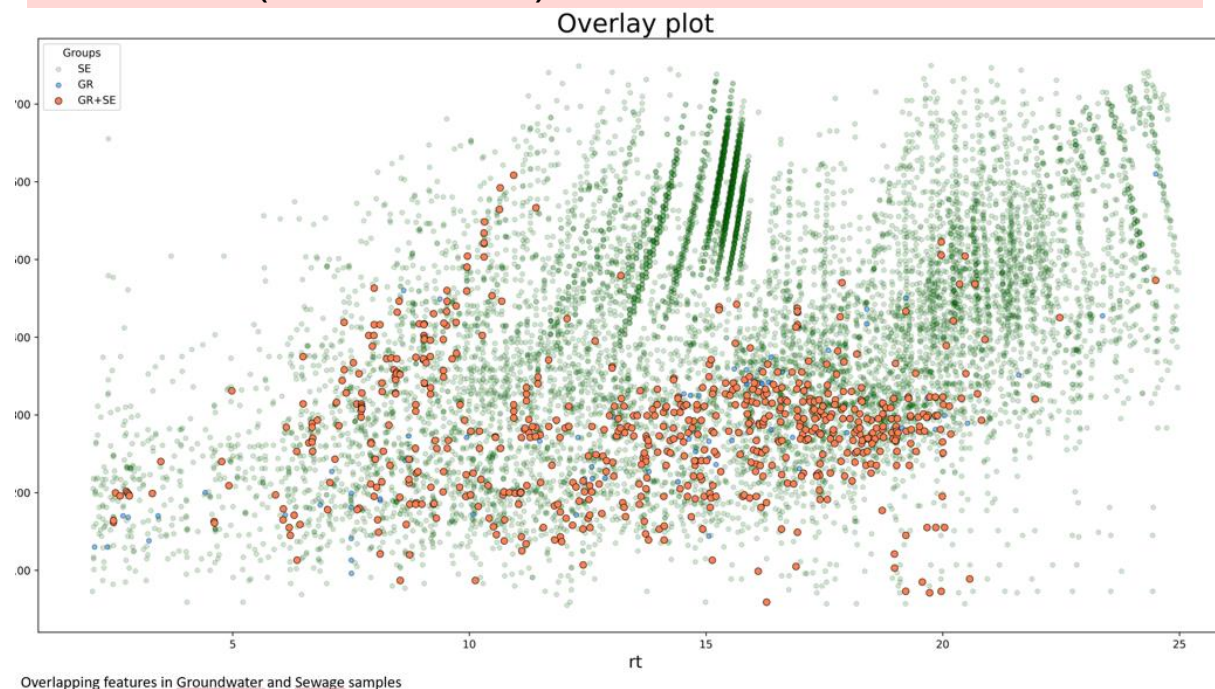


Linking groundwater near sewers with wastewater

TOP analysis shows substantial levels of precursors in wastewater — often coinciding with high PFAS levels in the groundwater



