Trace organic compounds in wastewater-loaded lowland River Erpe

Key findings from 12 years of research

Jörg Lewandowski[1,2], Anja Höhne[1,3], Anna Jäger[1,2], Anna Lena Kronsbein[1,5], Karin Meinikmann[1,4], Birgit M. Müller[1,5], Malte Posselt[6], Christoph J. Reith[1,7], Jonas Schaper[1,8], Hanna Schulz[1,2], Maria Alejandra Villa Arroyave[1,2], Shai Arnon[9], Marcus A. Horn[10], Stefan Krause[11,12], James L. McCallum[3], Gunnar Nützmann[1,2], Anke Putschew[5], Stephanie Spahr[1]

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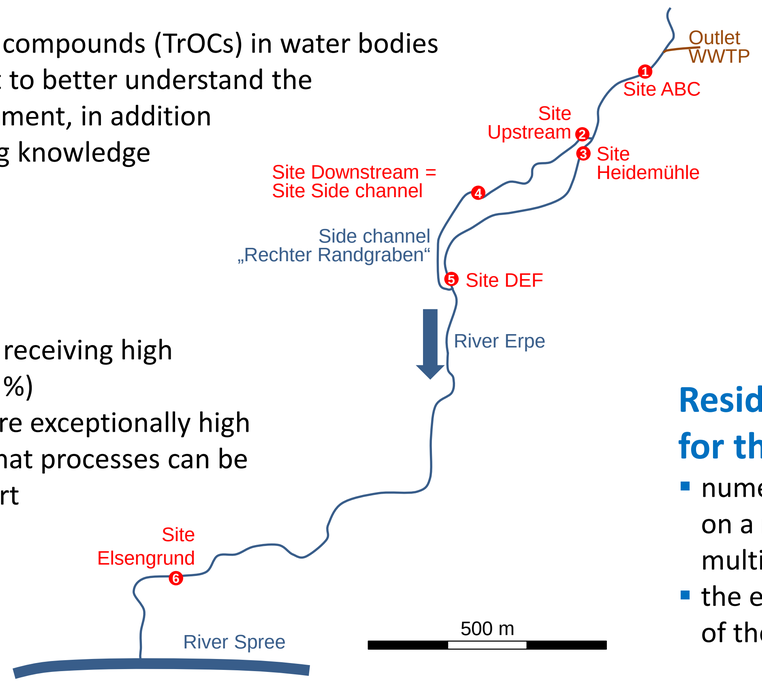
Introduction

The increasing concentrations of trace organic compounds (TrOCs) in water bodies worldwide are a major concern. It is important to better understand the behavior and retention of TrOCs in the environment, in addition to reducing TrOC concentrations and improving knowledge of their ecotoxicological effects.

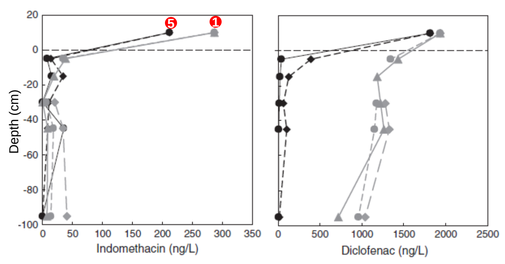
Study site River Erpe

- urban lowland river in Berlin & Brandenburg receiving high loads of treated wastewater (usually 60 – 90 %)
- excellent study site as TrOC concentrations are exceptionally high compared to most other German rivers, so that processes can be reliably studied without much analytical effort
- diurnal fluctuations in discharge and electrical conductivity
- discharge: 0.5 $m^3\ s^{-1}$



Under gaining conditions low TrOC concentrations in riverbeds

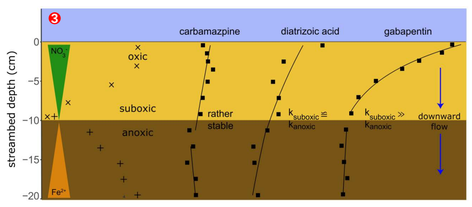
- in 2011, gaining conditions (infiltration of ground-water into River Erpe) at site DEF prevented import of TrOCs into the hyporheic zone
- today: lower groundwater levels lead to loosing conditions (exfiltration of river water into the aquifer) along the entire river reach
- at site ABC attenuation of several TrOCs, e.g. indomethacin, naproxen, ibuprofen, despite strictly anoxic conditions

