Unraveling biogeochemical transformation of organic carbon and nitrogen turnover in groundwater along the hillslope transect

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OSPP voting

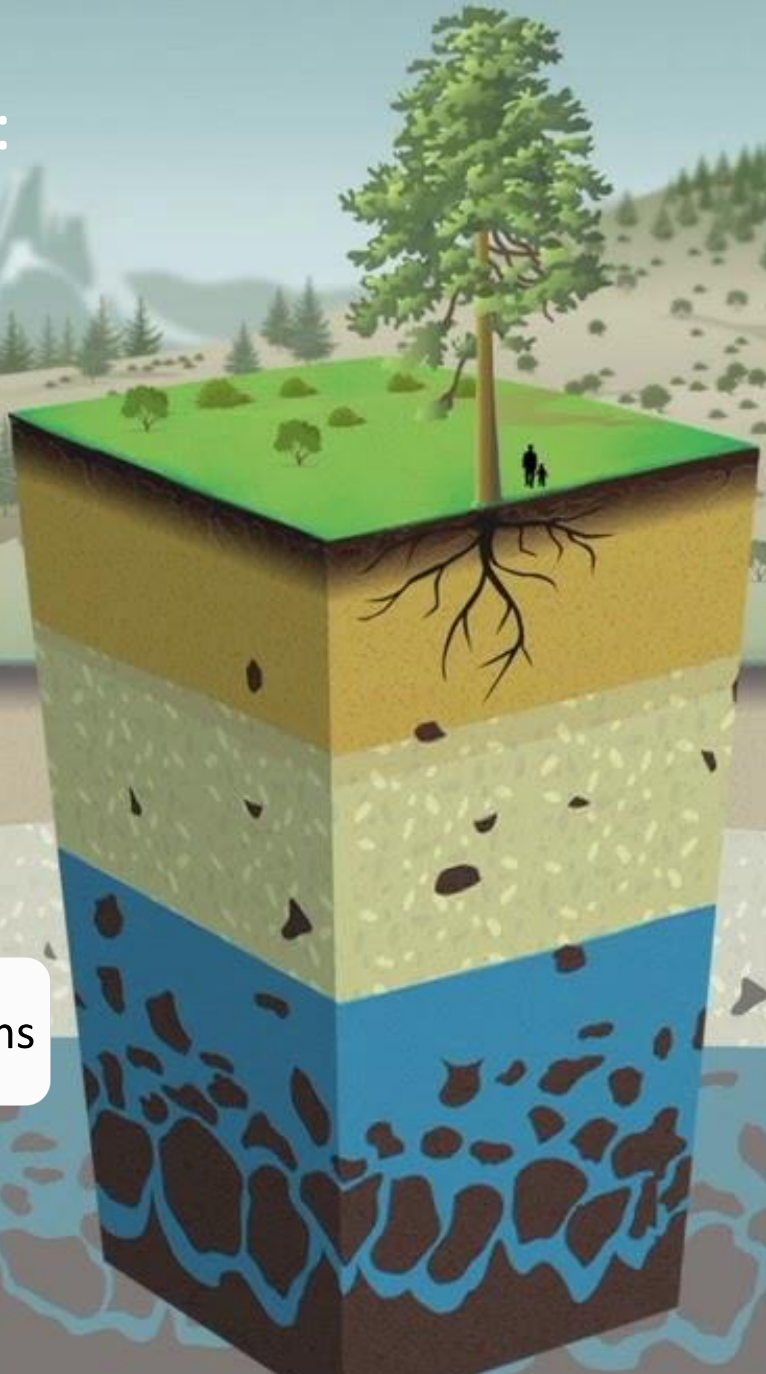
Introduction:

The Earth‘s Critical Zone:

