PMT/vPvM chemicals in agricultural wastewater reuse - potential for human exposure and ground water contamination

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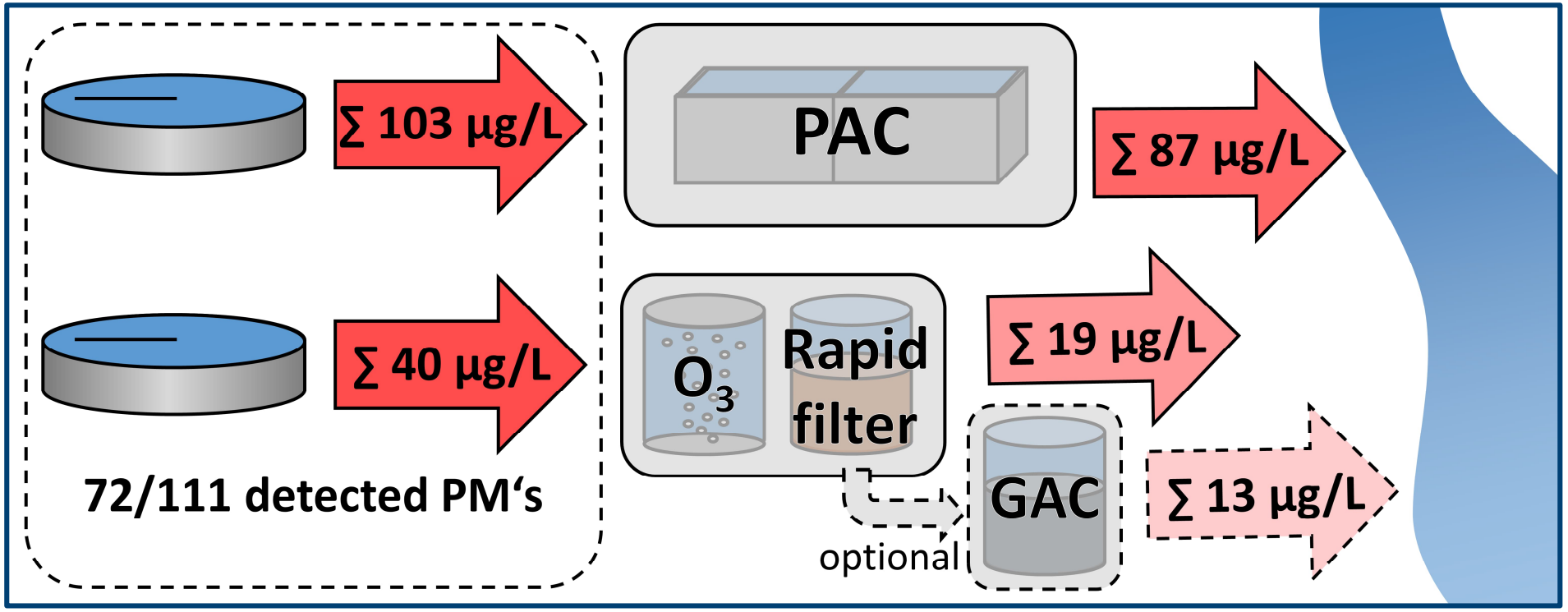
ZeroPM final workshop
9th of September 2026

Motivation
Water Scarcity

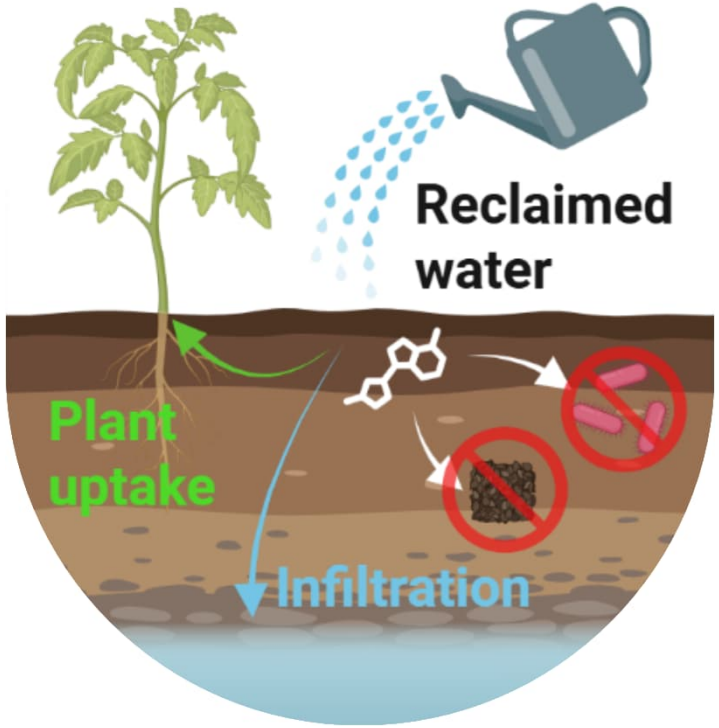
- Agriculture responsible for 71% of global freshwater withdrawal

Motivation

Poor Removal of PM Chemicals in Advanced Wastewater Treatment



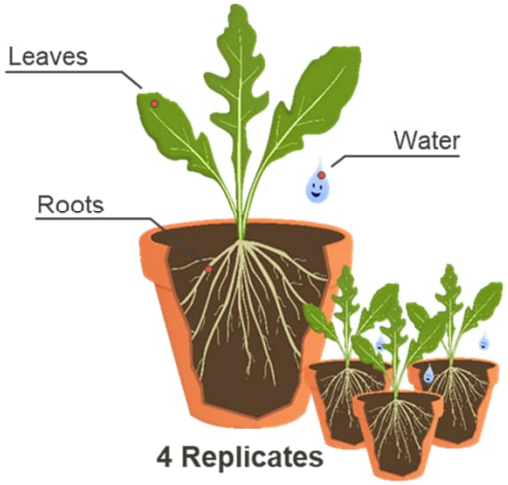
Motivation
Wastewater Reuse



Research Question & Scientific Approach

Which **P**ersistent, **M**obile, (and **T**oxic) chemicals have the highest potential for…