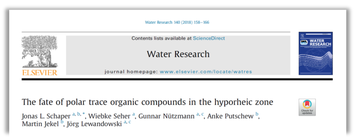



Science of the Total Environment
Fate of organic micropollutants in the hyporheic zone of a eutrophic lowland stream: Results of a preliminary field study
Jörg Lewandowski, Anke Putschew, David Schwesig, Christiane Neumann, Michael Radke

Increased TrOC attenuation in (sub-)oxic zones of hyporheic zones (HZ)

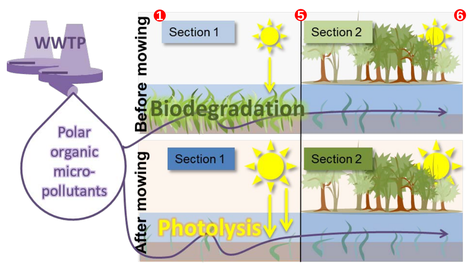
- steep redox gradients in the top 20 cm of the HZ
- some TrOCs (e.g. carbamazepine, venlafaxine) are very stable in the HZ
- attenuation of many TrOCs (e.g. gabapentin, diclofenac, acesulfame, benzotriazole) strongly redox dependent, i.e. significant decrease under oxic/suboxic (denitrifying) conditions, no decrease under anoxic conditions
- several TrOCs (e.g. diatrizoic acid, sulfamethoxazole) show a redox-independent but weak attenuation

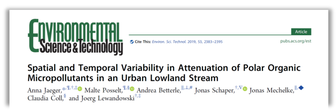



Water Research
The fate of polar trace organic compounds in the hyporheic zone
Jonas L. Schaper, Wiebke Seher, Gunnar Nützmann, Anke Putschew, Martin Jekel, Jörg Lewandowski

Fate of TrOCs in streams depends on both compound and stream characteristics

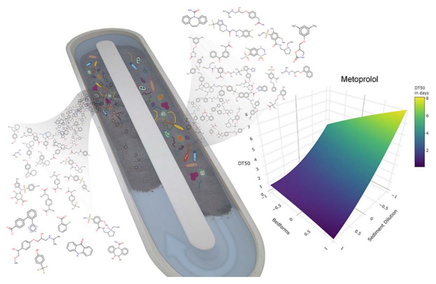
- depending on the TrOC and its degradation pathways, the removal efficiency differs in different river sections
- photolysis dependent on shading by riparian vegetation and in-stream macrophytes
- macrophytes promote biodegradation (large growth area for biofilms)
- TrOC removal depends on solar radiation, temperature, and presence of macrophytes

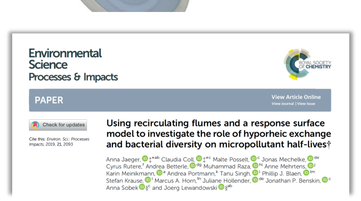



Environmental Science & Technology
Spatial and Temporal Variability in Attenuation of Polar Organic Micropollutants in an Urban Lowland Stream
Anna Jaeger, Malte Posselt, Andrea Betterle, Jonas Schaper, Claudia Coll, and Joerg Lewandowski

Bacterial diversity controls TrOC attenuation

- relevant factors for TrOC attenuation are bedforms (controlling hyporheic exchange) and microbial community composition in the HZ
- 20 (of 31) TrOCs responded significantly to bacterial diversity and 4 to both diversity and hyporheic exchange
- half-lives ranged from 0.5 (fluoxetine) to 306 days (carbamazepine)




Environmental Science Processes & Impacts
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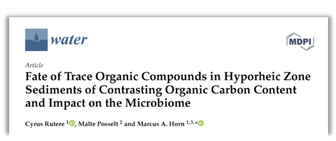
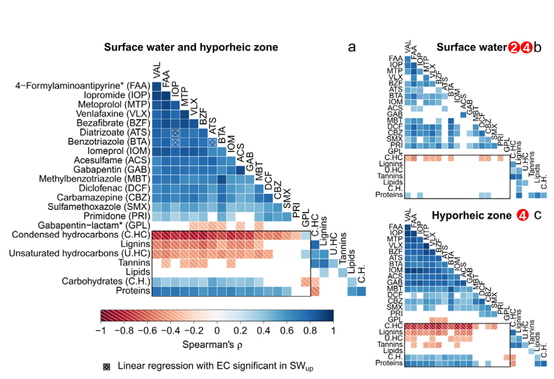
Using recirculating flumes and a response surface model to investigate the role of hyporheic exchange and bacterial diversity on micropollutant half-lives†