where all of life happens

Collaborative research Centre AquaDiva

Understading the links between Surface and Subsurface Biogeosphere



The Earth‘s Critical Zone =
earth‘s thin, heterogeneous, living, permeable layer

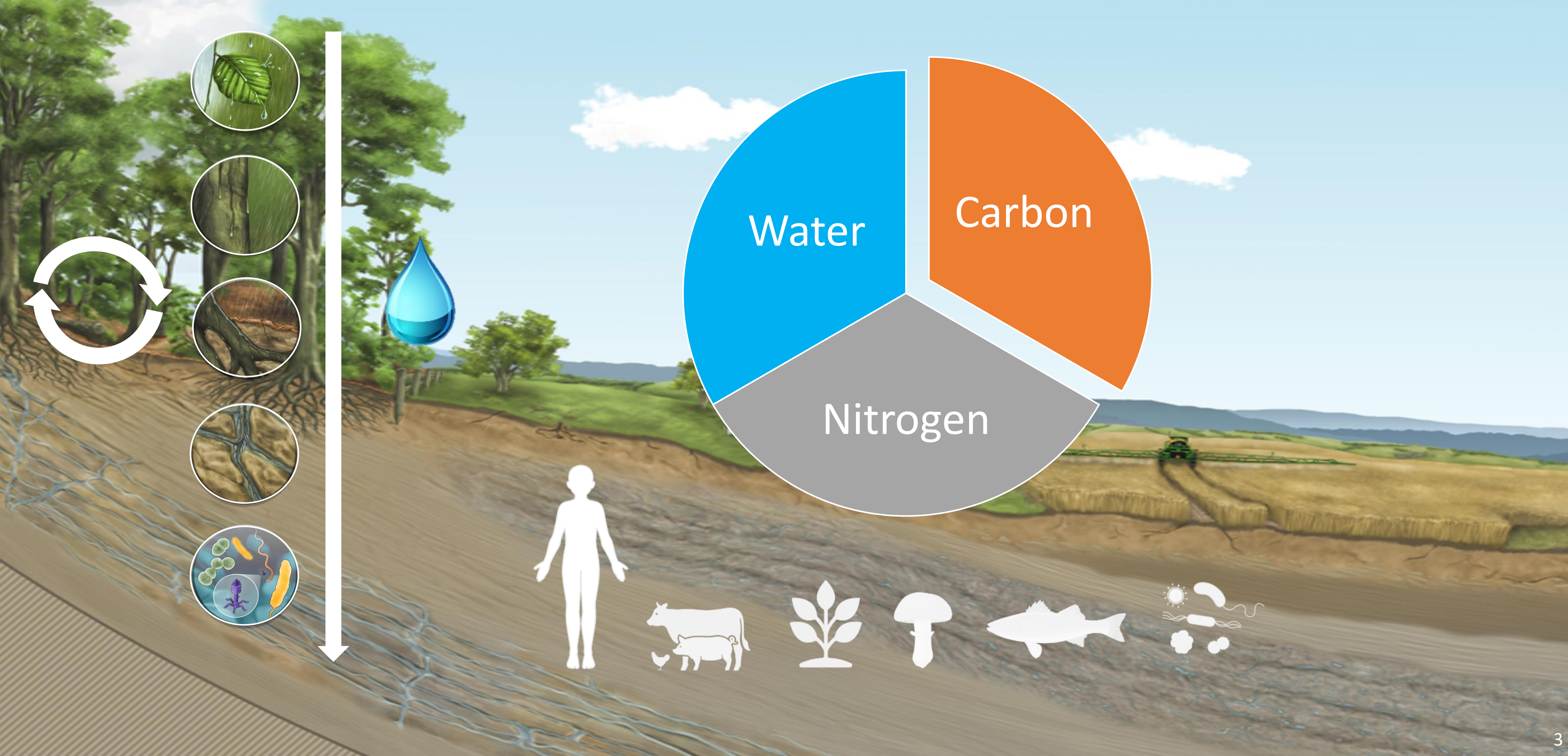
rock, soil, water, air, and living organisms