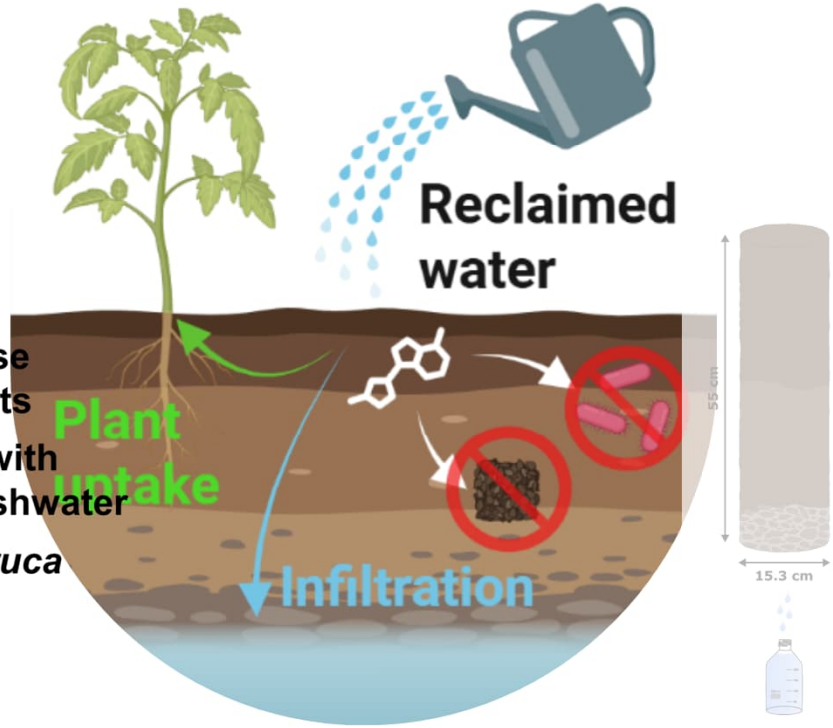
Plant uptake



Greenhouse experiments

Irrigation with spiked freshwater

Rocket (*Eruca sativa*)



Infiltration

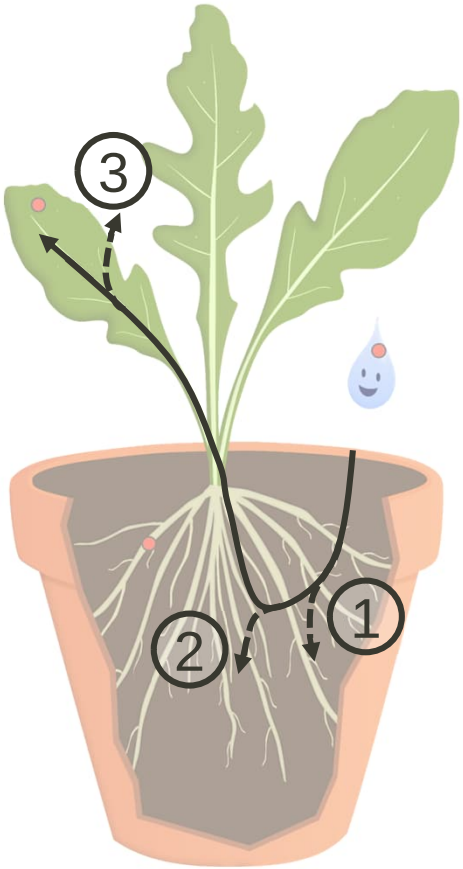
Operated outdoors for 37 weeks

30 cm topsoil, 20 cm subsoil, and 5 cm gravel

Irrigated to 110% field capacity with spiked wastewater

Plant Uptake

The Relative Uptake Concept

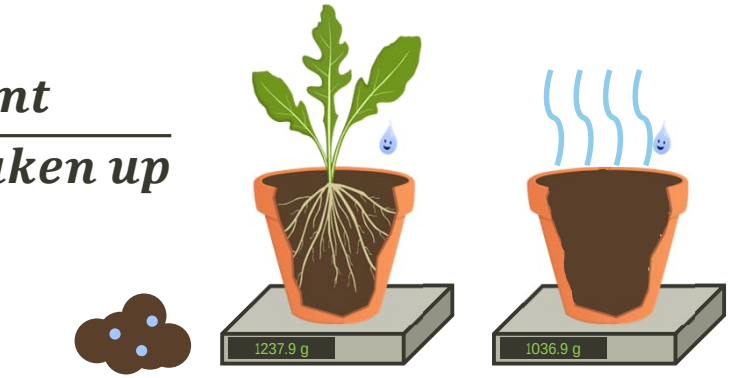


Concentrations of chemicals in plant parts can be influenced by:

1. Sorption to soil (likely less relevant for PM-chemicals)
2. Amount of water taken up by plant
3. Elimination (e.g. volatilization, transformation)

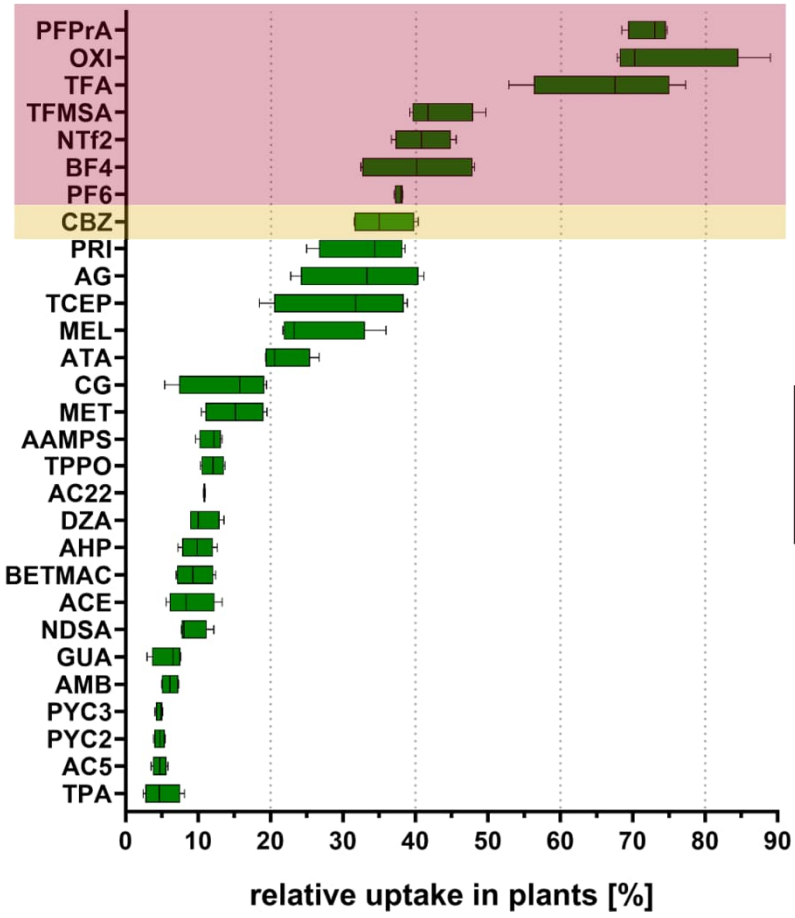
Likely large variation between experiments and rarely taken into consideration!

