Safeguarding drinking water resources: engineering microbial activity for organic micropollutant biodegradation

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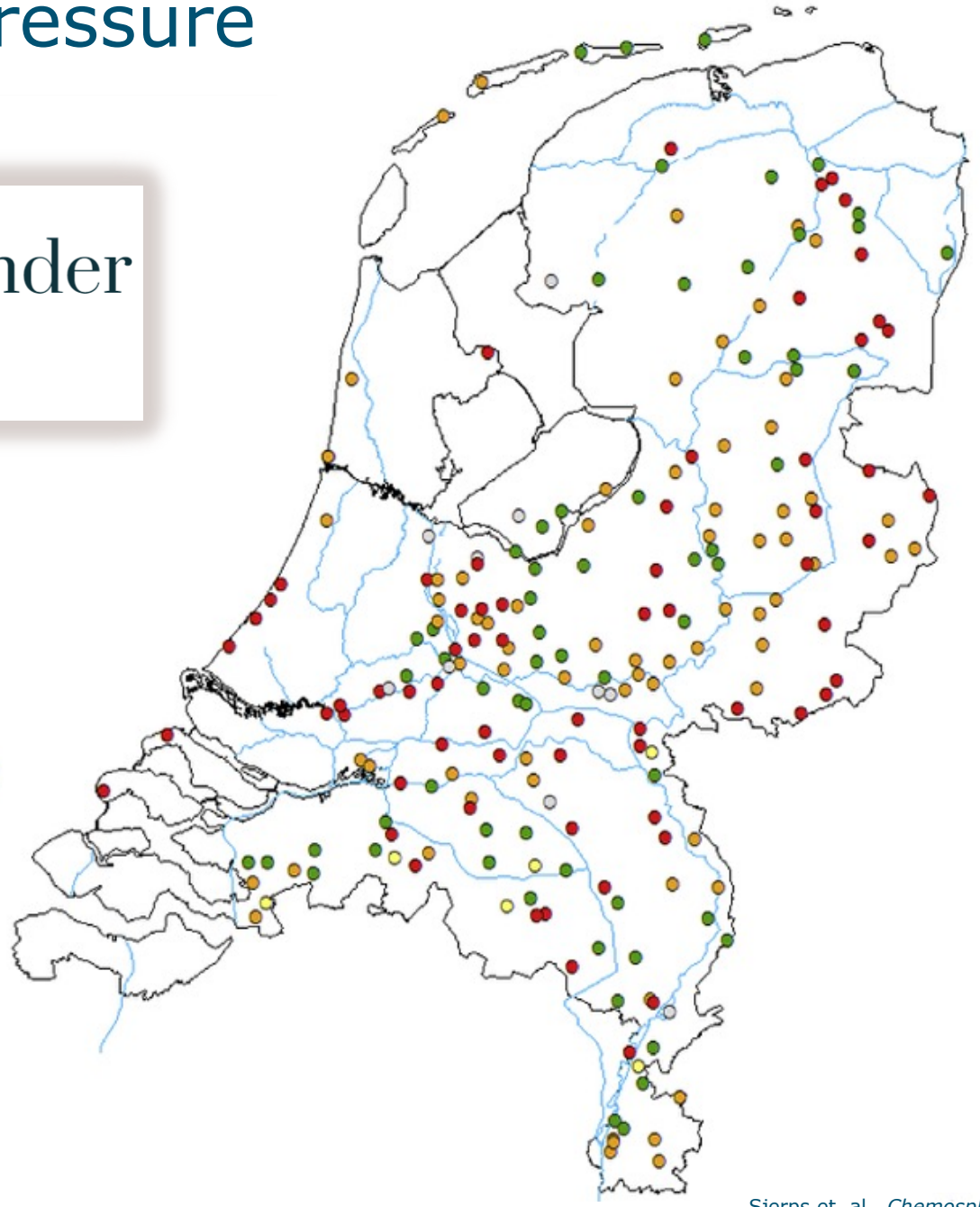
Drinking water sources under pressure

12 SEPTEMBER 2019

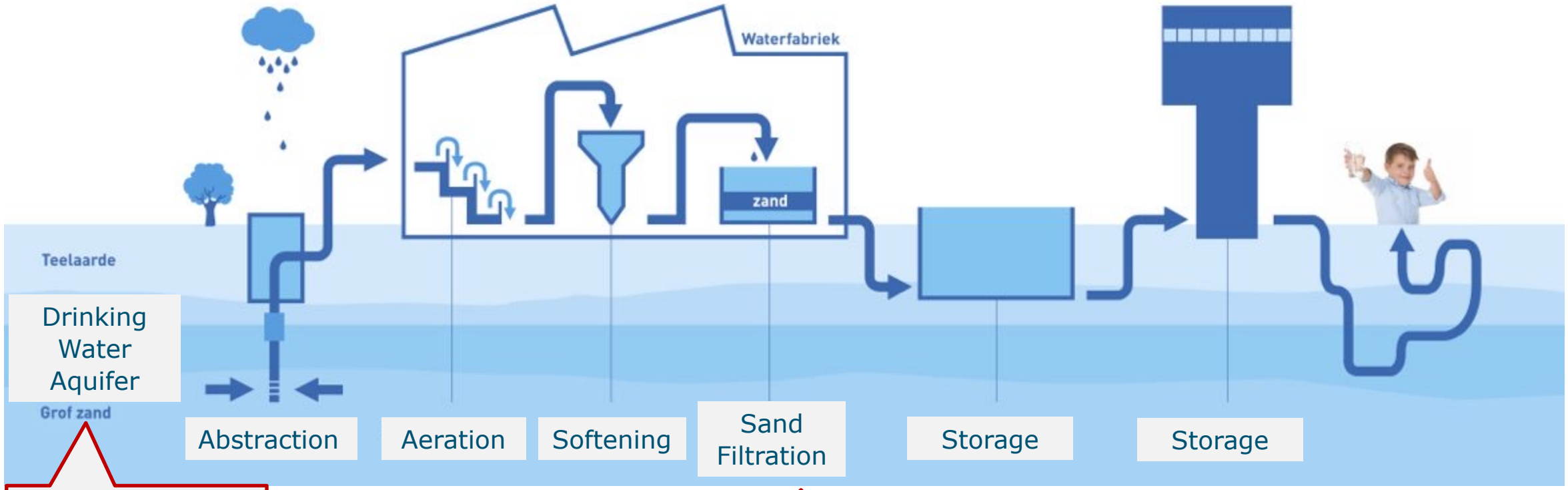
Quality of drinking water sources under growing pressure

