

Stream restoration reduces nitrate loads in agricultural landscapes

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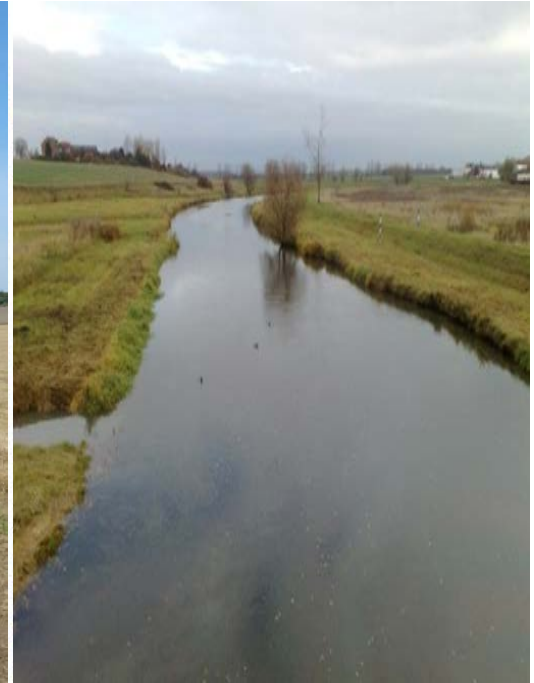
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Modified streams in agricultural landscapes



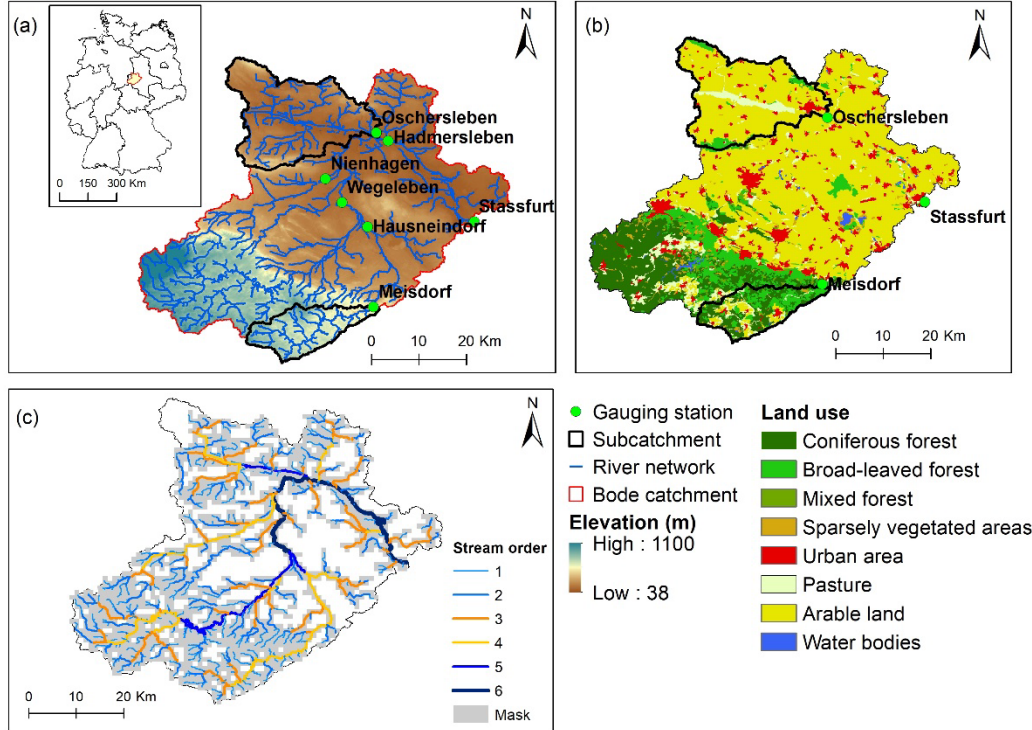
Motivations

- Altered stream morphology and diffuse pollution are the major pressures
- Channelization and straitening of streams reduces water residence time, exchange of water with the hyporheic zone and hence reduces nutrient retention of streams
- In general, stream restoration is thought to promote nutrient uptake due to primary production and denitrification
- But, systematic research on the effect of stream restoration on nutrient uptake in whole stream networks is still missing