$$RU\% = \frac{total\ amount\ in\ plant}{total\ amount\ in\ water\ taken\ up}$$



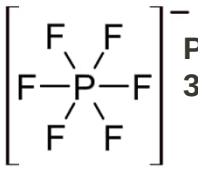
Remaining water | Irrigation | Evaporation

Plant Uptake
Relative Uptake

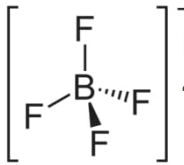


- **Carbamazepine (CBZ)** with a median RU of **35%**
- **44 chemicals** with an RU **below 20%**
- **Seven chemicals** with a higher RU than **Carbamazepine**

2 Inorganic ions

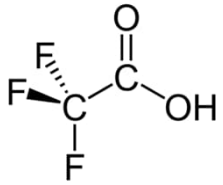


PF_6^-
38% RU

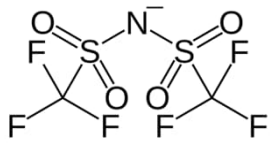


BF_4^-
40% RU

4 PFAS

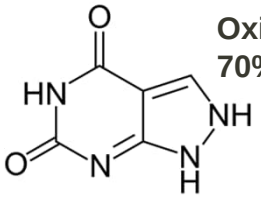


Trifluoroacetic acid (TFA)
67% RU

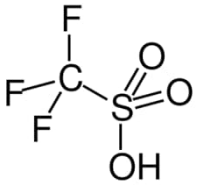


Bistriflimide (NTf_2)
41% RU

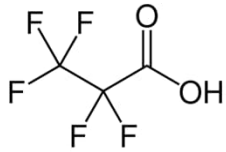
1 Pharmaceutical



Oxipurinole (OXI)
70% RU



Trifluoromethanesulfonic acid (TFMSA)
42% RU



Perfluoropropionic acid (PFPrA)
73% RU

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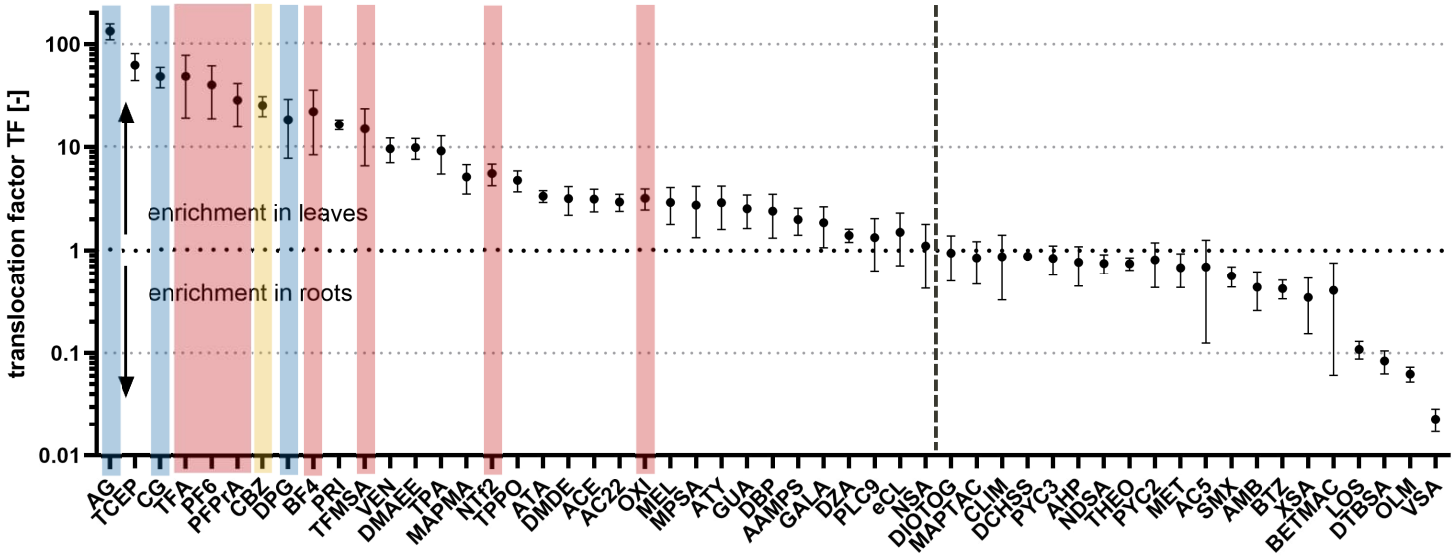
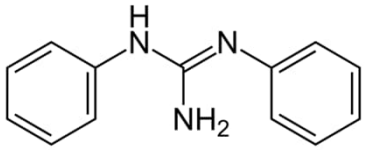
Plant Uptake

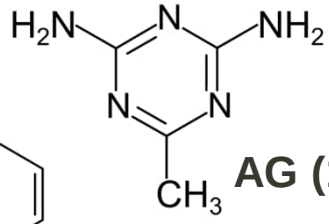
Translocation of PM-chemicals in Rocket



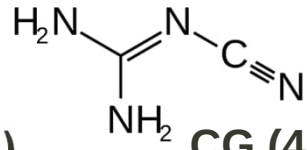
- **34 PM** chemicals **TF > 1**
- **CBZ** with TF of **23**
- **PFAS** and **inorganic ions** show TFs between **5 and 43**
- **OXI** with TF of **3**
- **3 guanidines with high TF**