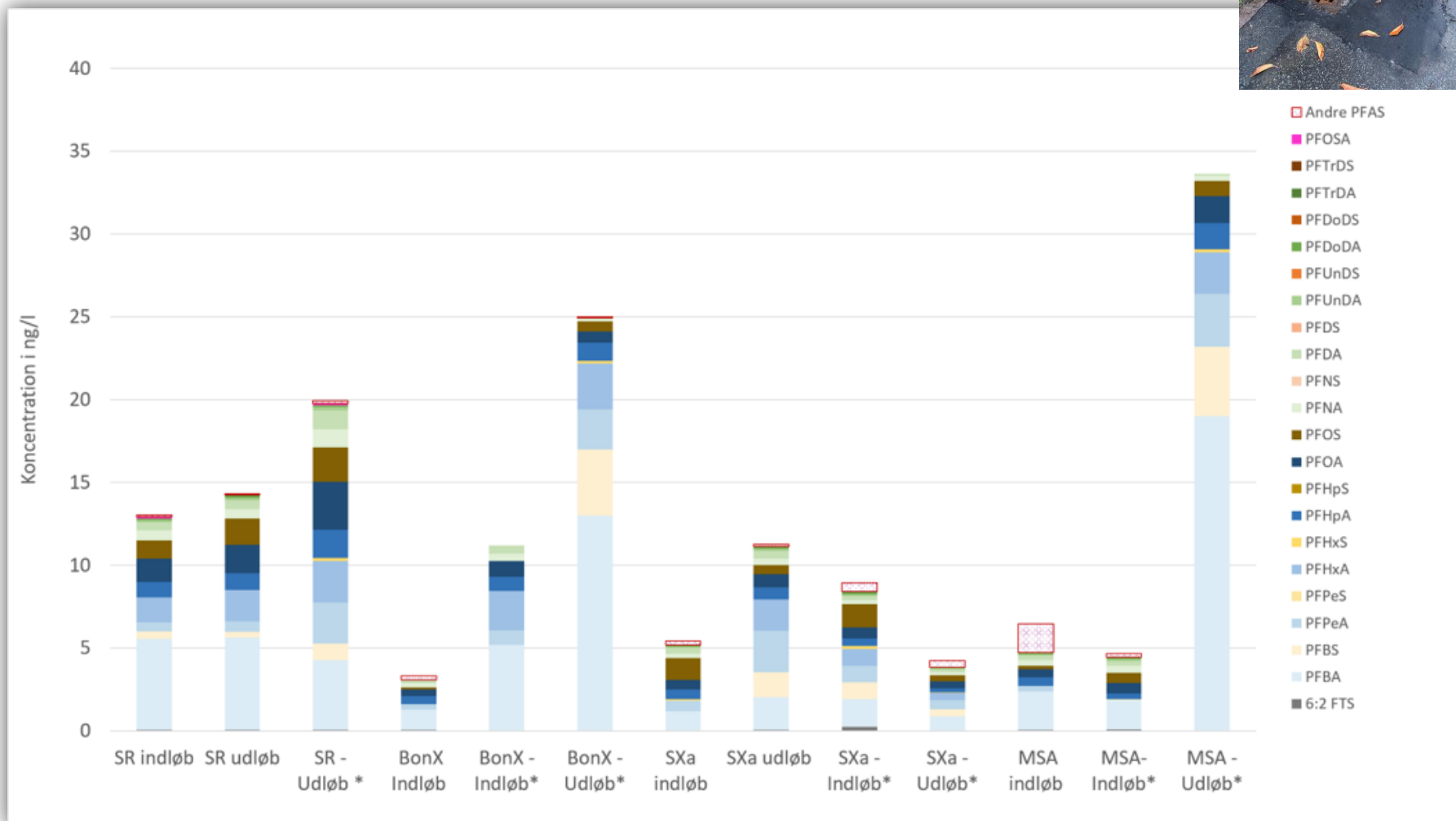
The presence of several pharmaceuticals and caffeine in the groundwater samples indicates wastewater influence (Bovali, 2026).