Objectives

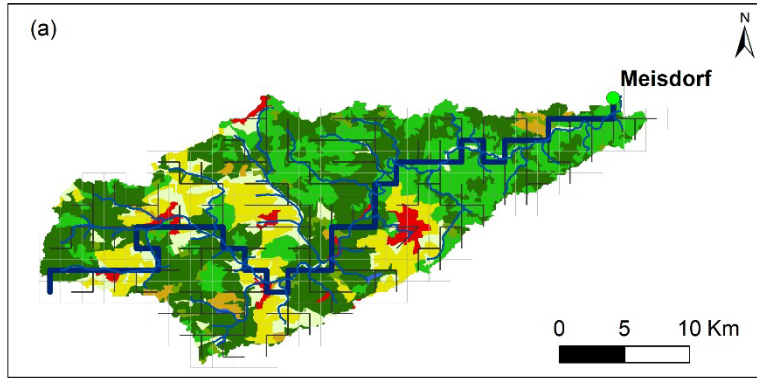
- Evaluate the reliability of fully distributed hydrological nitrate model by assessing stream assimilatory uptake and denitrification
- Characterization of spatiotemporal variability in retention dynamics and identify key factors to inform stream restoration measures
- Simulate the effects of re-meandering on NO_3 concentrations and retention efficiency for stream networks

Study site Bode catchment in central Germany

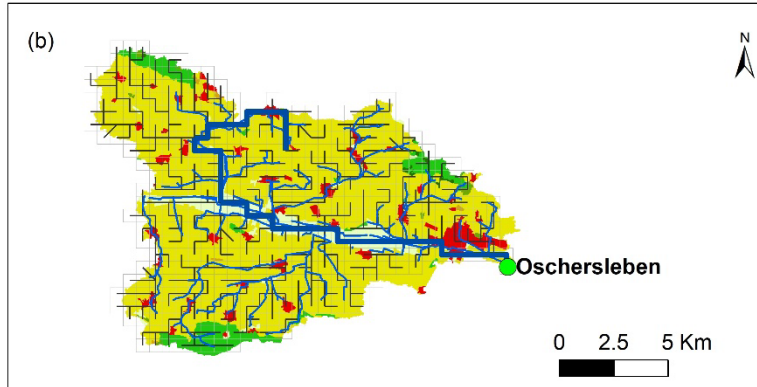


- Agricultural catchment of 3200km²
- Low land areas are characterized by the most fertile soils in Germany
- Intensive agriculture results in heavily modified streams
- We choose two sub-catchments with representative landscapes

Model river network of (a) Upper Selke and (b) Großer Graben sub-catchments



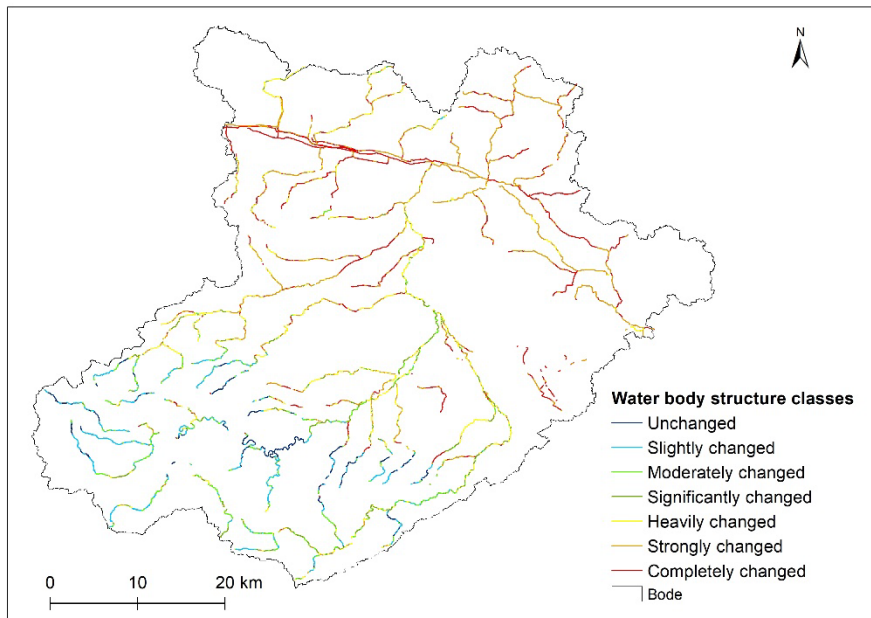
Upper Selke (177km²)
Harz mountains with 73% forest
Mostly natural streams