DPG (20)





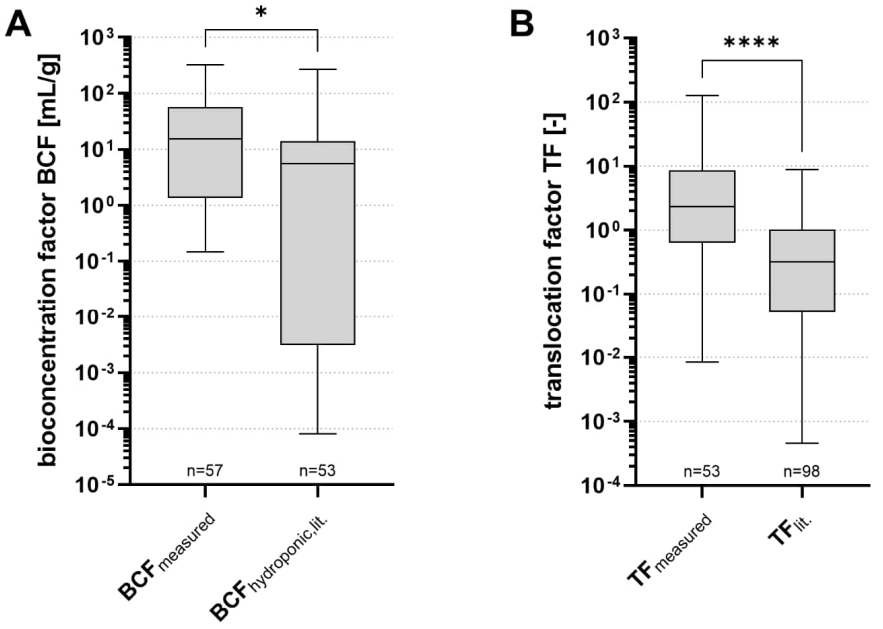
AG (132)



CG (48)

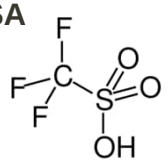
Results and Discussion

Comparison to literature data for less polar chemicals



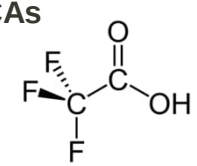
- RU not widely used so BCF was calculated
- Low sorption to soil so comparison with hydroponic experiments
- Only experiments with rocket, lettuce or spinach and long cultivation times (21-55 days) considered
- Stronger bioaccumulation ($p \leq 0.05$) and translocation ($p \leq 0.0001$) than less polar chemicals from literature
- High uptake of TFMSA is remarkable since PFSAs usually show much lower uptake than PFCAs

TFMSA

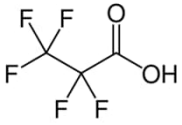


BCF: 188

PFCAs



BCF: 294



BCF: 312

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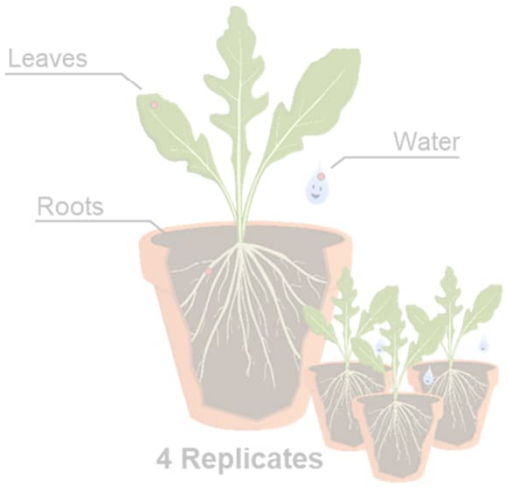

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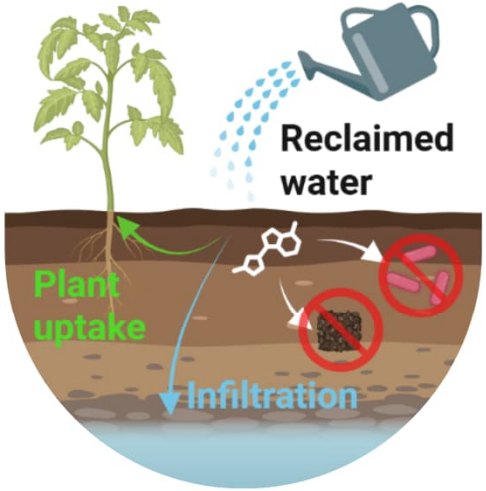
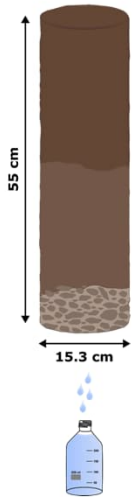