PFAS in stormwater runoff



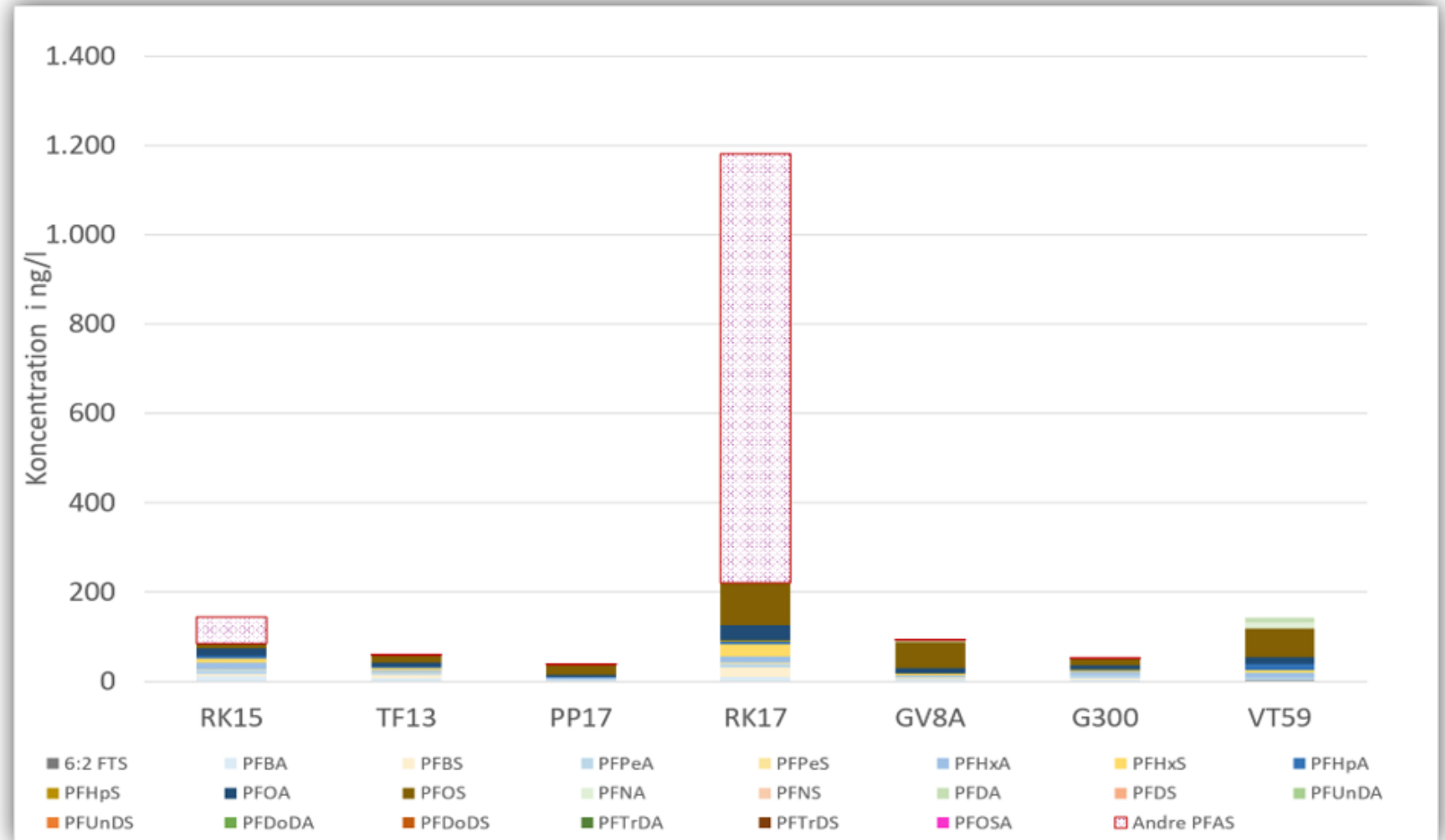
- Mostly PFAS 22, up to 35 ng/l
- Outlet concentrations often exceed inlet
- Carboxylic acids dominate
 - ⑩PFOA, PFHpA and PFBA are present in every sample.
 - ⑩PFNA, PFDA, PFUnDA and PFDoDA appear in nearly all inlet samples and in many outlet samples.
- PFOS was detected in the filter media
- PFOS is the only sulfonic acid found in many samples (11 of 13) at 5-15% of the total concentration.
- Detected several PFAS beyond PFAS 22: *PFBSA*, *Perfluoro-4-(perfluoroethyl)cyclohexylsulfonic acid*, *EtFOSAA*, *MeFOSAA*, 8:2 FTS, *PFTeDA*, 8:2 diPAP, 6:2 FTCA, *HPFHpA*