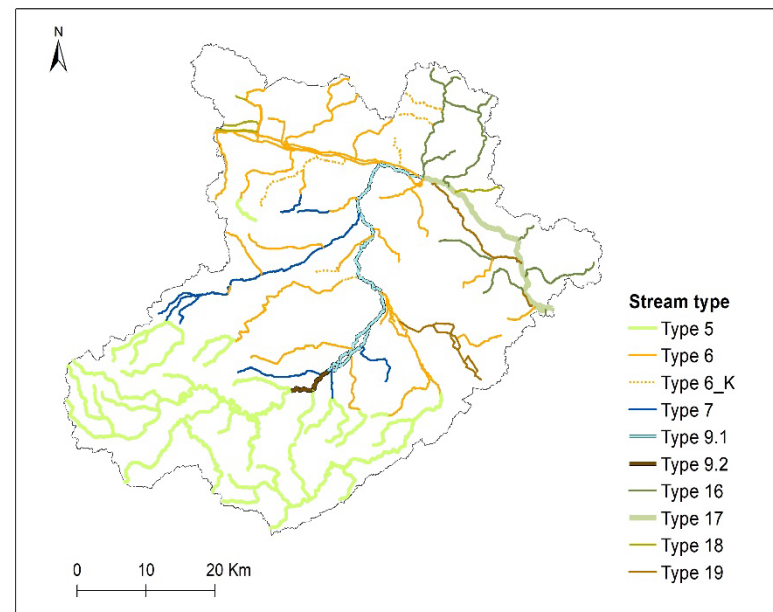
Großer Graben (435 km²)
Intensively farmed lowlands with
87.4% arable land
80% heavily modified streams