Infiltration



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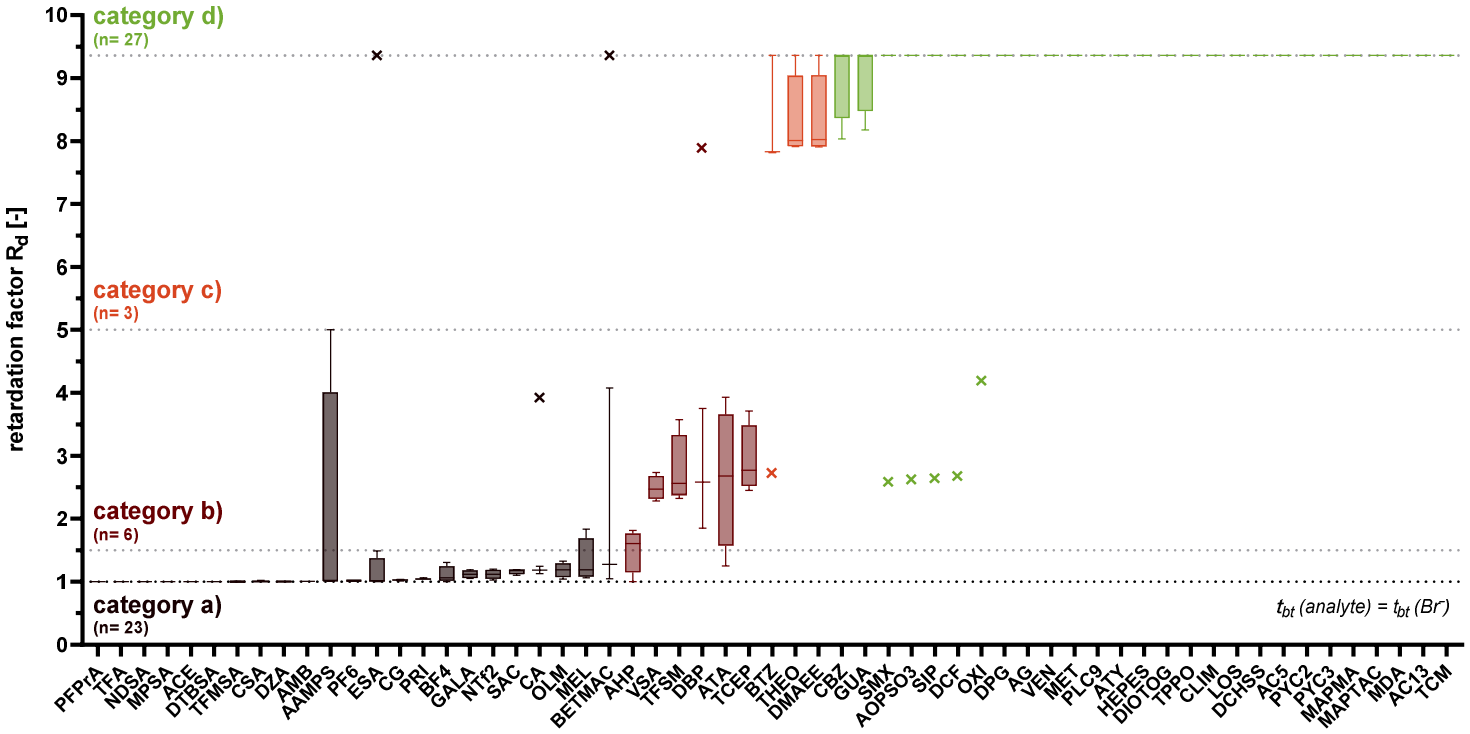
30 cm topsoil, 20 cm subsoil, and 5 cm gravel

Irrigated to 110% field capacity with spiked wastewater

Infiltration
Retardation Factors



Retardation coefficients (R_d) calculated based on bromide tracer:

Category a: R_d < 1.5

Category b: R_d 1.5-5

Category c: R_d > 5

Category d: no elution during experiment run time

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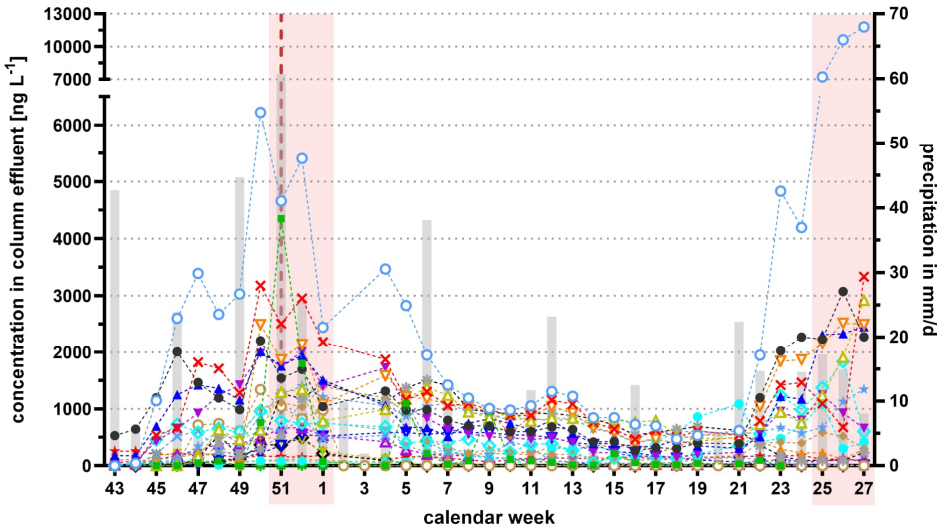
Infiltration
Breakthrough curves