“biogeochemical reactor” transforms water, gases, and other materials

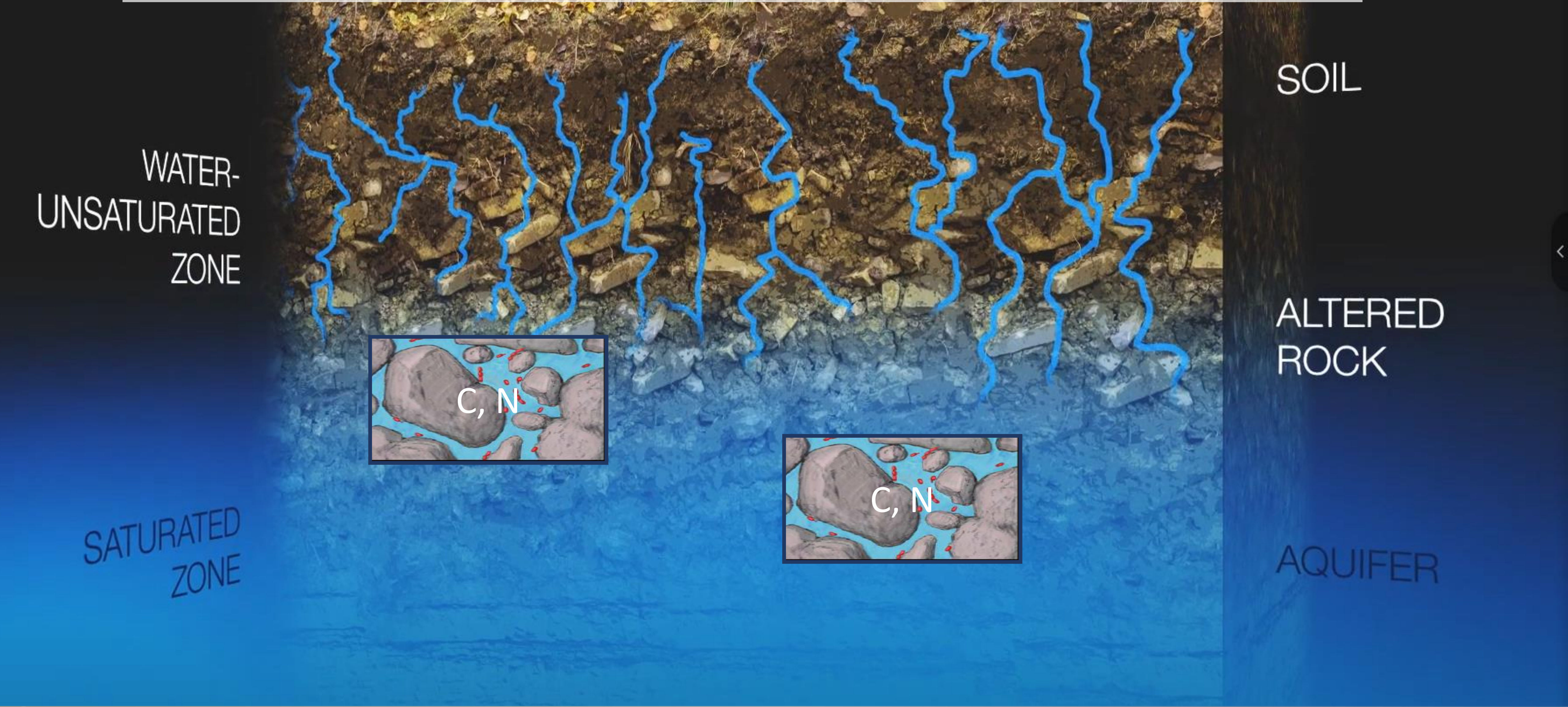
require a large transdisciplinary team

Source: Konstanze Hild,2022
https://www.youtube.com/watch?v=aezWKCQxR5U

BIOGEOCHEMICAL CYCLES: cycles of chemical elements and compounds between the living and non-living parts of the Earth

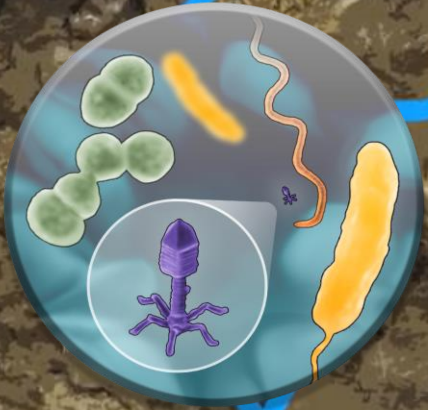


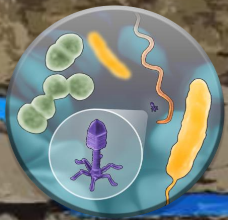
SUBSURFACE IS A BIG STORE OF C &N



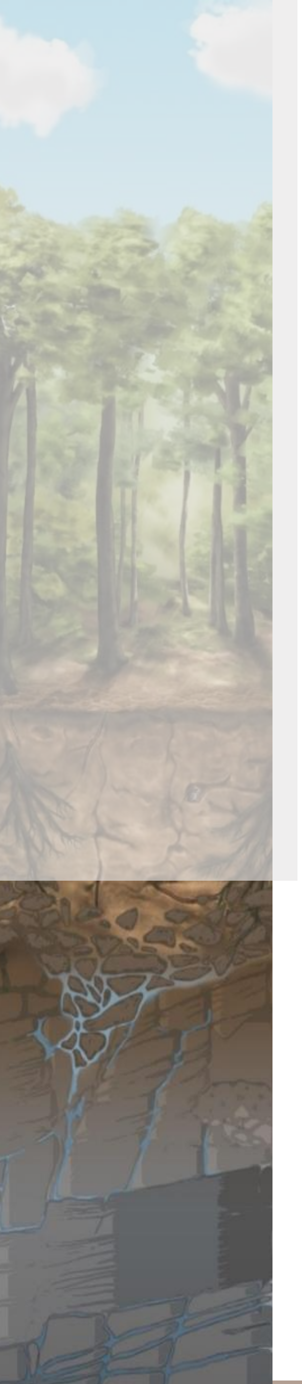
MAIN CHALLENGE: SPATIAL HETEROGENEITY OF THE SUBSURFACE