Water body structure of the Bode river network

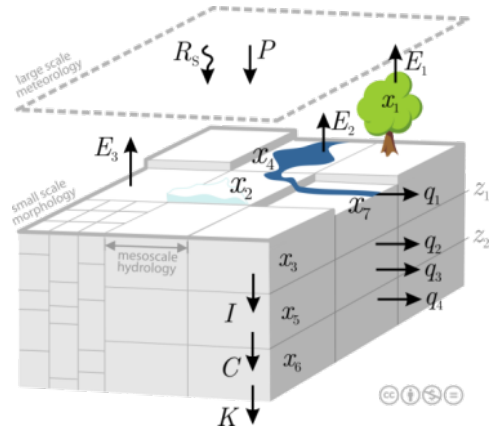
Water body structure classes



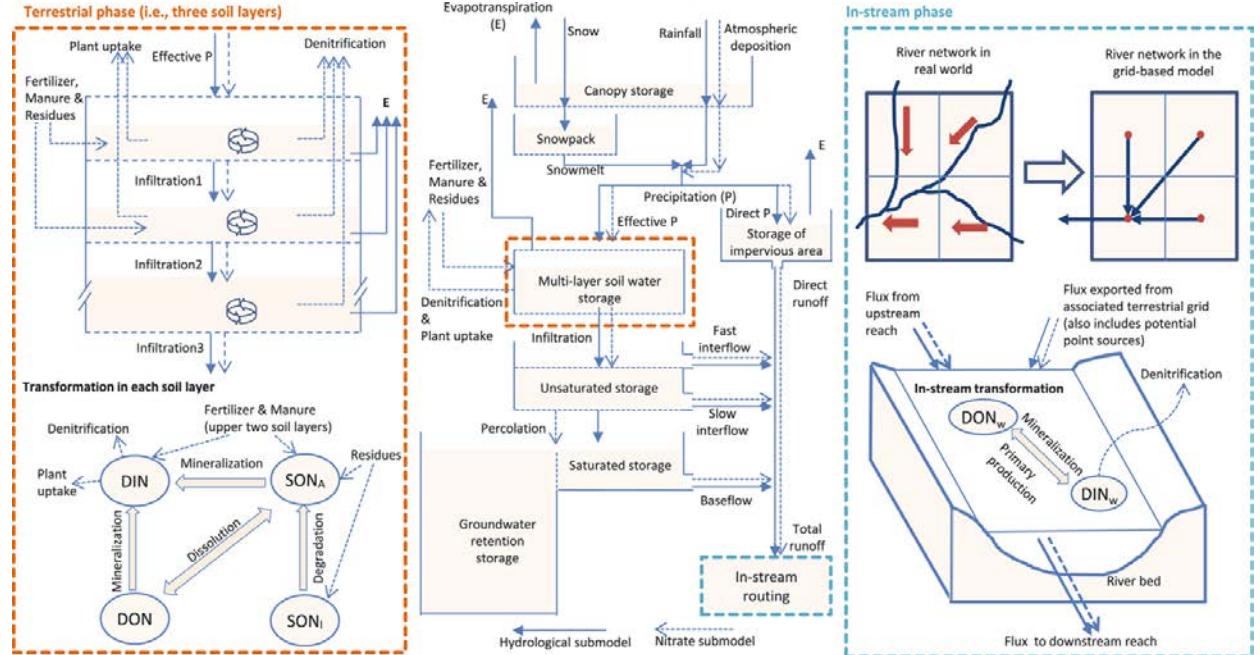
Stream types



mHM-Nitrate model structure



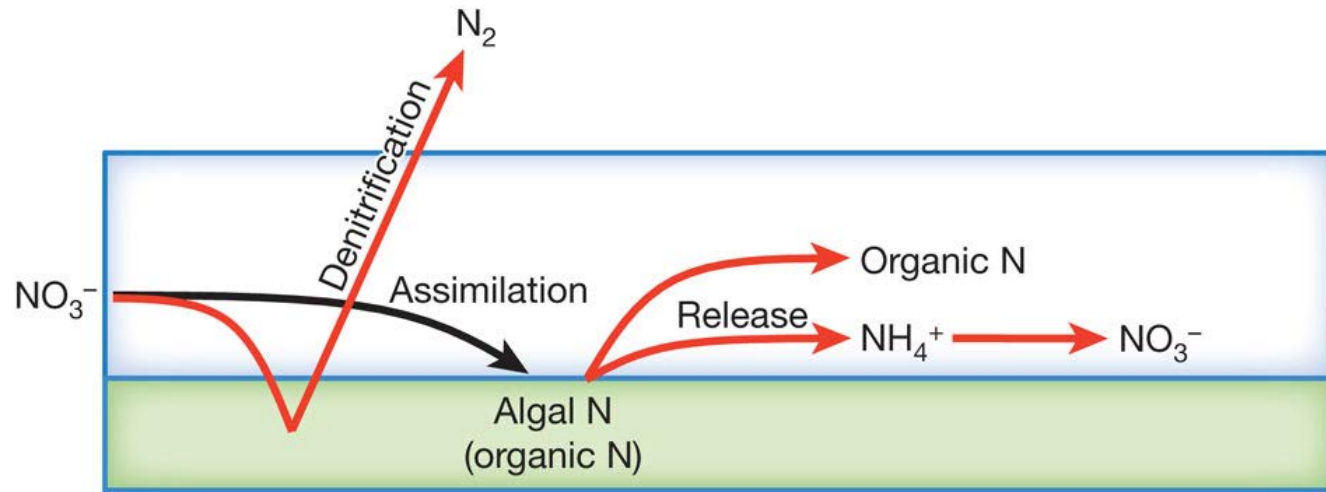
(Samaniego et al. 2010 WRR;
Kumar et al. 2013 WRR)



(Yang et al., 2018, WRR.; Yang et al., 2019, WR)

Source code: Yang and Rode (2020)