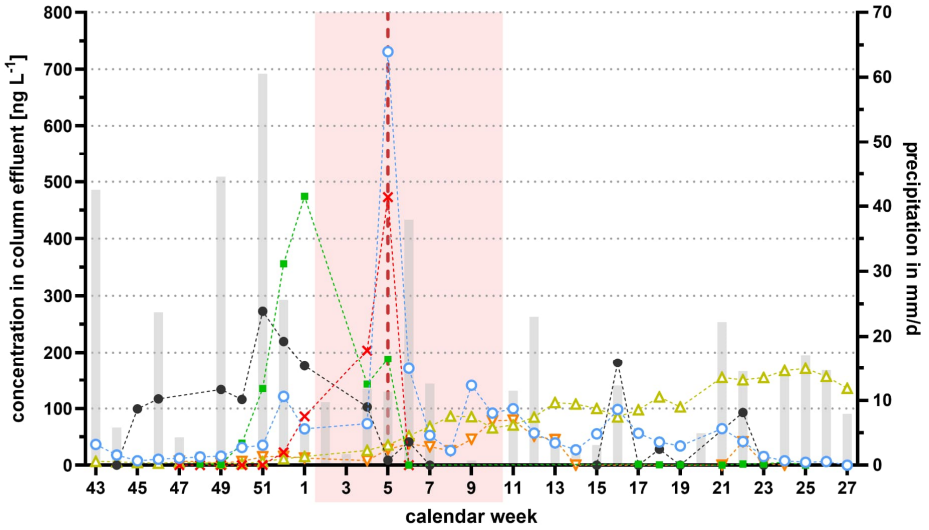
Category a: R_d < 1.5

A



Category b: R_d 1.5-5

B



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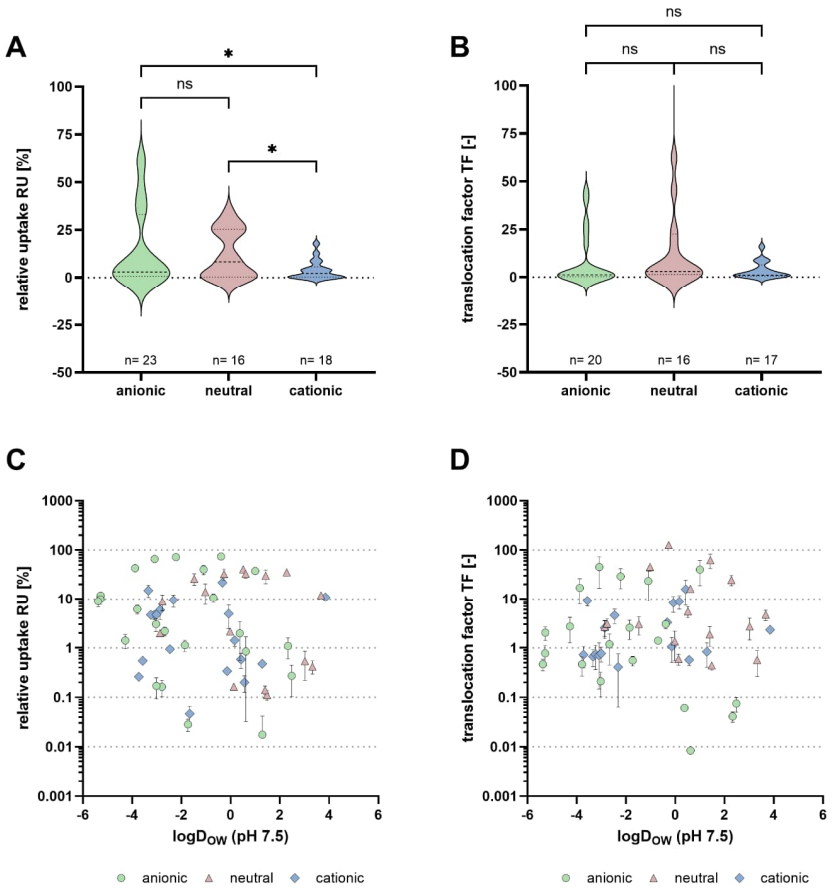
Plant Uptake
Influence of physico-chemical properties



- Slightly lower RU for cations ($p \leq 0.05$)
- Charge state seems to have no pronounced influence on translocation
- Neither RU nor translocation factors seem to correlate with the log D_{OW} (often used as indicator for polarity)

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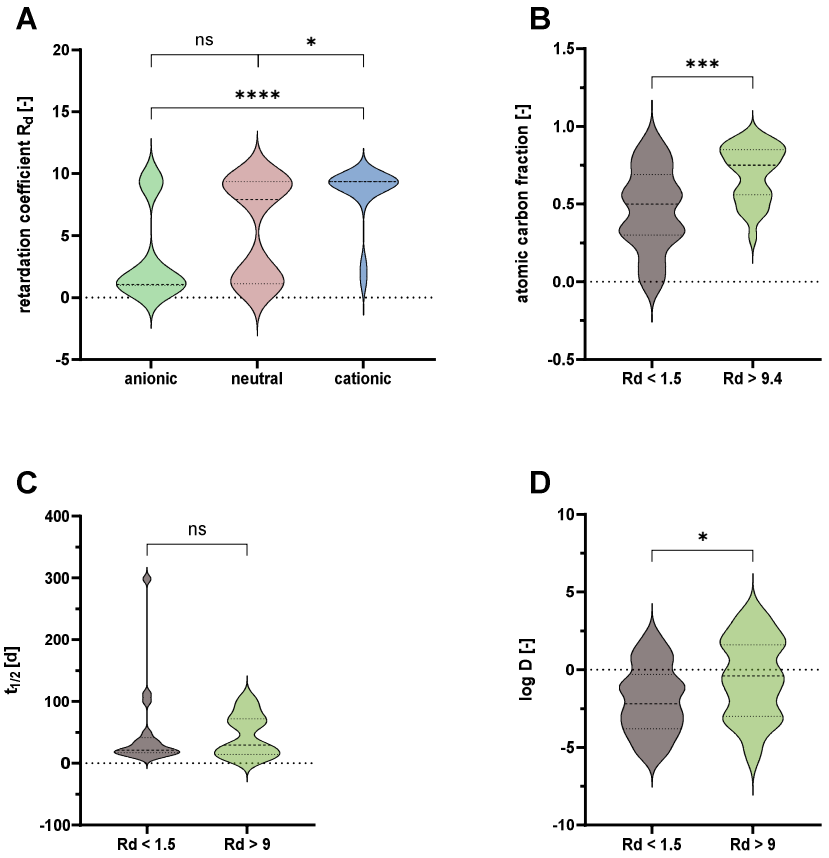
Infiltration

Influence of physico-chemical properties



- Comparison between Category a and d
- Log D and half-live had little effect
- Once a chemical is “polar enough” other factors may become dominant
- Lack of experimental half-live data for soil
- Charge state as key factor also for PM-chemicals

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Conclusions
Taking an exposure perspective