KWR Bridging Science to Practice



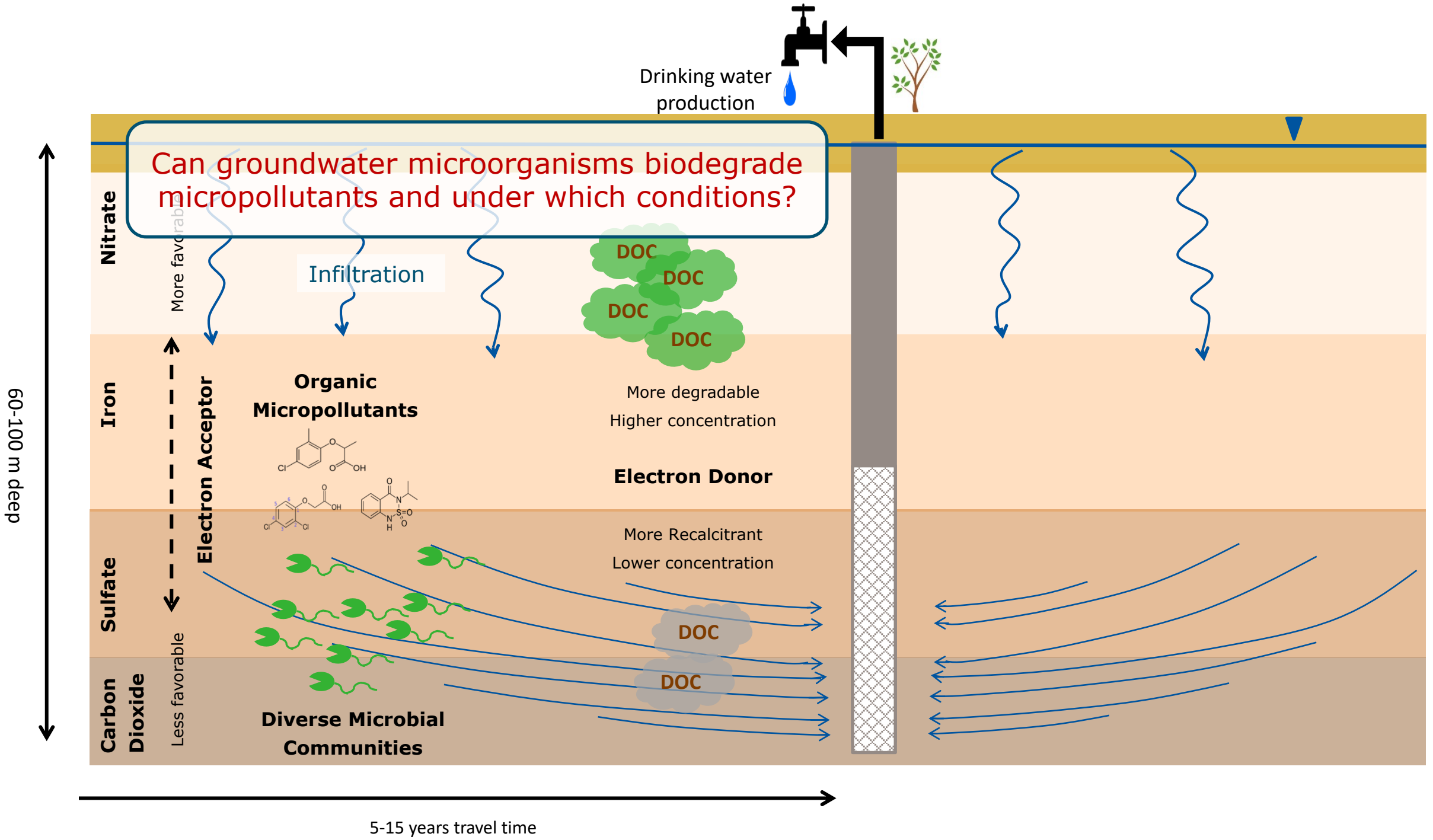
Sjerps et. al., *Chemosphere*, 2019

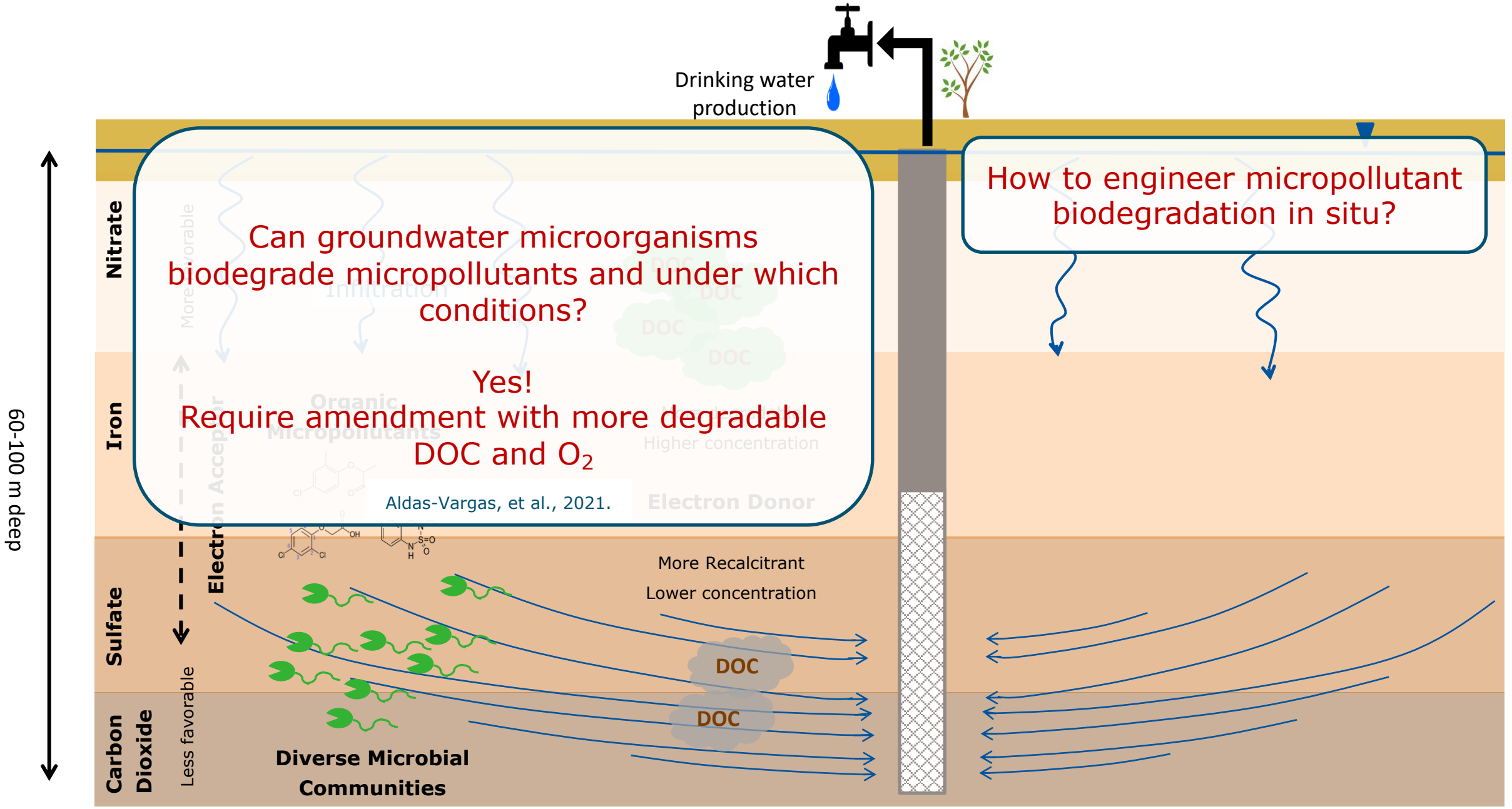
Where to treat micropollutants?