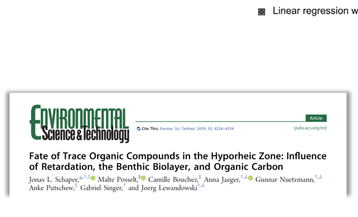

water
Fate of Trace Organic Compounds in Hyporheic Zone Sediments of Contrasting Organic Carbon Content and Impact on the Microbiome
Cyrus Rutere, Malte Posselt and Marcus A. Horn


Environmental Science & Technology
Bacterial Diversity Controls Transformation of Wastewater-Derived Organic Contaminants in River-Simulating Flumes
Malte Posselt, Jonas Mechelke, Cyrus Rutere, Claudia Coll, Anna Jaeger, Muhammad Raza, Karin Meinikmann, Stefan Krause, Anna Sobek, Jörg Lewandowski, Marcus A. Horn, Juliane Hollender, and Jonathan P. Benskin

Co-metabolic attenuation of TrOCs and mineralization of organic matter

- similar or linked attenuation pathways for biodegradable dissolved organic matter (DOM) and TrOCs (co-metabolism, no competition)
- high potential for DOM turnover and TrOC attenuation in the HZ (not in surface water)

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Fate of Trace Organic Compounds in the Hyporheic Zone: Influence of Retardation, the Benthic Biolayer, and Organic Carbon
Jonas L. Schaper, Malte Posselt, Camille Bouchez, Anna Jaeger, Gunnar Nuetzmann, Anke Putschew, Gabriel Singer, and Joerg Lewandowski


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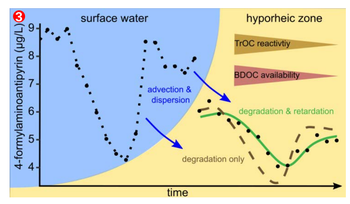
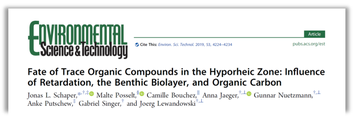
Simultaneous attenuation of trace organics and change in organic matter composition in the hyporheic zone of urban streams
Birgit M. Mueller, Hanna Schulz, Robert E. Danczak, Anke Putschew & Joerg Lewandowski

Retardation of TrOCs in the HZ

- retardation is more important for most compounds than previously assumed
- some TrOCs are stable (8 out of 22), others have half-lives from 0.1 h (iopromide) to 17.1 h (metformin)

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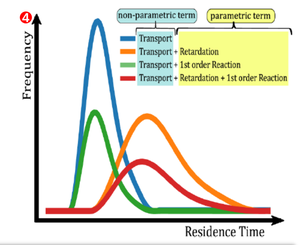
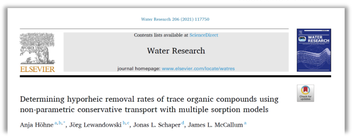
Residence time distributions (RTDs) are important for the evaluation of TrOC attenuation

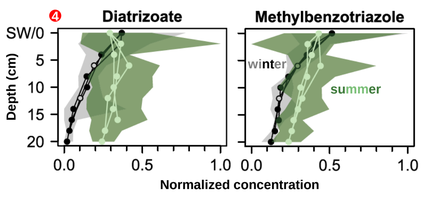
- numerical modelling of hyporheic TrOC transformation based on a non-parametric residence time approach combined with multiple sorption models and first order reactions
- the exact shape of the RTDs is important for the determination of the reactive parameters




Water Research
Determining hyporheic removal rates of trace organic compounds using non-parametric conservative transport with multiple sorption models
Anja Höhne, Jörg Lewandowski, Jonas L. Schaper, James L. McCallum

Hyporheic residence times more important for TrOC attenuation than seasonal effects

- contrary to expectations, the attenuation of 12 of 18 TrOCs was higher in winter in the HZ (3 higher in summer)
- longer and more diverse residence times in winter are more important than the effects of temperature and oxygen distribution