Water Research 266 (2024) 122436

Contents lists available at ScienceDirect

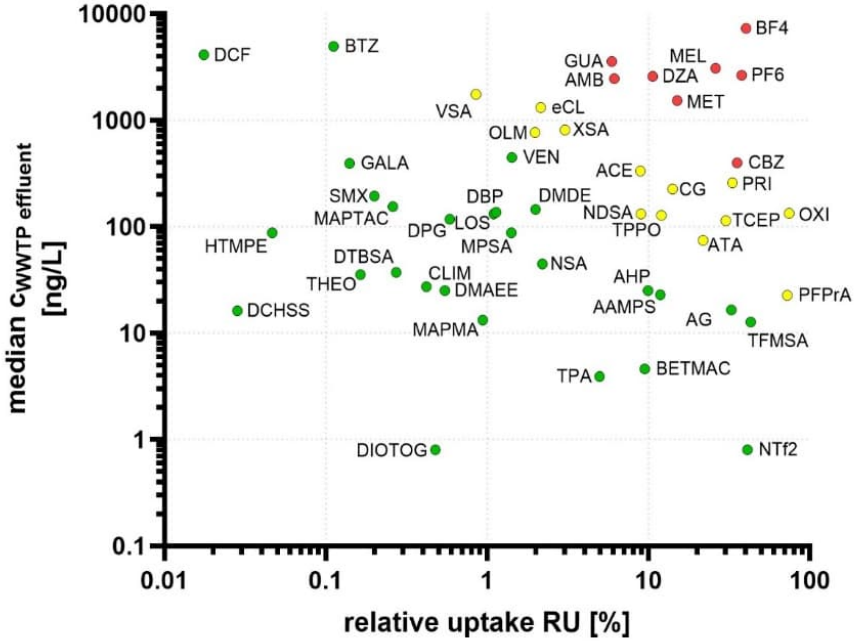
Water Research

journal homepage: www.elsevier.com/locate/watres

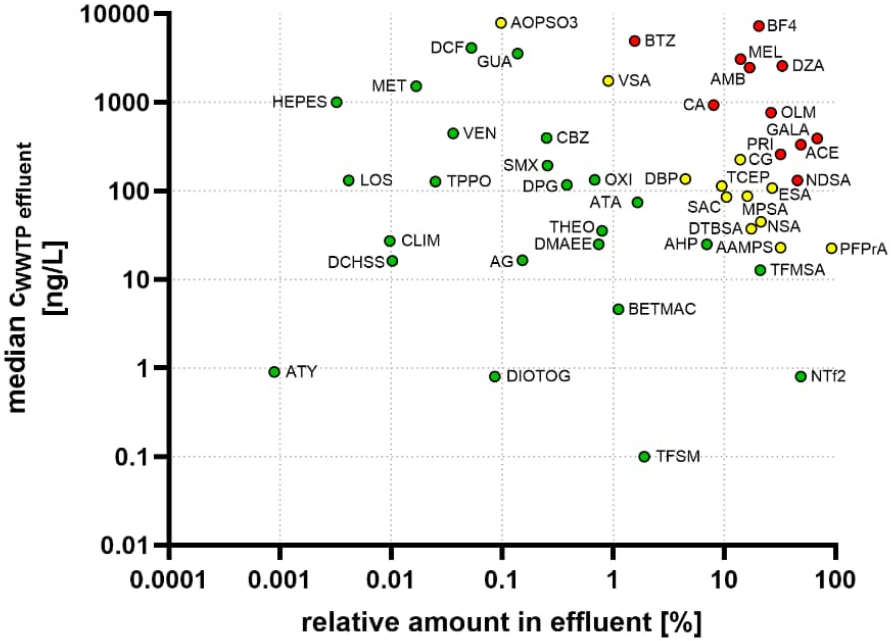
Fate of persistent and mobile chemicals in the water cycle: From municipal wastewater discharges to river bank filtrate

Matthias Muschket [a,1], Isabelle J. Neuwald [b], Daniel Zahn [a,1], Alina H. Seelig [a], Jochen Kuckelkorn [c], Thomas P. Knepper [b], Thorsten Reemtsma [a,d,*]