In situ bioremediation- biodegrade micropollutants in groundwater before abstraction

Rapid Sand Filtration- improve micropollutant removal in existing infrastructure


Drinking water production
Can groundwater microorganisms biodegrade micropollutants and under which conditions?
Nitrate
Iron
Sulfate
Carbon Dioxide
More favorable
Less favorable
Electron Acceptor
Infiltration
Organic Micropollutants
DOC
DOC
DOC
DOC
More degradable
Higher concentration
Electron Donor
More Recalcitrant
Lower concentration
DOC
DOC
Diverse Microbial Communities
60-100 m deep
5-15 years travel time


Drinking water production
How to engineer micropollutant biodegradation in situ?
Can groundwater microorganisms biodegrade micropollutants and under which conditions?
Yes!
Require amendment with more degradable DOC and O_2
Aldas-Vargas, et al., 2021.
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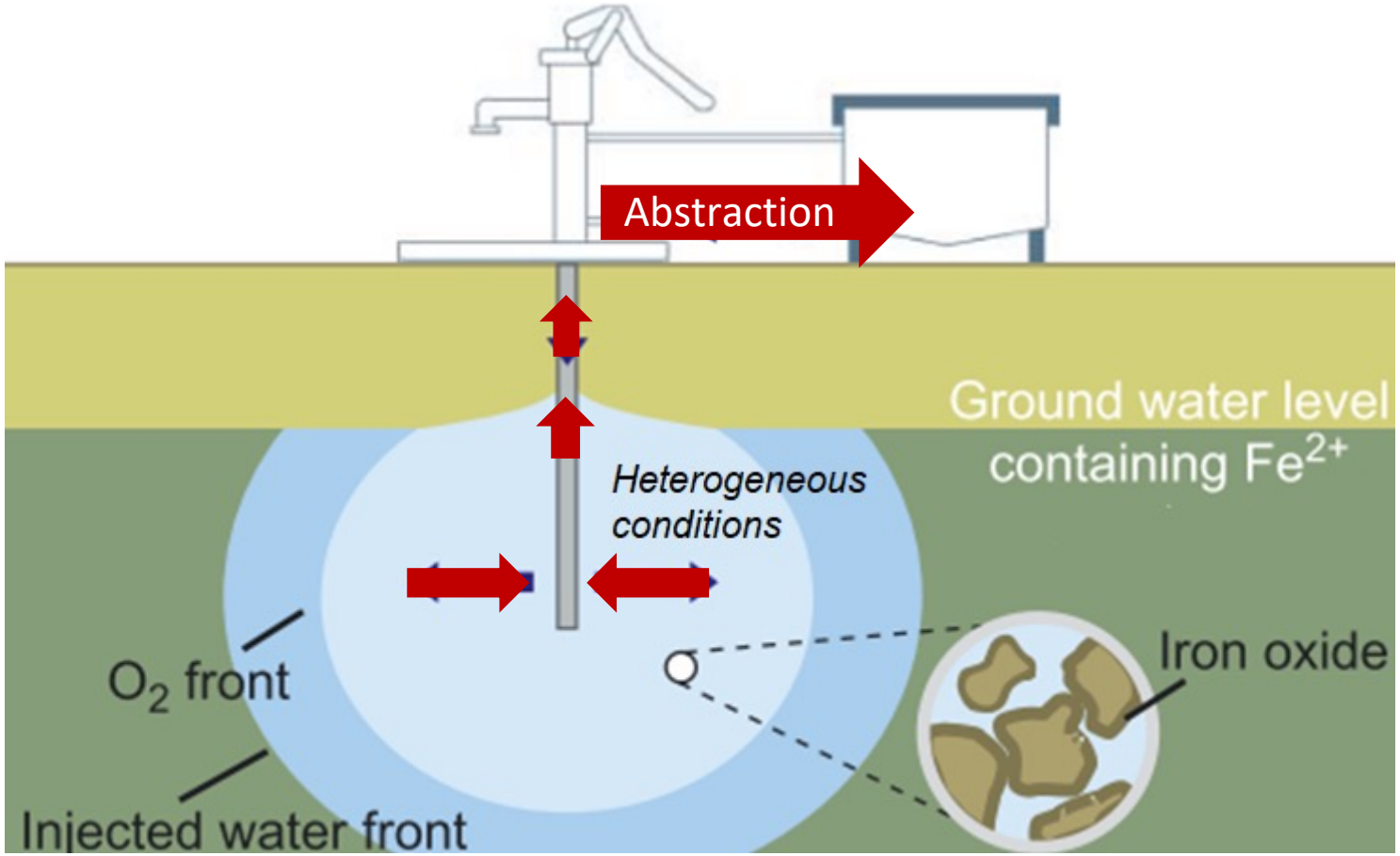
Subsurface Iron Precipitation



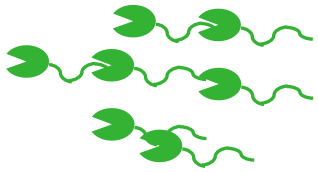
- Fe^{2+} oxidized and precipitated
- Possible micropollutant (co)-metabolic biodegradation?
  - Aerobic conditions
  - DOC amendment

Do trace oxygen concentrations support micropollutant biodegradation?

van Halem et al., 2011

Does subsurface iron precipitation support micropollutant biodegradation?

Microbial Community



Groundwater from a drinking water aquifer

+

Micropollutants

23 OMPs (pesticides, pharmaceuticals, metabolites)
1.9 µg/L

+

Amendments

Condition	Initial O_2 (mg/L)	Cumulative O_2 (mg/L)
High O_2	1.6	1.6
Frequent O_2	0.4	1.6
Low O_2	0.4	0.4

Oxygen Availability

Dissolved organic carbon
(3 mg/L)

NH_4^+

Ammonium
(1 mg/L)

Fe^{2+}

Iron (Fe^{2+})
(6 mg/L)