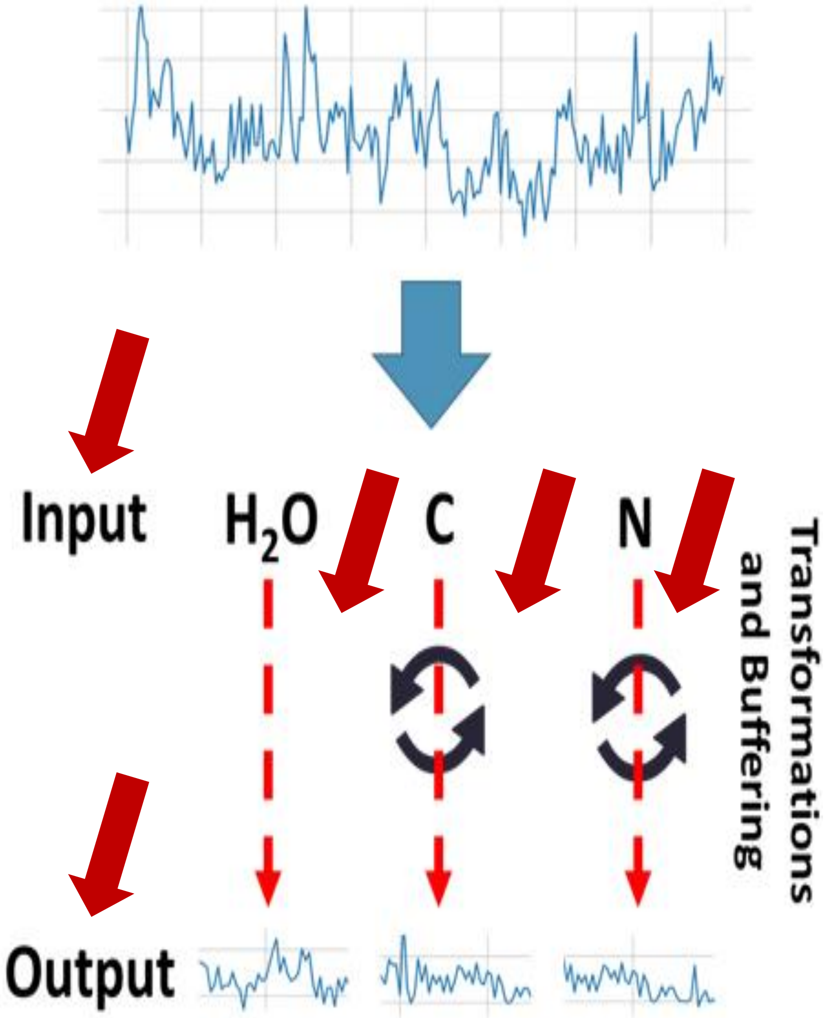
Transformation of C, N mediated by microbes





C, N, and microbes distribute heterogeneously



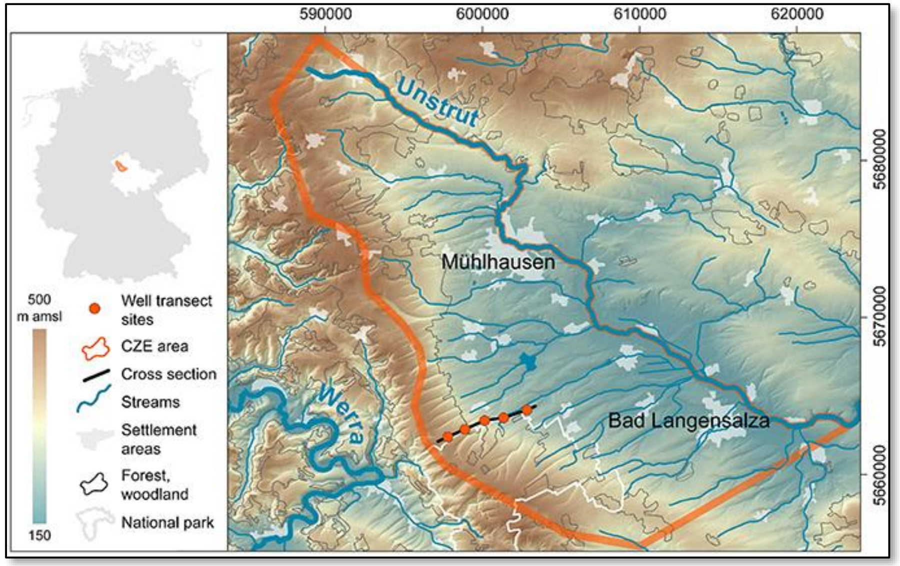


The overarching aim of the modeling

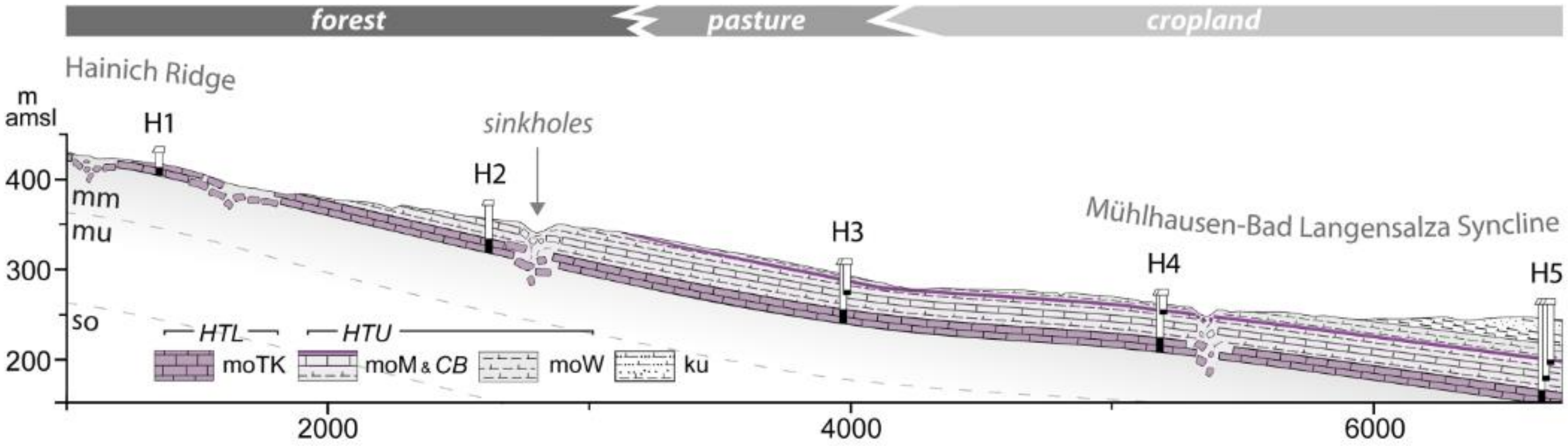
- How deep penetrate signals from the surface?
- What are the long-term effects due to climate and land use change?