Human exposure potential

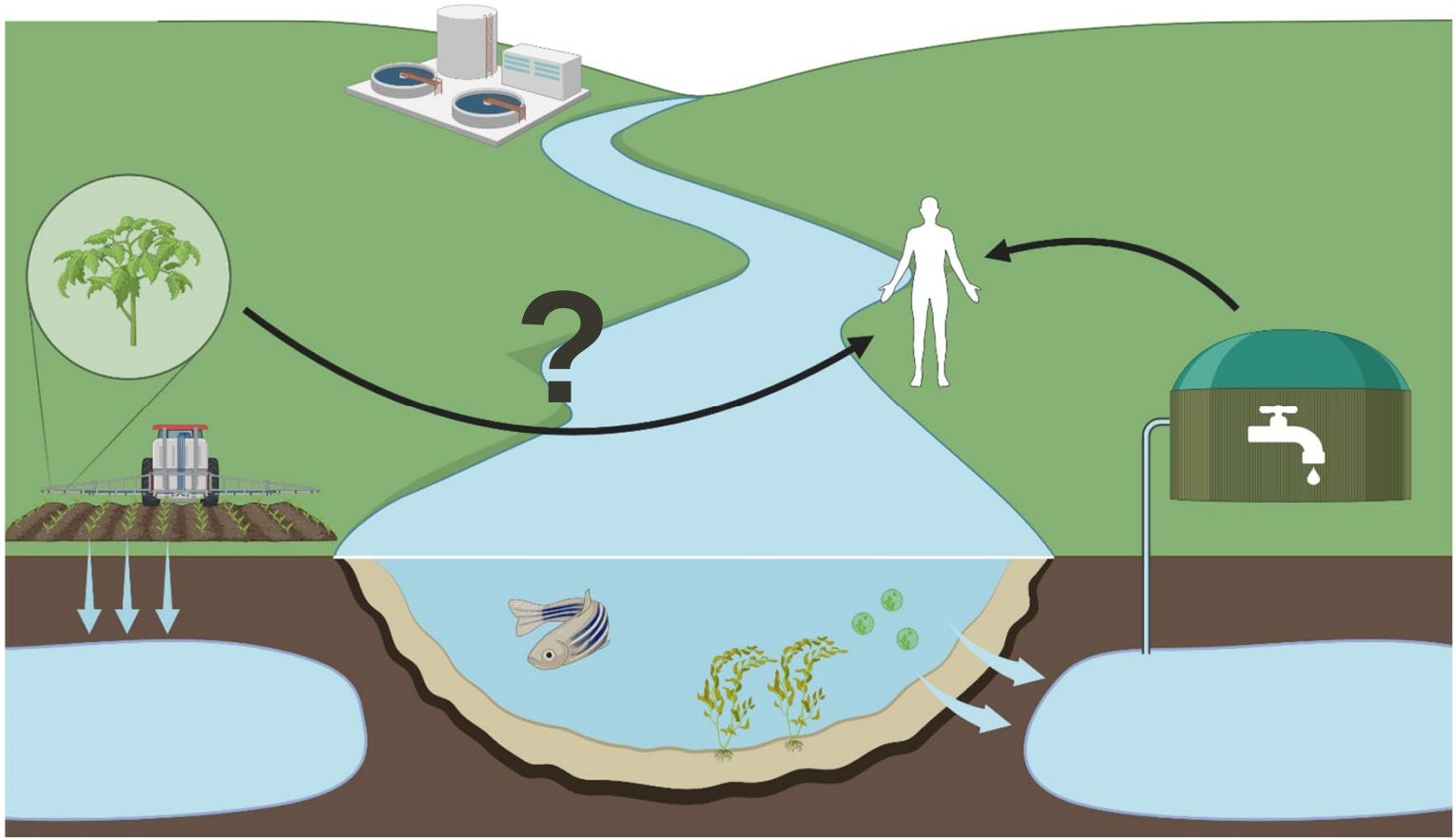


Groundwater exposure potential



Conclusions

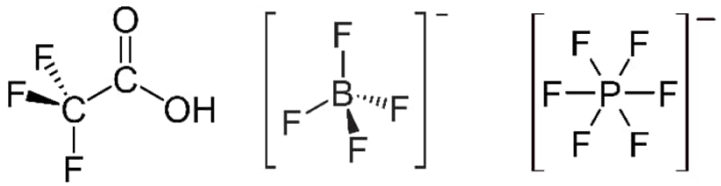
Crop Consumption as Relevant Exposure Pathway?



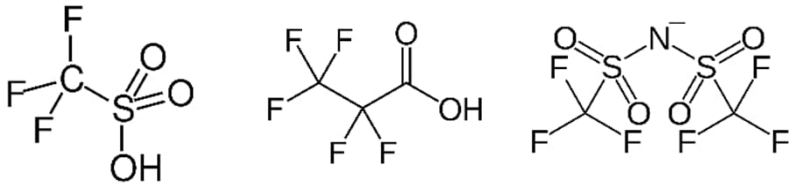
Conclusions

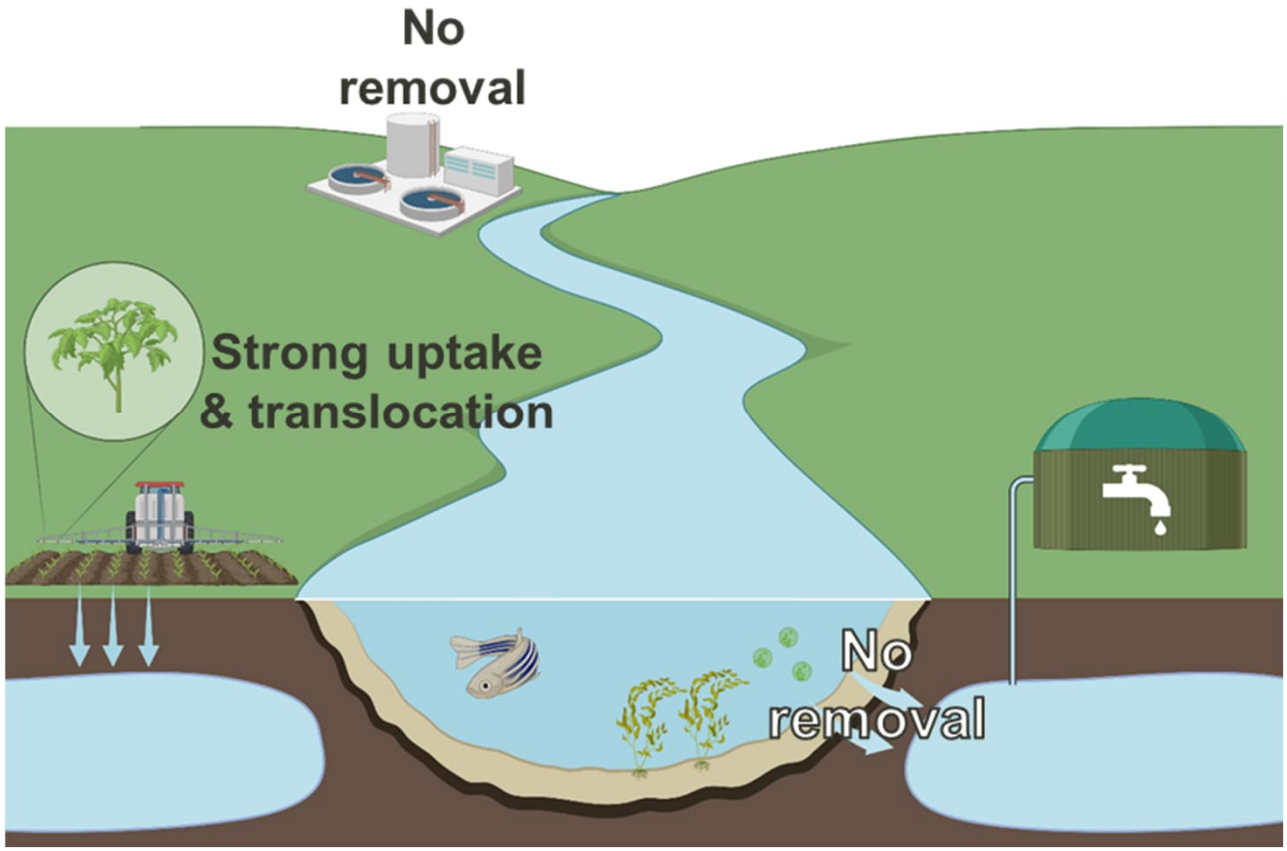
Small persistent anions as potential chemicals of concern

High concentration:



Low concentration:





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Plant Uptake of Persistent and Mobile Chemicals in Rocket (*Eruca sativa*)—A Greenhouse Study on Agricultural Wastewater Reuse

Alina H. Seelig, Veikko Junghans, Thorsten Reemtsma, and Daniel Zahn*

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Read Online

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- **The ZeroPM Project for this invitation**
- **And you for your attention**

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WavE Water Technologies: Reuse

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