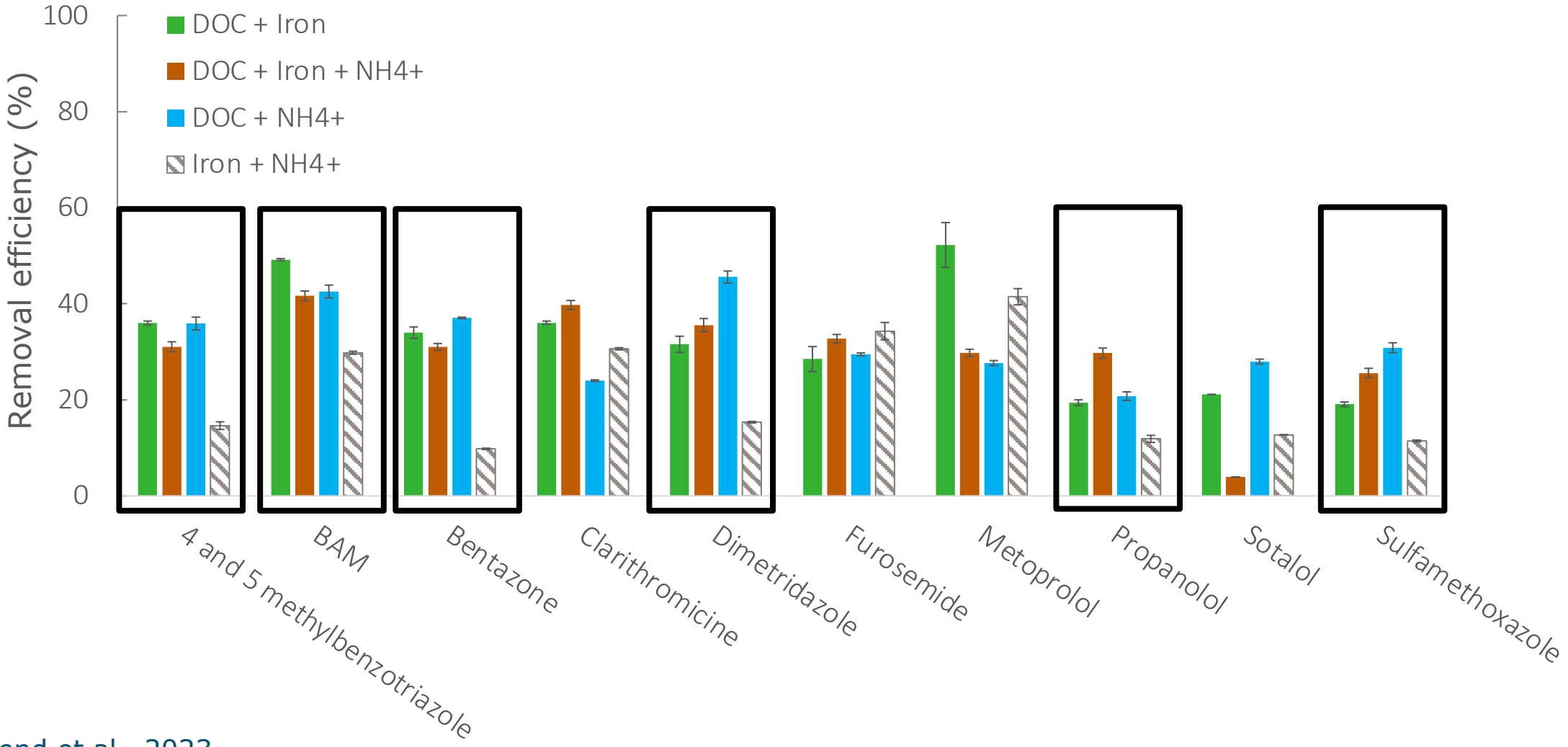
Does subsurface iron precipitation support micropollutant biodegradation?

- Many micropollutants degraded within 21 days. Degradation dependent on initial oxygen availability.

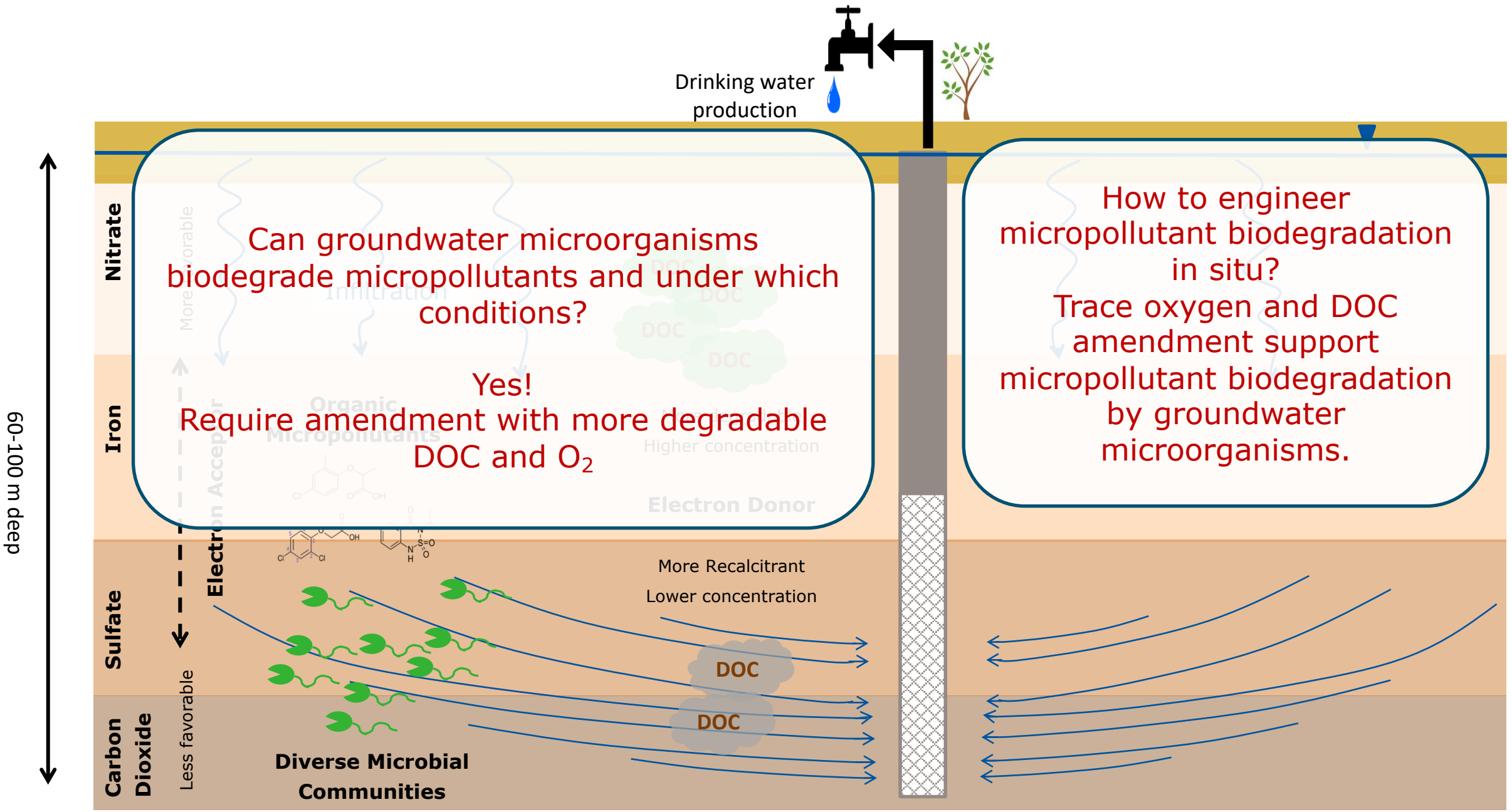
Micropollutant	High O_2		Freq O_2		Low O_2		Abiotic	
BAM[a]	41%	±6%	12%	±2%	6%	±1%	0%	±0%
Metoprolol	38%	±4%	28%	±2%	25%	±4%	2%	±1%
Clarithromicine	33%	±4%	39%	±3%	16%	±6%	14%	±3%
Dimetridazole	32%	±3%	20%	±2%	18%	±3%	0%	±0%
Furosemide	31%	±6%	28%	±3%	22%	±4%	0%	±0%
4 and 5 methylbenzotriazole	29%	±2%	29%	±3%	16%	±6%	0%	±0%
Bentazone	28%	±1%	10%	±1%	18%	±3%	0%	±1%
Sotalol	22%	±1%	17%	±2%	8%	±1%	0%	±1%
Sulfamethoxazole	22%	±3%	10%	±1%	6%	±3%	0%	±0%
Propanolol	20%	±4%	22%	±2%	6%	±3%	0%	±0%
Mecoprop MCPP	20%	±1%	7%	±1%	15%	±0%	0%	±1%
2,4-D[b]	18%	±3%	5%	±2%	-1%	±0%	0%	±0%
Diclofenac	16%	±2%	12%	±2%	6%	±2%	0%	±0%
Trimethoprim	12%	±4%	12%	±1%	2%	±6%	0%	±0%
Benzotriazole	12%	±5%	8%	±1%	0%	±3%	0%	±0%
DEET	10%	±3%	9%	±1%	0%	±0%	0%	±0%