STUDY SITE: HAINICH TRANSECT

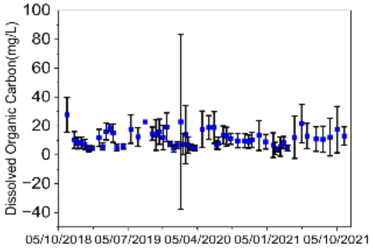
- Located northwest of Thuringia (central Germany) in a hillslope sub-catchment Nägelstedt of river Unstrut (850 km^2)
- Hainich CZE: 5.4km long hillslope transect.
- Intensively monitoring of surface and subsurface

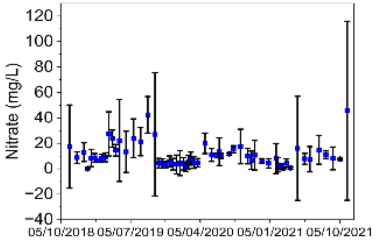


(Kuesel et al., 2016)

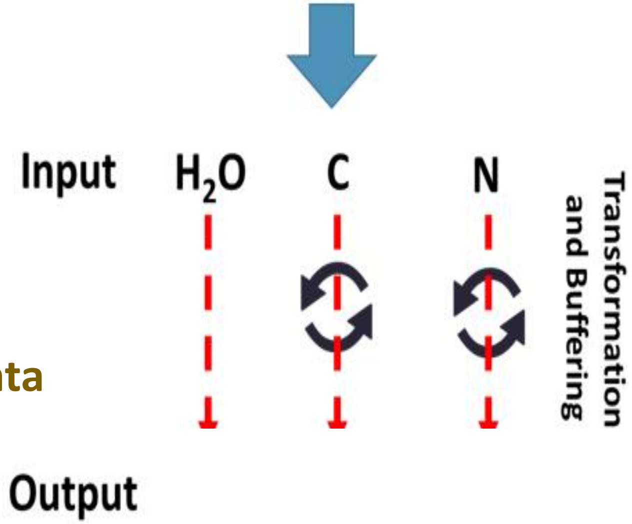


DATA MEASUREMENTS