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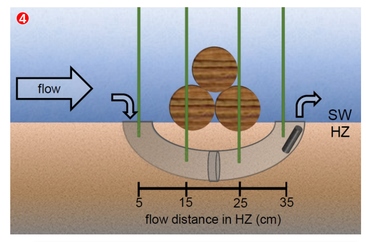
Water Resources Research
RESEARCH ARTICLE
Seasonal Differences in the Attenuation of Polar Trace Organics in the Hyporheic Zone of an Urban Stream
Birgit M. Mueller, Hanna Schulz, Anja Höhne, Anke Putschew, and Joerg Lewandowski

Sampling along flow paths is essential for process understanding

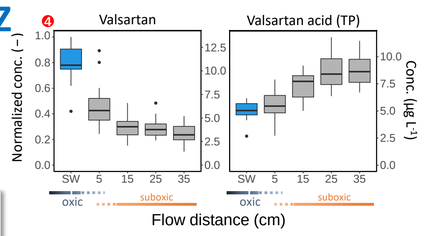
- pore water sampling along flow paths is challenging
- novel experimental setup for presetting hyporheic flow paths
- sampling along flow paths allows sampling of the same water parcel and thus reliable recording of biogeochemical turnover

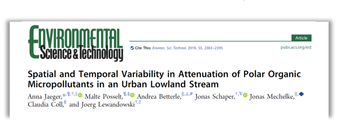



Journal of Hydrology
Attenuation of trace organic compounds along hyporheic flow paths in a lowland sandbed stream
Christoph J. Reith, Stephanie Spahr, Anke Putschew, Joerg Lewandowski

Formation of transformation products in the HZ

- many transformation products are unknown
- toxicological data of the transformation products are often missing
- some transformation products are quite stable

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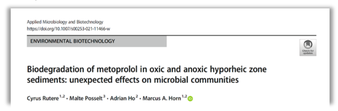
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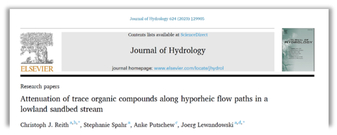
Biodegradation of metoprolol in oxic and anoxic hyporheic zone sediments: unexpected effects on microbial communities
Cyrus Rutere · Malte Posselt · Adrian Ho · Marcus A. Horn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Research papers
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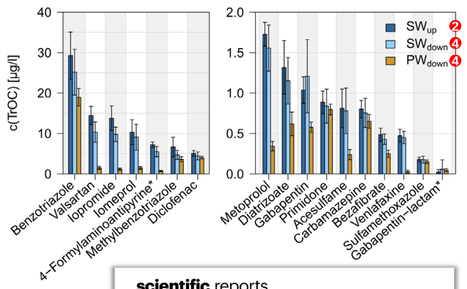
Ecosystem effects of the HZ on TrOCs only with sufficient hyporheic exchange

- hyporheic attenuation of TrOCs is relevant for a stream if both the TrOC attenuation in the HZ is high and a relevant proportion of the stream water flows through the HZ
- river restoration measures aiming at increasing TrOC attenuation should increase hyporheic exchange

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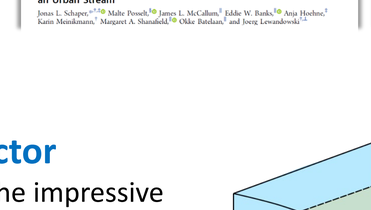
Environmental Science & Technology
Hyporheic Exchange Controls Fate of Trace Organic Compounds in an Urban Stream
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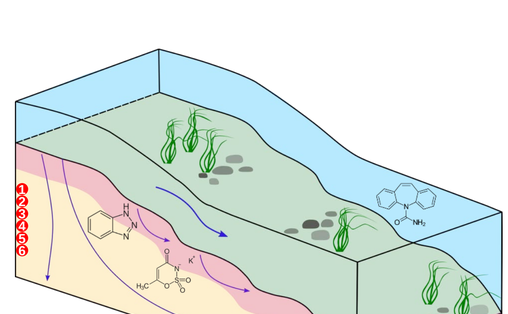
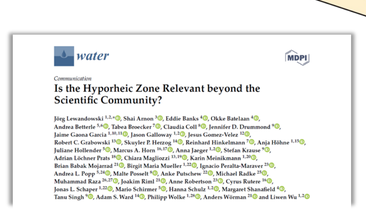
The HZ is an efficient bioreactor

- natural bioreactor responsible for the impressive self-purification capacity of streams including TrOC removal
- the HZ is a reactive urban interface that reduces TrOC concentrations




water
Is the Hyporheic Zone Relevant beyond the Scientific Community?

& all aforementioned papers