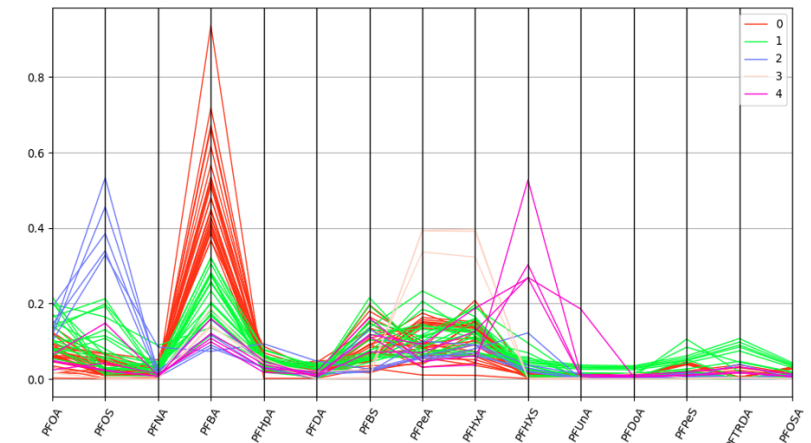
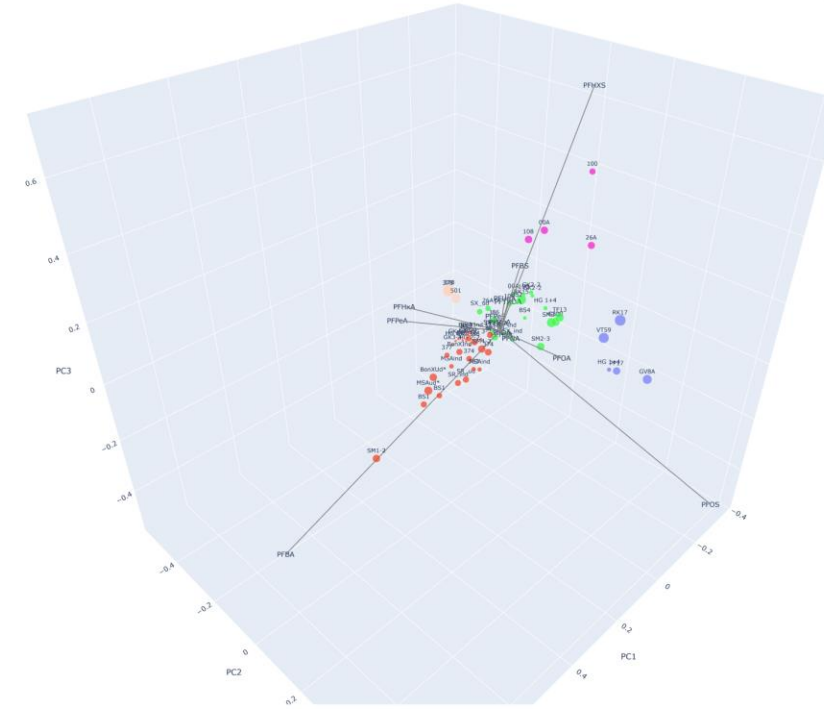
PFAS at known contaminated sites in the same urban area

- PFAS4: average 63 ng/l
- PFAS22: average 98 ng/l
- PFOS dominating
- Detected several PFAS beyond PFAS 22:
MeFOSAA, NEtFOSAA, PFTeDA, PFecHS and similar, PFPrS, PFBSA, PFHxSA, FOSAA, 8:2 diPAP



What the multivariate analysis reveals?

- We used PCA, HCA and UMAP to understand the data
- Point sources are clearly different from other sample types and **are marked by high PFOS fractions.**
- **Wastewater** forms its own clusters, driven mainly by **PFHxS** and **PFBS**.
- Green areas, infiltration systems and groundwater at sewers overlap far more, typically dominated by **PFBA**.
- Some clusters map to a specific source type; others hold mixed, low-concentration samples with less distinct profiles.
- The results show that **PFAS composition can be used as a tool for source differentiation**, especially to identify point source impacts.





Source identification needs multiple evidence, not a single compound or exceedance

Signs of a point source

- High concentrations
- Repeated, reproducible detections
- Clear PFOS-dominated profile (or another specific compound like PFOA)
- Different from the surrounding PFAS profiles
- Known local use of PFAS