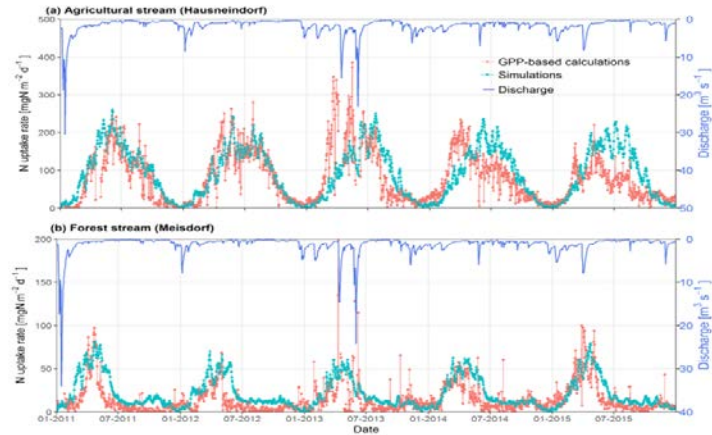
Nitrogen cycling in streams



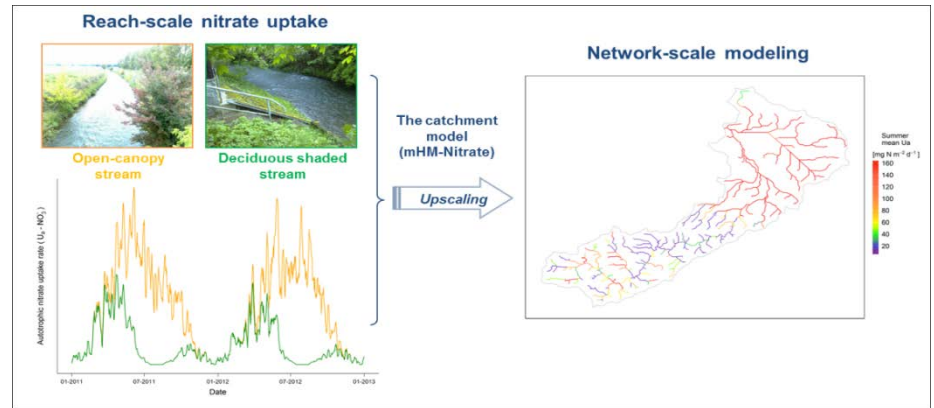
Regionalization of in-stream N-uptake

- Using diurnal high frequency data to quantify assimilatory N uptake for deviating land use
- Regionalization using global radiation and leaf area index for quantifying light availability
- Upscaling to the whole network based on mHM-Nitrate

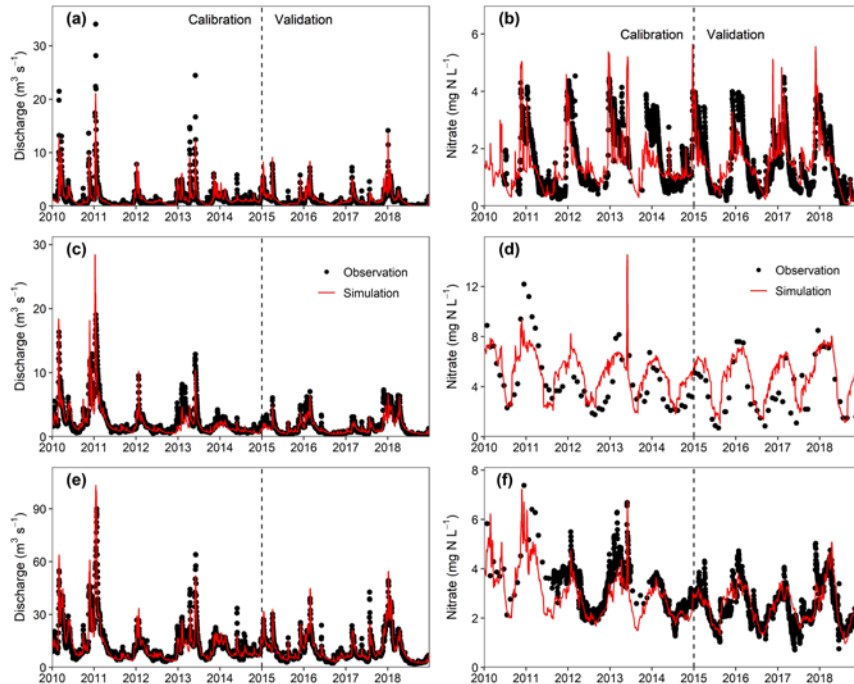
Reach-scale regionalization



Upscaling based on mHM-Nitrate



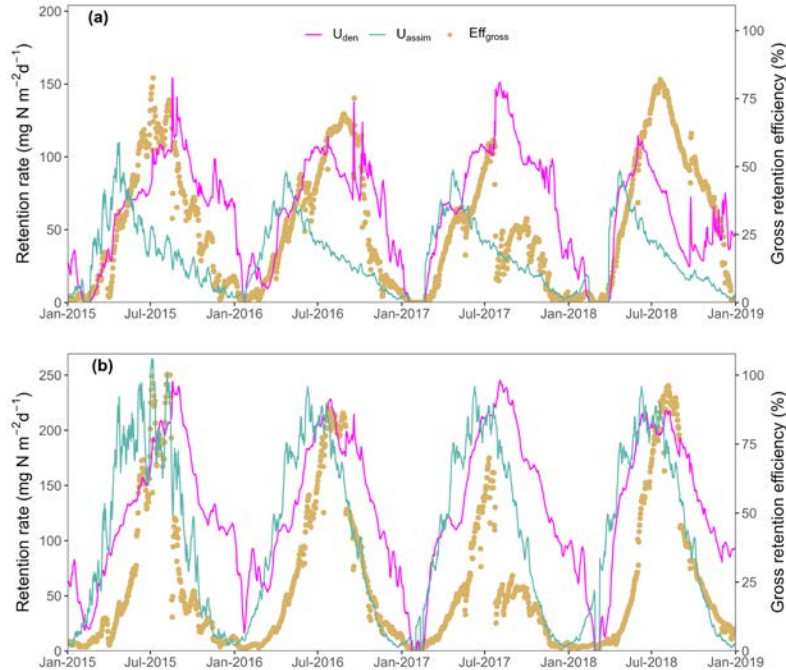
Calibration and validation of the distributed water quality model mHM-nitrate