Nederend et al., 2023

Does subsurface iron precipitation support micropollutant biodegradation?- DOC addition



Nederend et al., 2023


Drinking water production
Can groundwater microorganisms biodegrade micropollutants and under which conditions?
Yes!
Require amendment with more degradable DOC and O_2
How to engineer micropollutant biodegradation in situ?
Trace oxygen and DOC amendment support micropollutant biodegradation by groundwater microorganisms.
60-100 m deep
Nitrate
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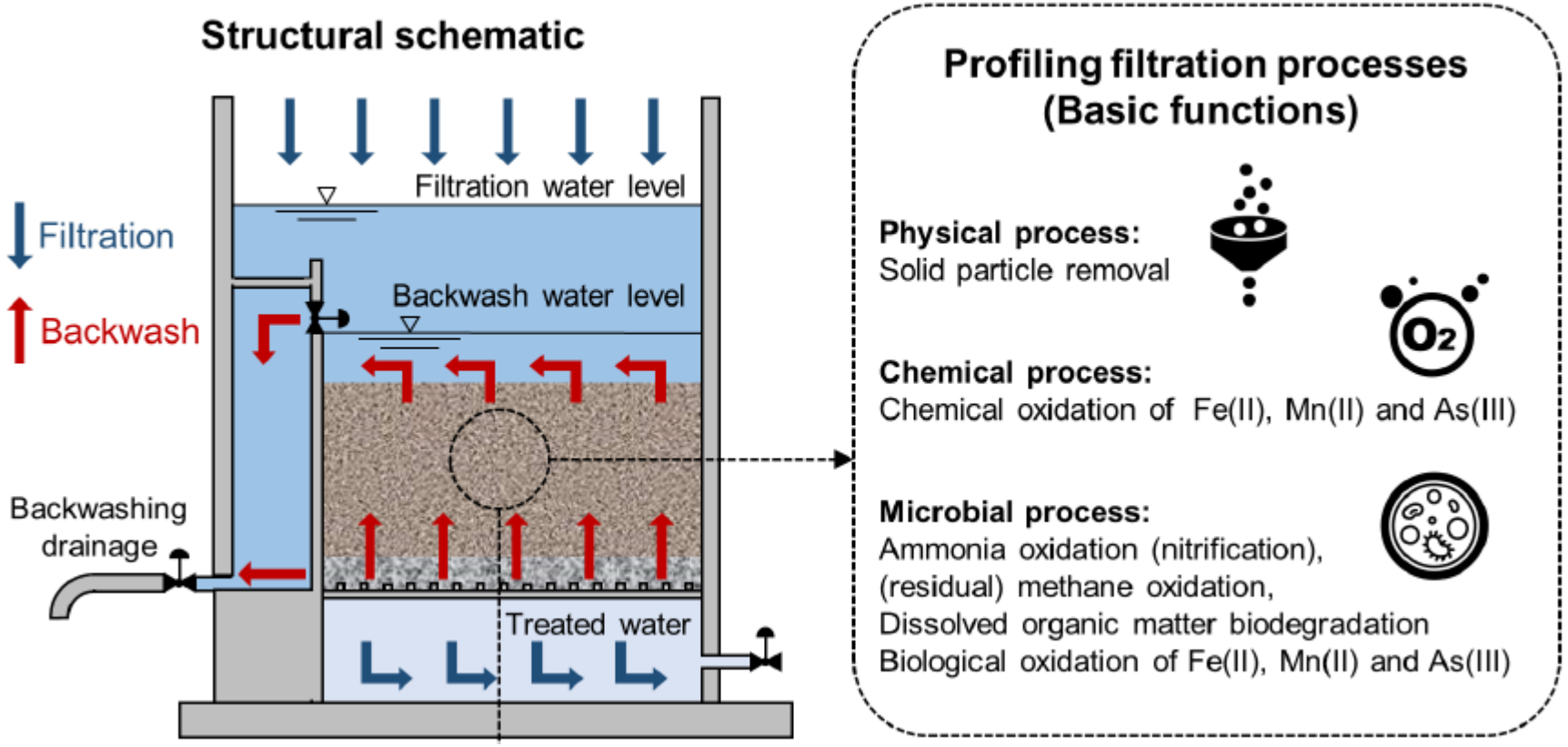
Diverse Microbial Communities

Rapid Sand Filters

RC Haris DWTP

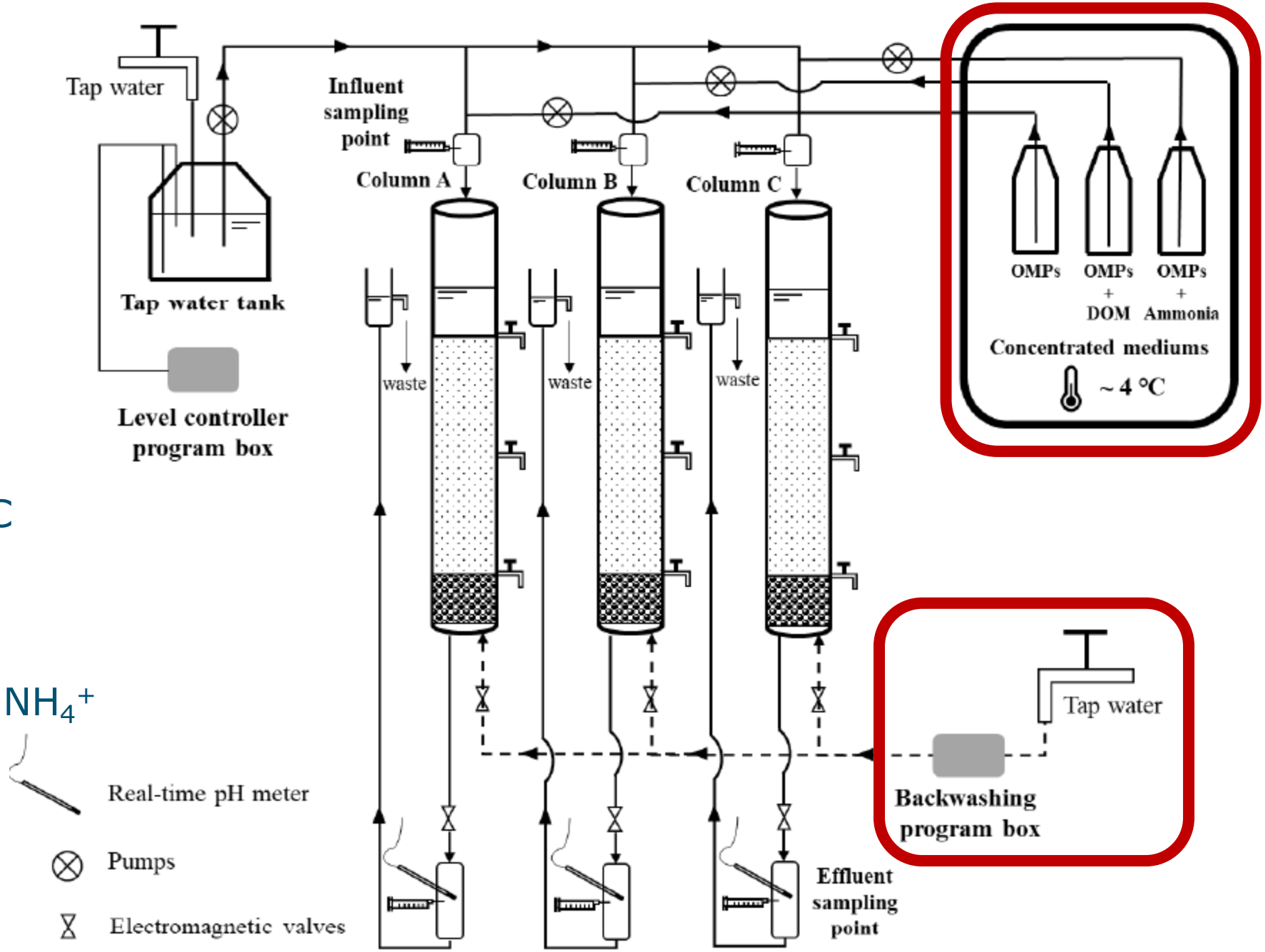
Rapid Sand Filters

How do substrate loading rate and contact time affect micropollutant biodegradation?