Signs of background impact

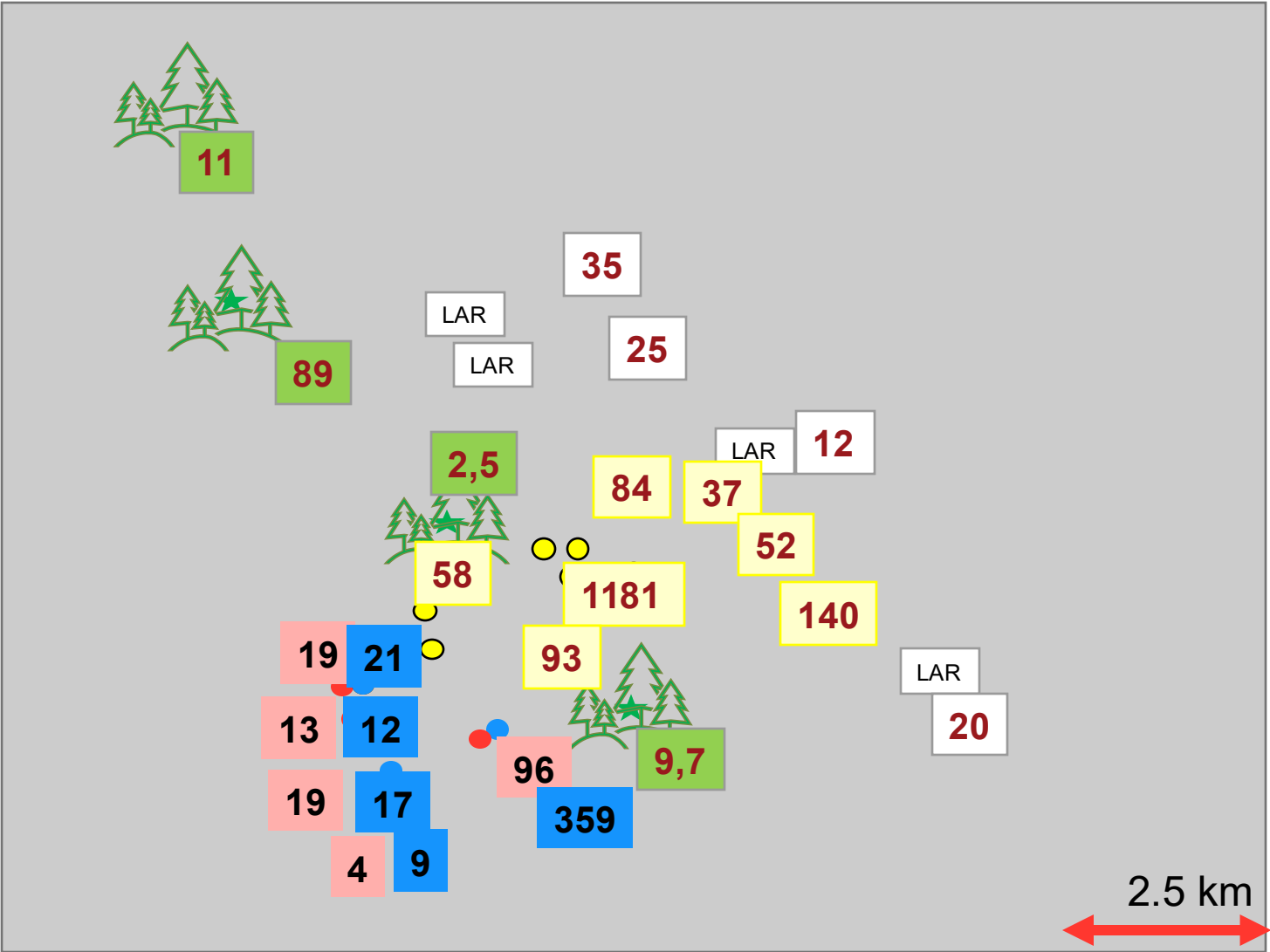
- Low Concentrations similar to literature or local background
- Wider profiles with more **mobile, short-chain PFAS in water**
- No known significant PFAS activity at the site

The grey zone:

- Local and diffuse contributions often cannot be separated unambiguously
- **PCA, HCA and UMAP** help separate sample types and source environments — but a chemical fingerprint alone is not proof of a source
- Strongest candidate indicators: **FTCA (5:3, 6:2, 7:3) and PFECHS**
- PFBSA in 8 of 10 groundwater samples at sewers — but not source-specific
- No compound is conclusive on its own; the **profile** carries more weight than any single substance



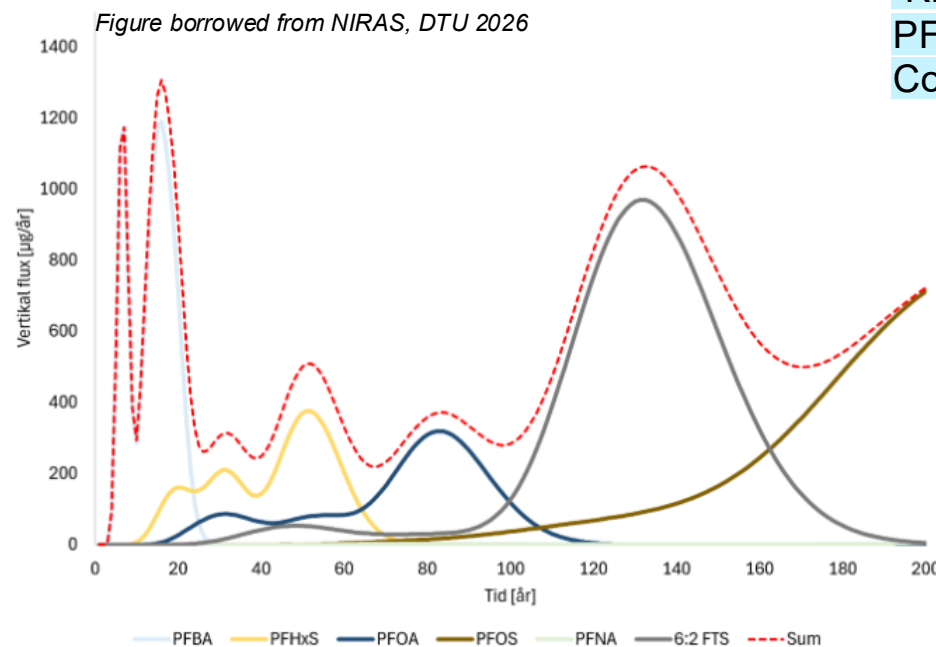
PFAS22 concentrations (ng/L)