- Model testing at three different gauge station
- NSE for **discharge** between 0.75 and 0.85 (cal.) and 0.78 and 0.92 (val.)
- NSE for **NO₃** between 0.48 and 0.50 (cal.) and 0.41 and 0.63

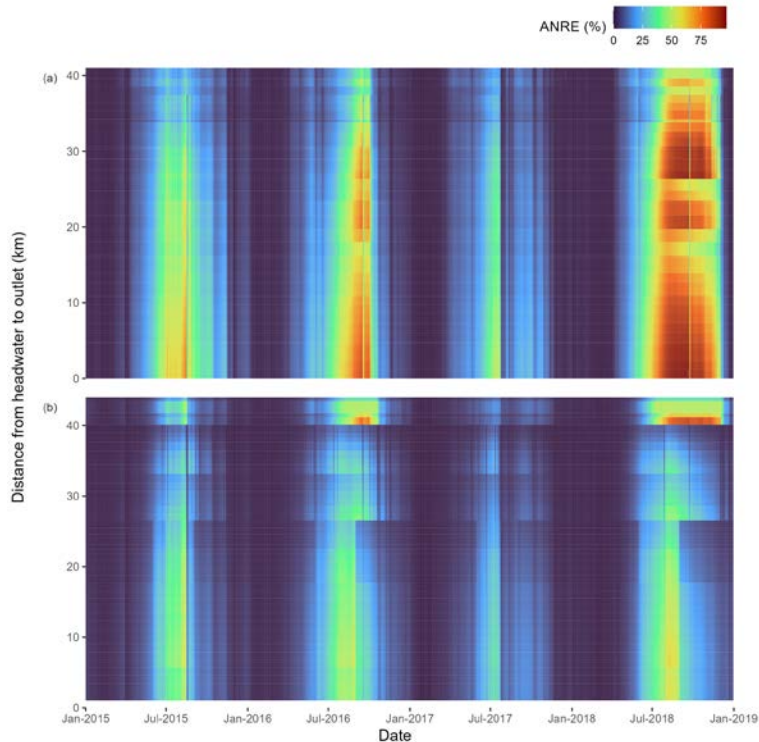
Forest (a-b) arable (c-d), and outlet gauge station (e-f)

Nitrate retention rates in the forest (a) and arable (b) sub-catchments



- Daily denitrification rates and assimilation rates show clear seasonal variation
- Assimilatory retention rates were three times higher in the arable than in the forest sub-catchment
- Gross retention efficiency shows clear annual pattern in both catchments
- Gross retention efficiency give similar values at annual scale with 26% (forest) and 35% (arable)