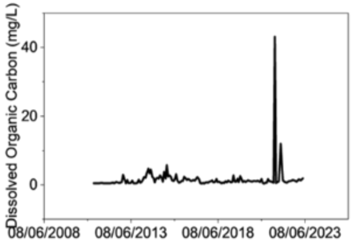


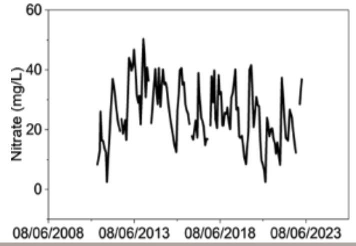


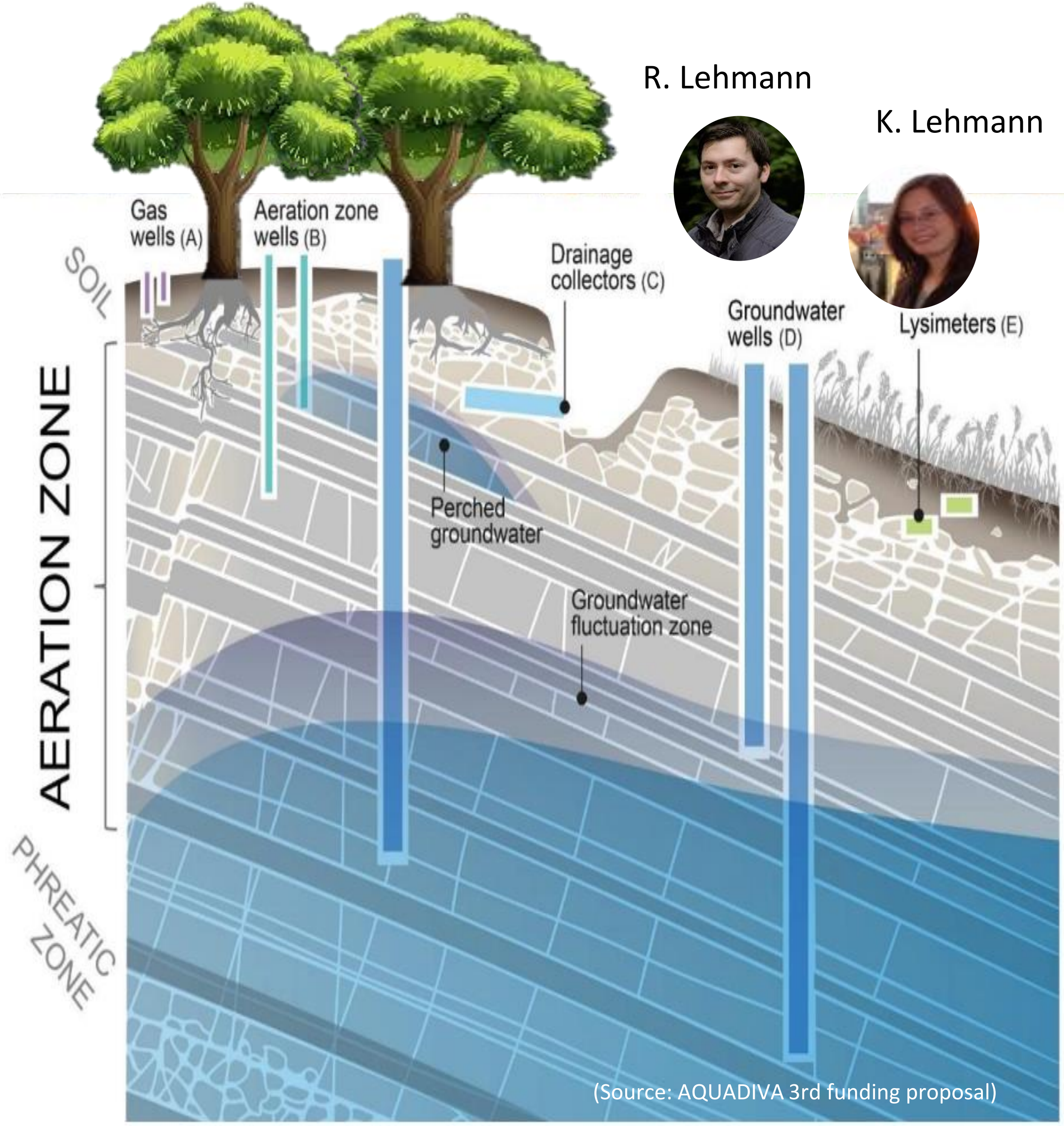
Lysimeter data



Groundwater data







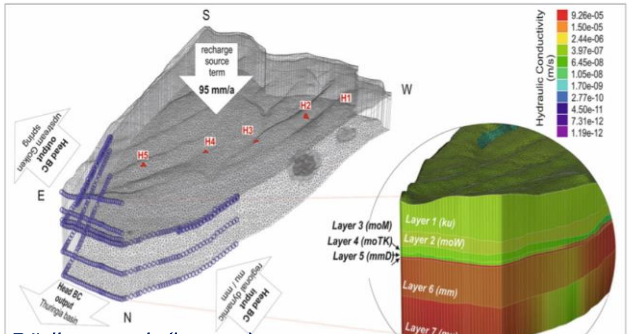
(Source: AQUADIVA 3rd funding proposal)

R. Lehmann

K. Lehmann

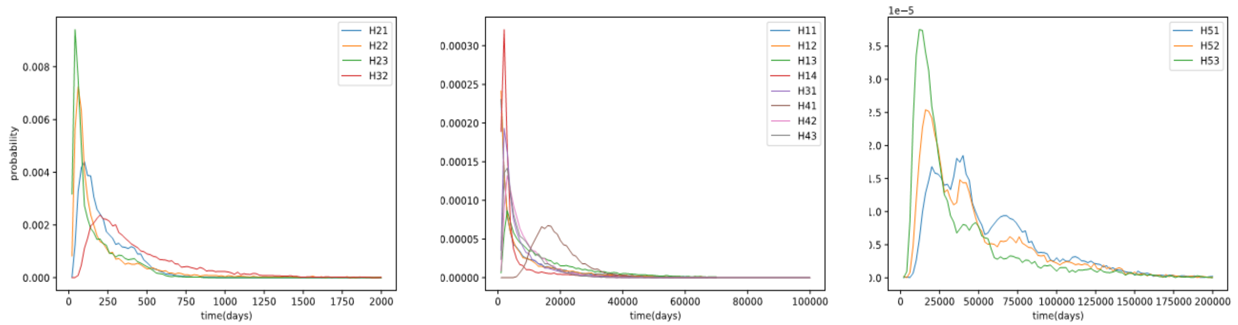
TRAVEL TIME-BASED MODEL APPROACH

1. Flow model of Hainich CZE

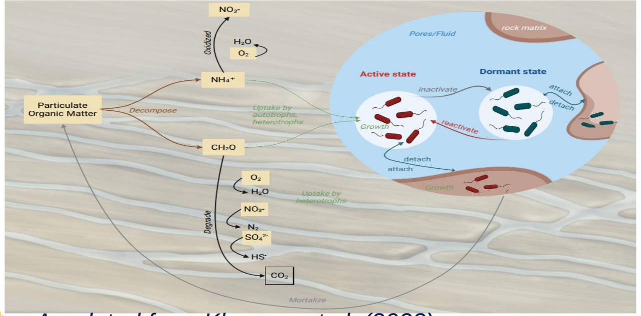


Rödiger et al. (in prep)