Wang, 2023.

- Column A: Control
  - 1 µg/L OMP
- Column B: DOC
  - 1 µg/L OMP
  - 2-6 mg/L DOC
- Column C: Ammonia
  - 1 µg/L OMP
  - 0.5-2.5 mg/L NH_4^+



Wang, et al. *Water Research* 2022.

How do substrate loading and contact times affect biodegradation?

Name
2,6-dichlorobenzamide (BAM)
Mecoprop
2,4-Dichlorophenoxyacetic acid (2,4-D)
Methyl-desphenyl-chloridazon
Desphenyl-chloridazon
Chloridazon
Bentazone
Metolachlor
Metribuzin
Salicylic acid
Caffeine
Paracetamol
Metformin
Benzotriazole
Diglyme
Perfluorooctanoic acid (PFOA)
Caffeine D-9
Benzotriazole D-4

Amount of substate applied to the column per unit of time

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Substrate loading rate	OMP (µg/h) DOC (mg/h) NH_4^+ (mg/h)	5.3 31.7 13.2	5.3 10.6 2.6	5.3 31.7 13.2	1.1 10.6 2.6	5.3 31.7 13.2
Contact Time	(h)	0.5	0.5	0.5	2.4	0.5

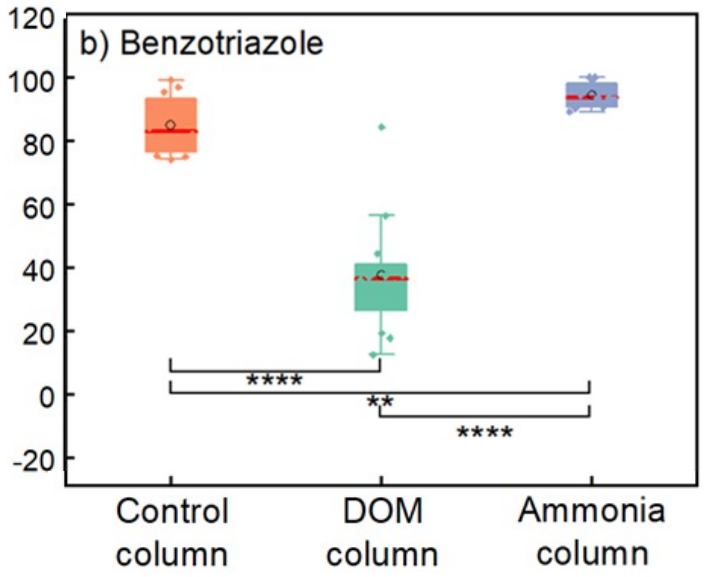
Retention time in the filter

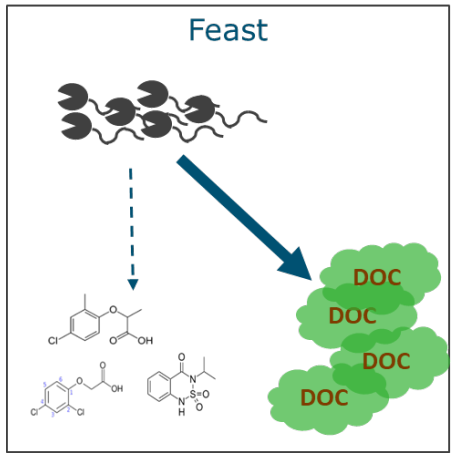
Lower DOC and NH_4^+ loading rate

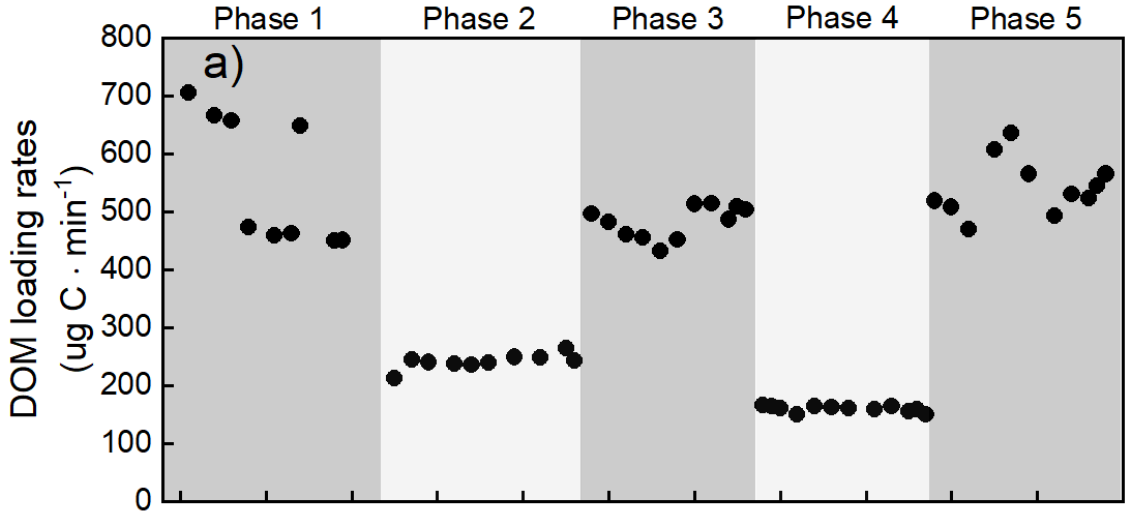
Lower OMP + DOC + NH_4^+ loading rate Higher contact time