- Pore water in green areas
- Known contaminated sites
- Boreholes near sewers
- Wastewater from a residential area
- Stormwater Infiltration Systems

From concentrations to mass flux to groundwater

- Concentration tells us what is present — flux tells us what actually reaches the groundwater
- Mobile, short-chain PFAS such as PFBA can produce high short-lived peak fluxes
- Long chain compounds like PFOS may be retained for decades in the unsaturated zone

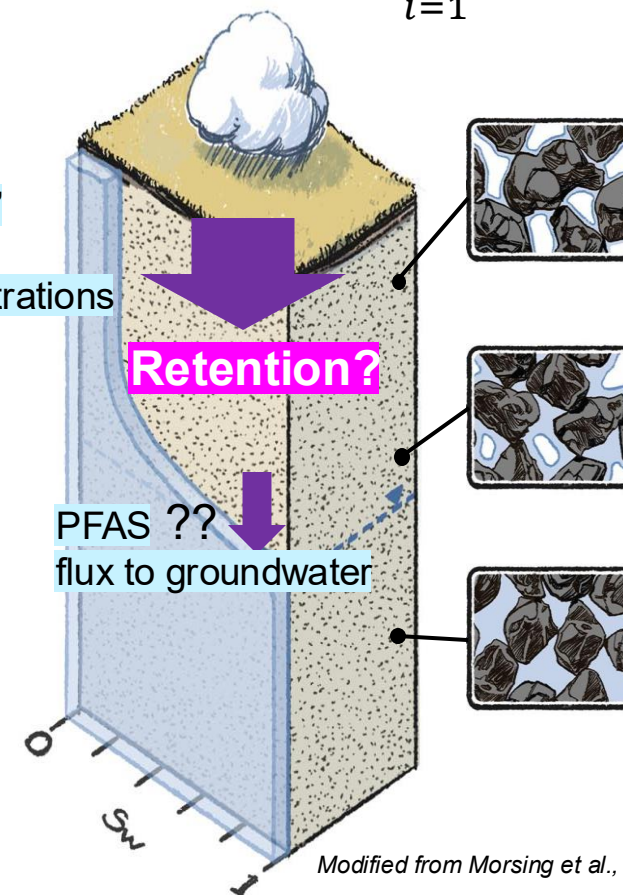


"Known"
PFAS
Concentrations

Retention?