Travel time distribution pi(t) for well i

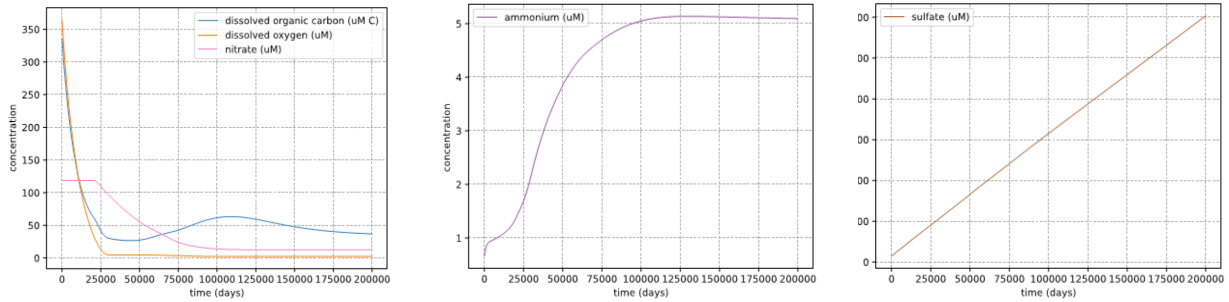


2. Schematic of simulated biochemical reaction networks



Appdated from Khurana et al. (2022)

Simulated concentration cj(t) of reactive species j along a flow path

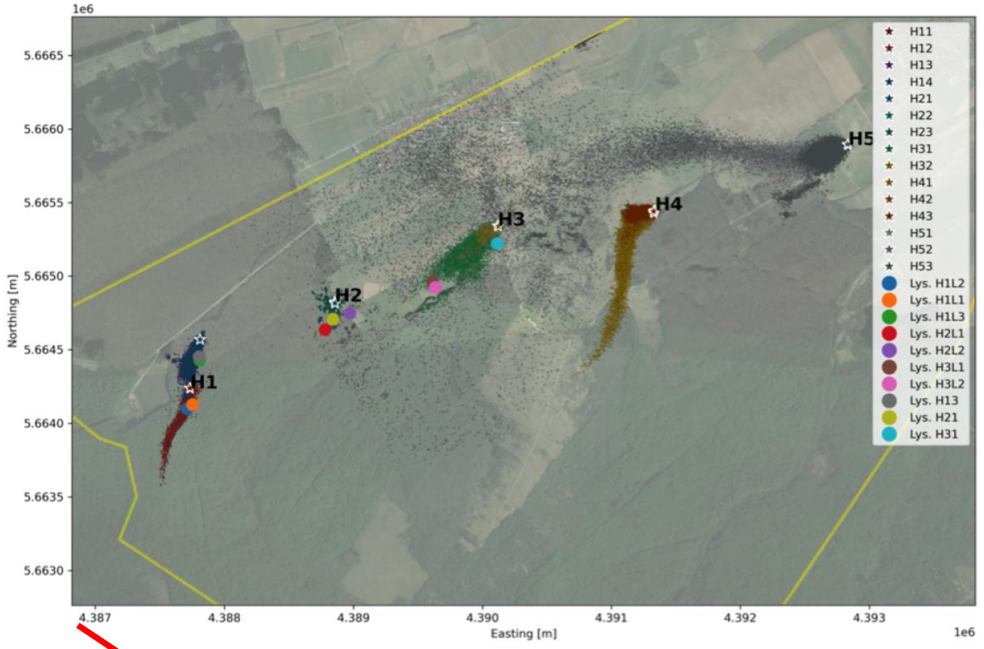


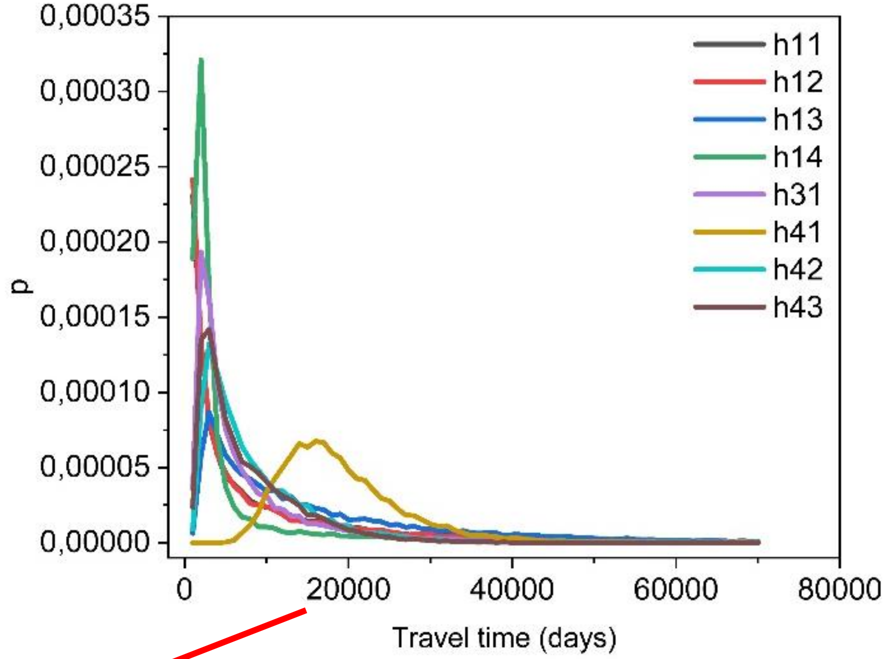
Combine 1st and 2nd components, we have:
3.Simulated concentration of species j at well i