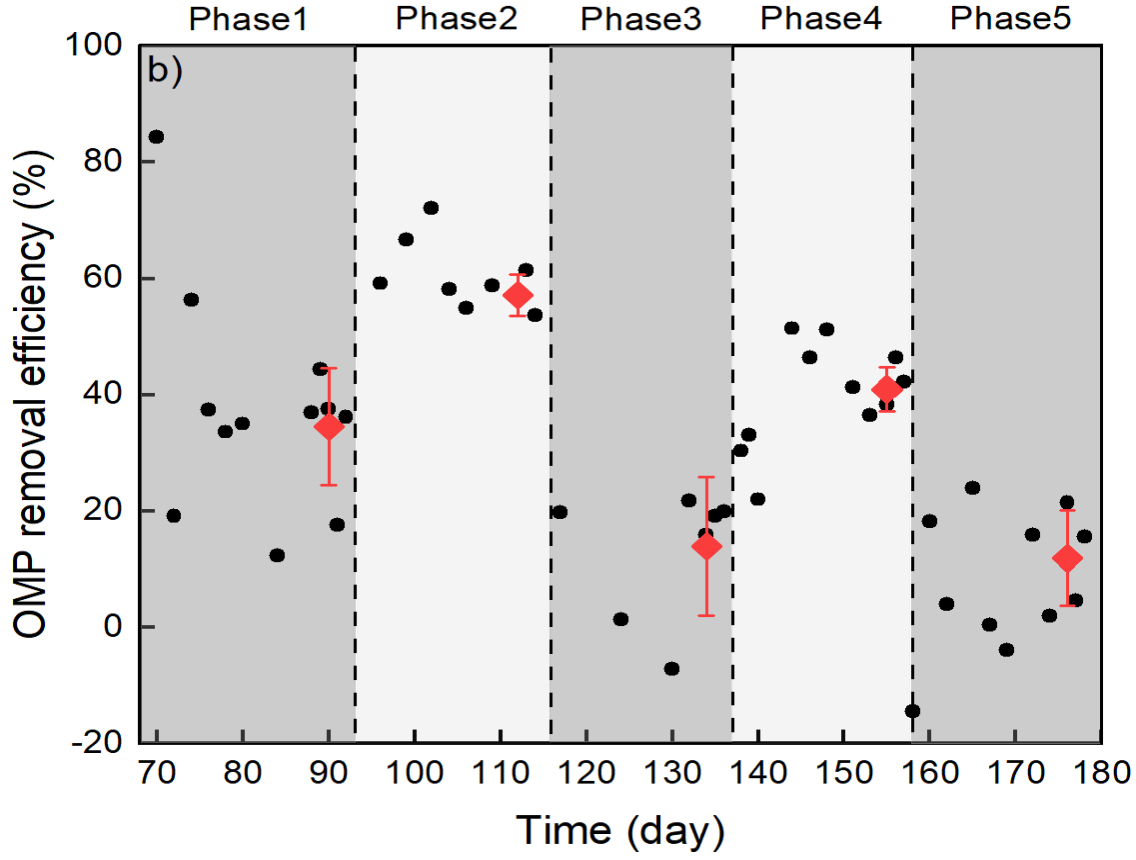
How do substrate loading and contact times affect biodegradation? Substrate Loading Rate

- Substrate competition between DOM and benzotriazole





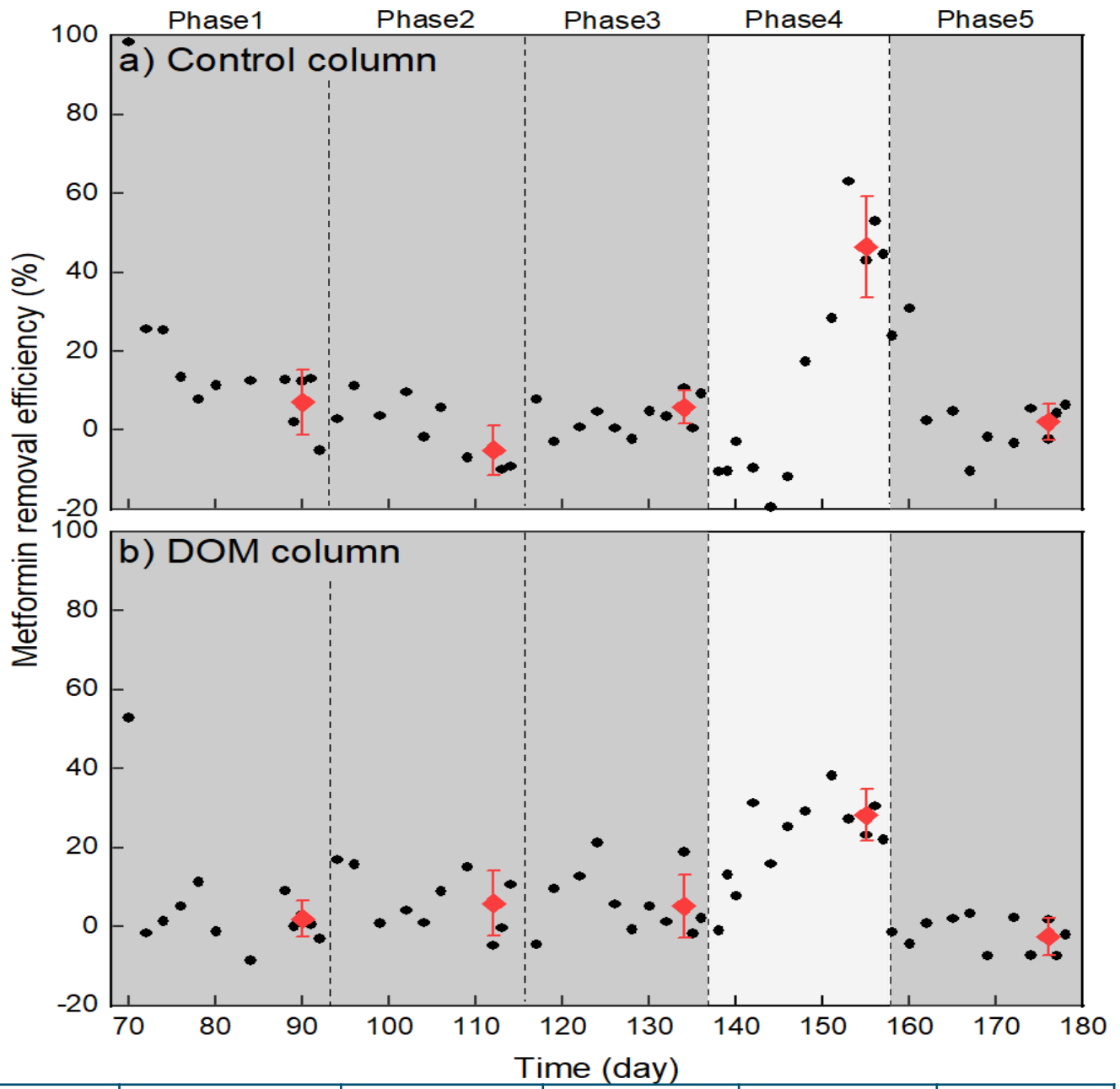




Wang, et al. *Water Research* 2022.