PFAS ??
flux to groundwater

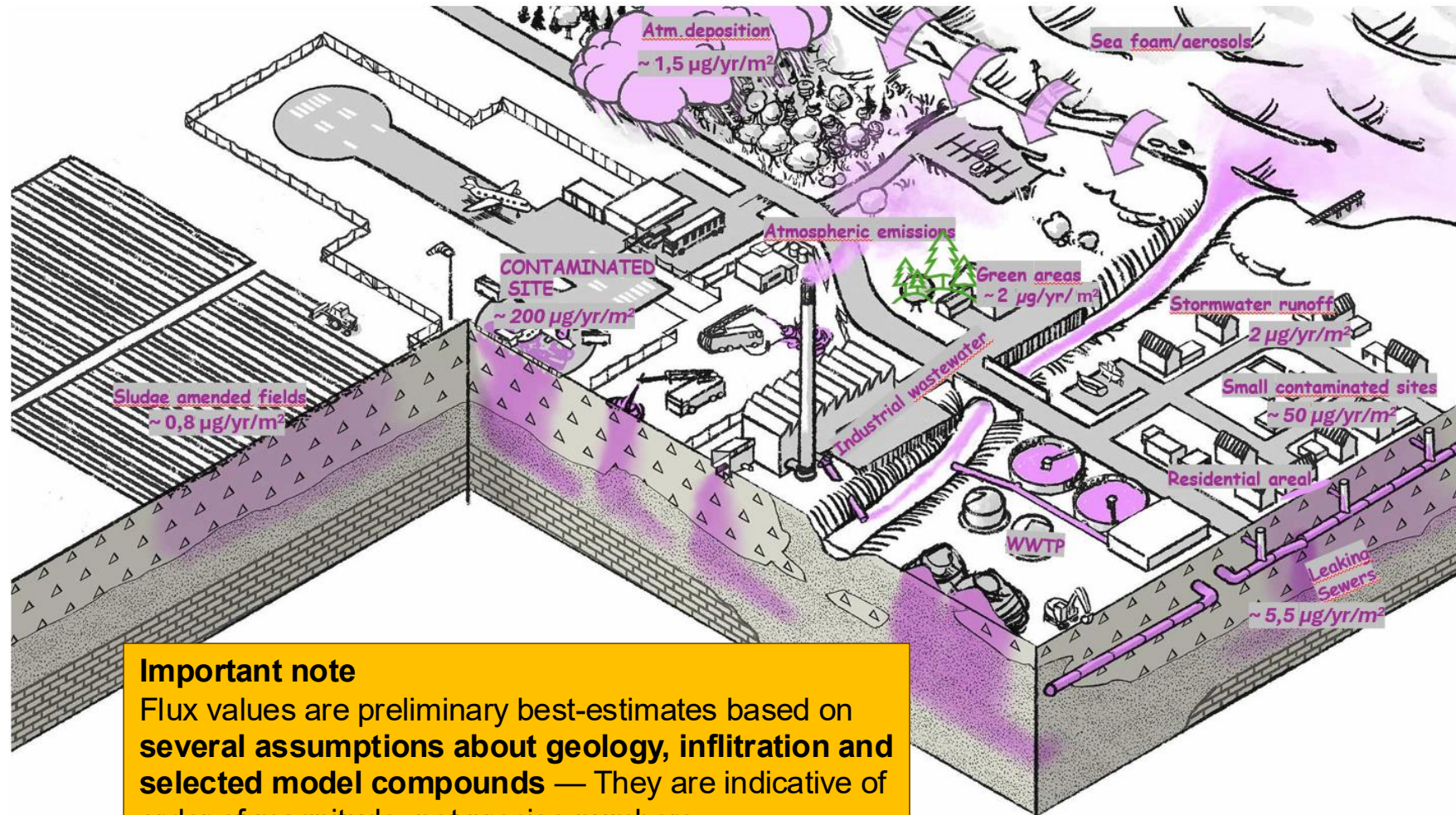
$$J = \sum_{i=1}^n C_i \cdot A_i \cdot I_i$$