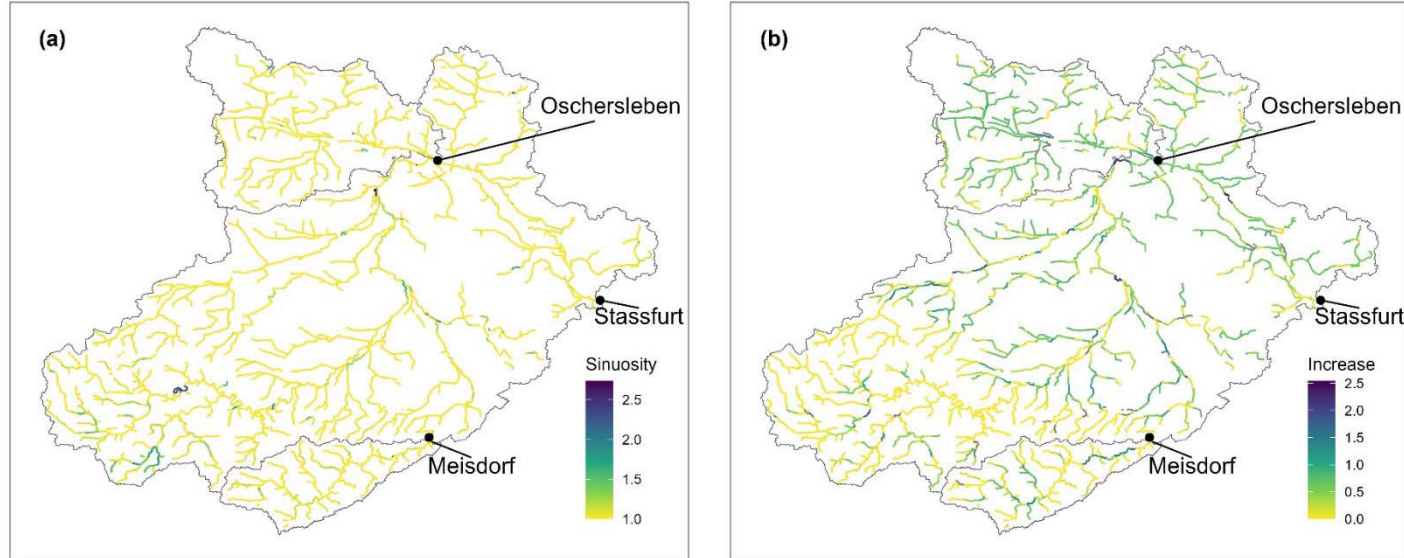
Accumulated net retention efficiency (ARNE)



a) Upper Selke (forest) and b) Großer Graben (arable)

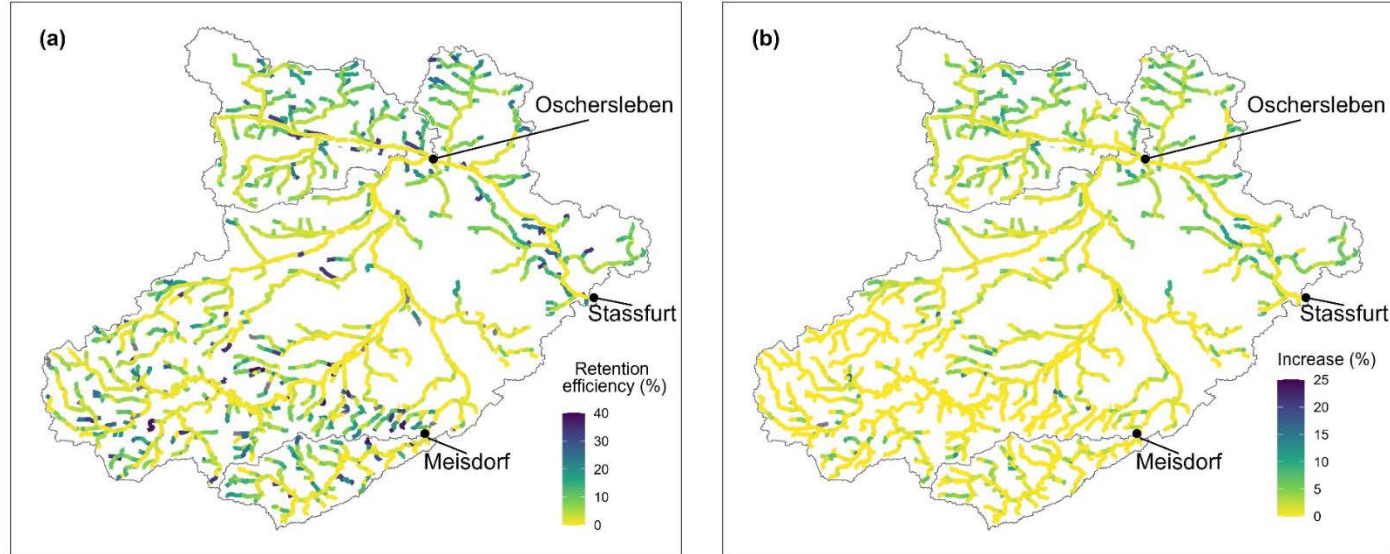
- ANRE is the ratio between total NO_3^- -retention within streams and the total NO_3^- input load
- ARNE is high between June and November in both catchments, in 2018 > 60%
- Discharge and N concentration strongly impacts the NO_3^- -instream uptake
- Total in-stream uptake from the whole network increased from headwaters to the outlet
- Tributaries mark dramatic changes of ARNE

Spatial distribution of (a) river sinuosity at baseline and (b) the increase of sinuosity under restoration scenario compared to baseline