How do substrate loading and contact times affect biodegradation? Contact time

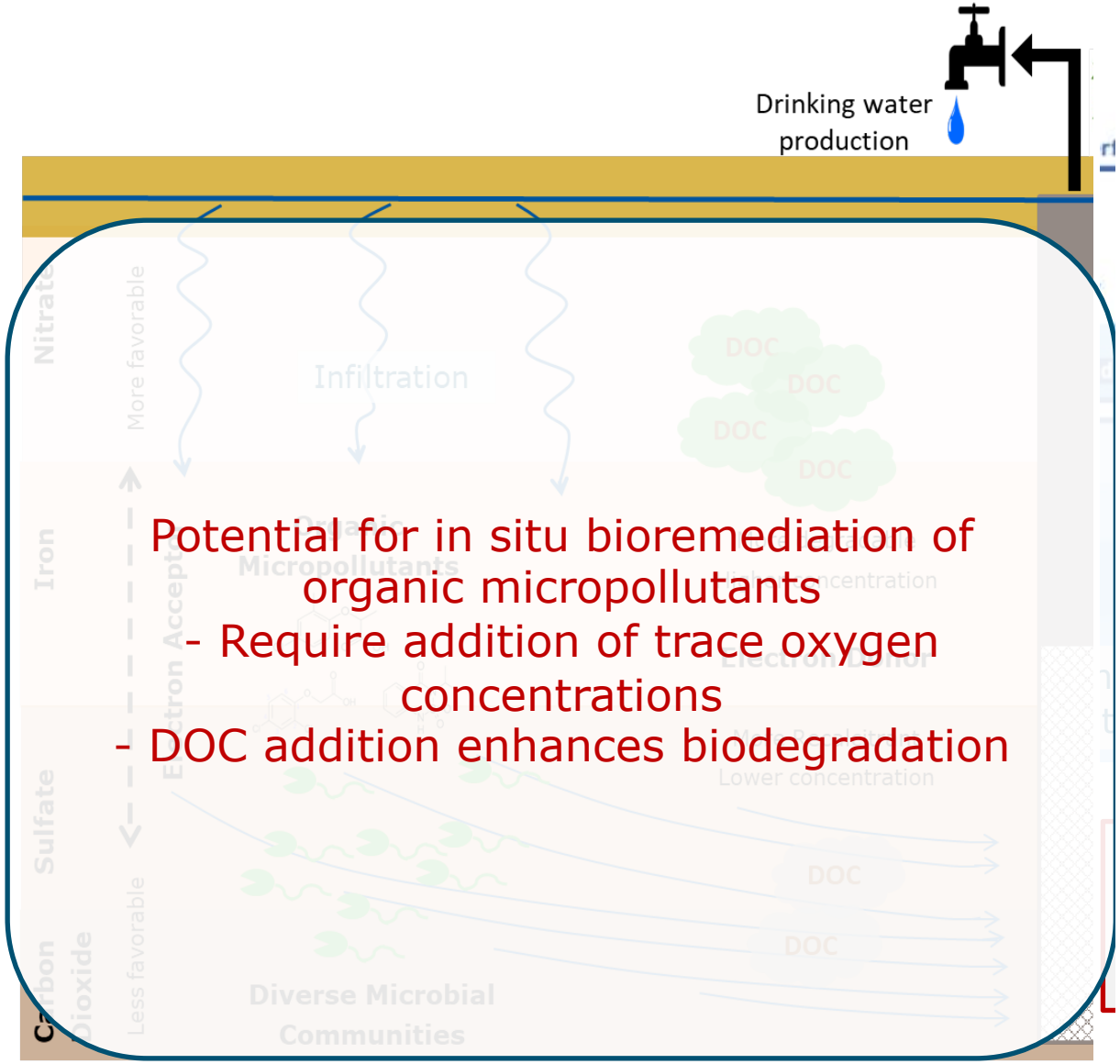
- Improved Metformin biodegradation with increased contact time
  - Observed for both control and DOM column



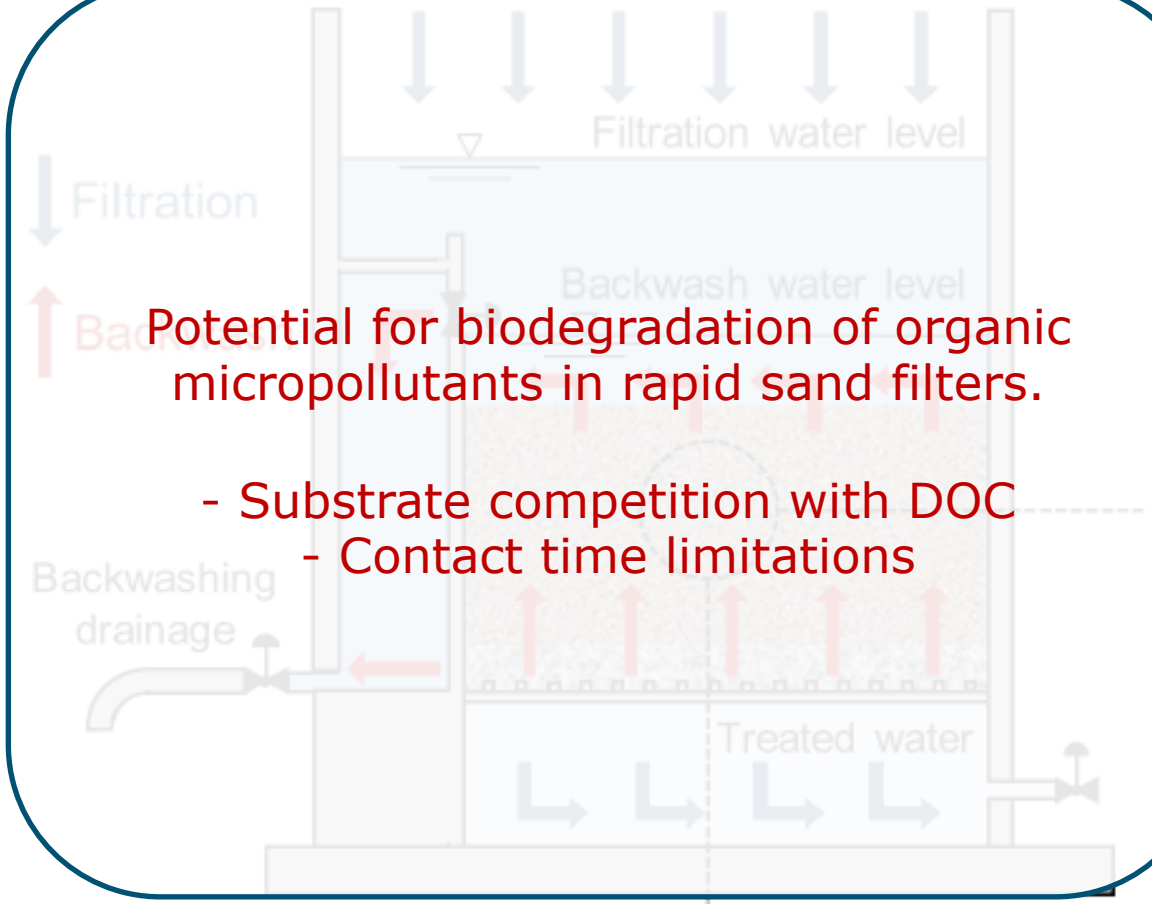
Contact Time	(h)	0.5	0.5	0.5	2.4	0.5

Wang, et al. *Water Research* 2022.

Where to treat micropollutants? Conclusions



Potential for in situ bioremediation of organic micropollutants
- Require addition of trace oxygen concentrations
- DOC addition enhances biodegradation



Potential for biodegradation of organic micropollutants in rapid sand filters.

- Substrate competition with DOC
- Contact time limitations

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Evides

wetsus

wln water | onderzoek | advies

NWO

WAGENINGEN UNIVERSITY & RESEARCH

Questions?

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Publication:

- Wang, J, NB Sutton et al., Exploring organic micropollutant biodegradation under dynamic substrate loading in rapid sand filters, *Water Research*, 2022.
- Aldas-Vargas, A, NB Sutton, et al. Biostimulation is a valuable tool to assess pesticide biodegradation capacity of groundwater microorganisms, *Chemosphere*, 2021.
- Jinsong Wang, Removal of organic micropollutants from drinking water in rapid sand filters, 2023, PhD thesis
- Merel Nederend, Synergies between micropollutant biodegradation and subsurface iron precipitation, 2023, MSc thesis