Modified from Morsing et al., 2025



Updated conceptual model with estimated fluxes



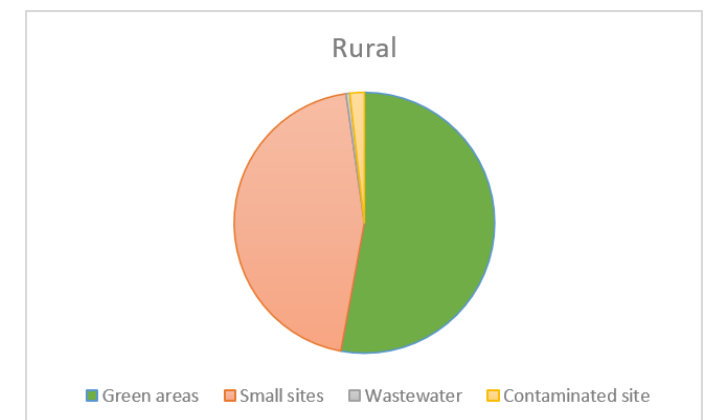
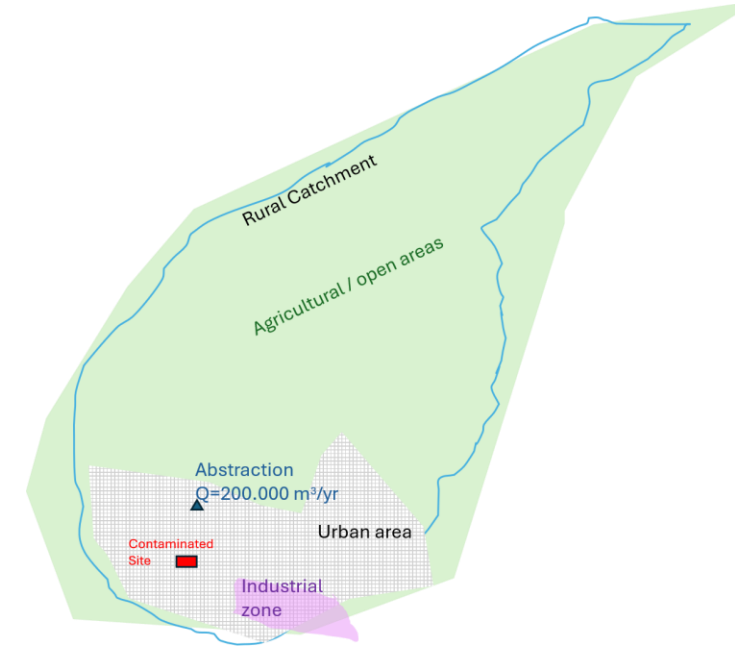
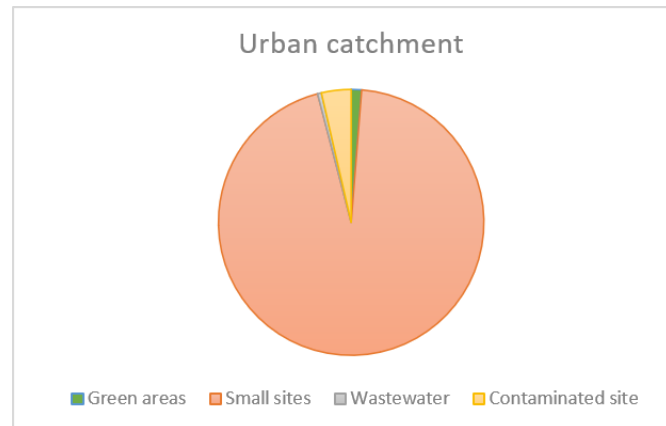
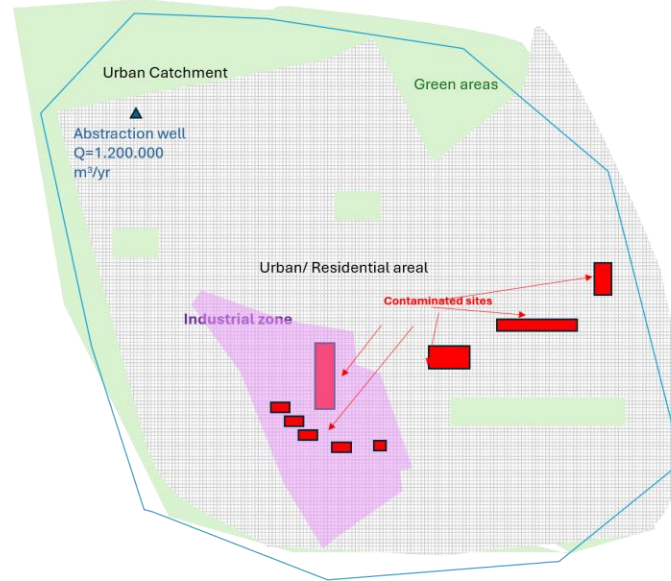
Important note

Flux values are preliminary best-estimates based on several assumptions about geology, infiltration and selected model compounds — They are indicative of order of magnitude, not precise numbers.



Should risk assessment move from site scale to catchment scale?

- Point sources may dominate locally
- Background inputs can be significant at catchment scale
- Concentration alone does not describe the total load. Low concentrations occurring over large areas and long time periods can result in a substantial mass flux.
- Future risk assessments should therefore evaluate whether a given site contributes significantly beyond the expected anthropogenic background level.



Take home message

- PFAS concentrations are best assessed against the expected background level
- A specific source may be indicated when both level and composition stand out
- Consider the full picture: level, profile, geology, land use and site history — no single substance is conclusive on its own
- Standard packages may under-report — TOP analysis and wider panels are worth considering where precursors or indicator compounds are of interest.
- Urban infrastructure can be a source in itself — leaky sewers and stormwater infiltration. Non-PFAS co-tracers such as pharmaceuticals and caffeine can strengthen the source allocation
- Tools like PCA, HCA and UMAP can help interpretation