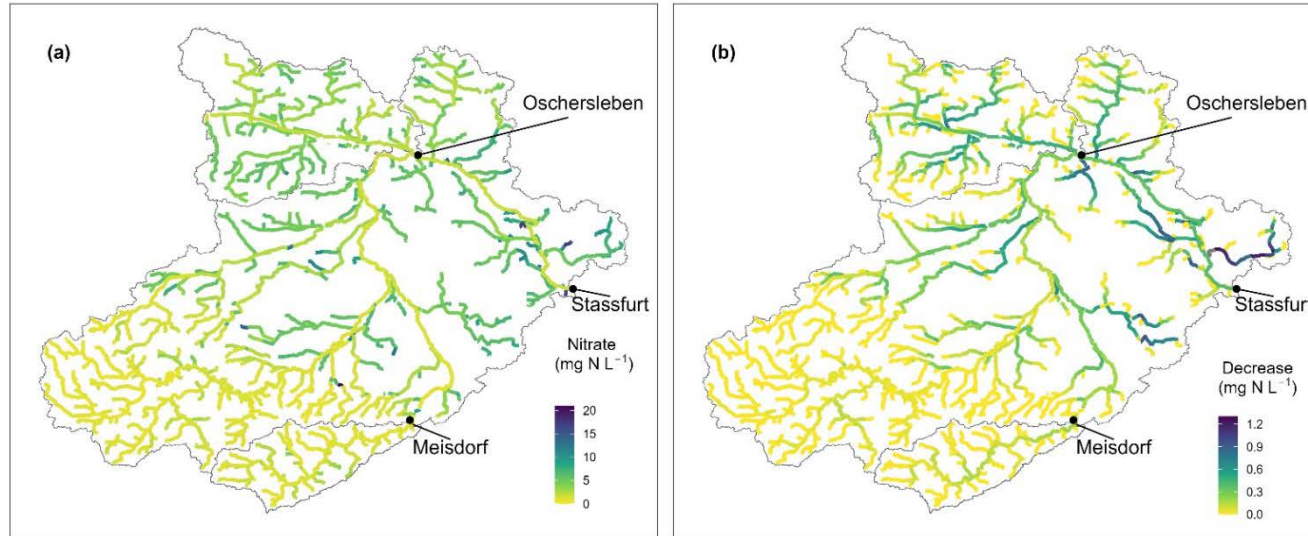
- Stream sinuosity is low under current baseline conditions (<1.07) and increased for restoration scenario up to 3.5

- Median net nitrate retention efficiency in summer in a) baseline and it's increase in b) restoration scenario



- Net NO_3 retention efficiency was larger for small streams than for larger streams
- Retention effects are larger in lowland streams than in upland streams

Spatial pattern of mean summer nitrate concentration in a) baseline and b) restoration scenario



- NO_3 concentration were higher in small than in large streams
- Larger streams show higher decline in NO_3 concentration (2.3-2.6 mgN/L) between 0.3-0.5 mg/l
- Summer NO_3 concentration can be reduced between 20 and 25% at the catchment outlet

Conclusions

- In-stream gross nitrate assimilatory uptake and denitrification amounted to 24.6% of total yearly N loading in the study catchment
- Gross nitrate retention ranged between 74% in summer and 5% in winter
- Stream restoration due to re-meandering of streams increased net N-uptake up to 25.4% in summer.
- Greater effects were seen in small streams
- Restoration efforts should consider augmenting stream sinuosity to decrease nitrate concentration

Many thanks

The related literature is available as:

Zhou, X., Jomaa, S., Yang, X., Merz, R., Wang, Y., Rode, M. (2023): Stream restoration can reduce nitrate levels in agricultural landscapes *Sci. Total Environ.* 896 , art. 164911 10.1016/j.scitotenv.2023.164911

Zhang, X., Yang, X., Hensley, R., Lorke, A., Rode, M. (2023): Disentangling in-stream nitrate uptake pathways based on two-station high-frequency monitoring in high-order streams. *Water Resour. Res.* 59 (3), e2022WR032329 10.1029/2022WR032329

Kunz, J.V., Hensley, R., Brase, L., Borchardt, D., Rode, M. (2017): High frequency measurements of reach scale nitrogen uptake in a fourth order river with contrasting hydromorphology and variable water chemistry (Weiße Elster, Germany) *Water Resour. Res.* 53 (1), 328 - 343 10.1002/2016WR019355