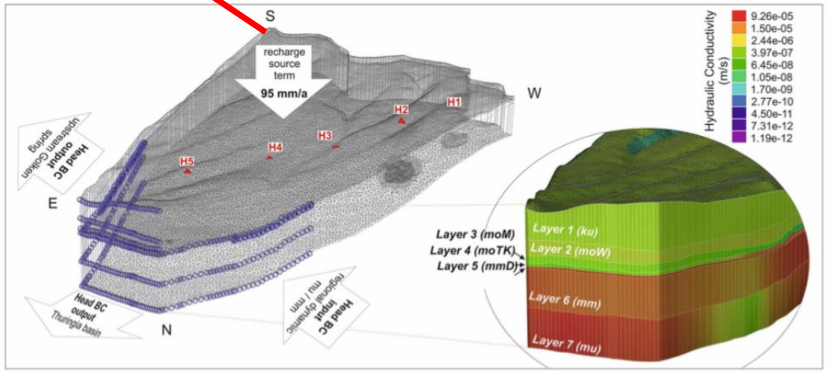
$$c_{i,j} = \int p_i(t) \cdot c_j(t) dt$$

Flow model of Hainich CZE transect

FLOW PATHS AND TRAVEL TIMES TO THE OBSERVATION WELLS



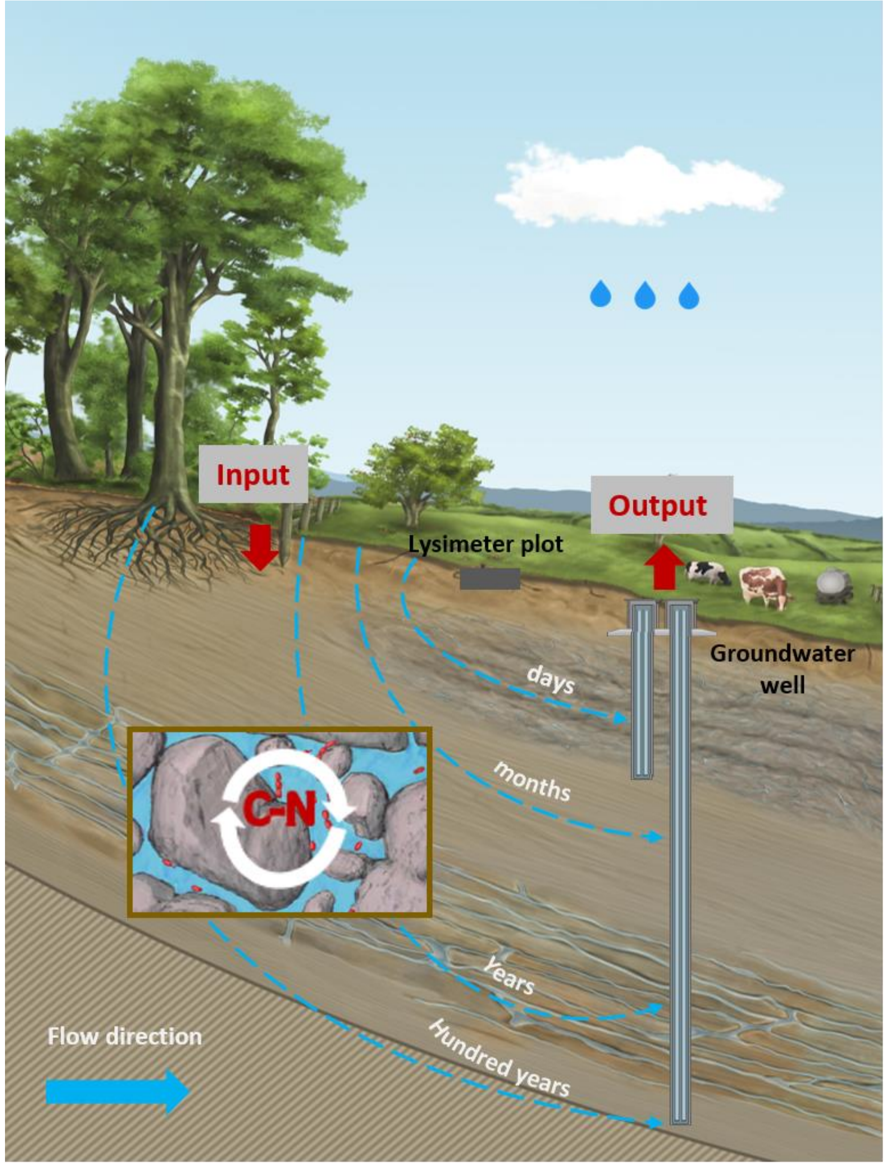


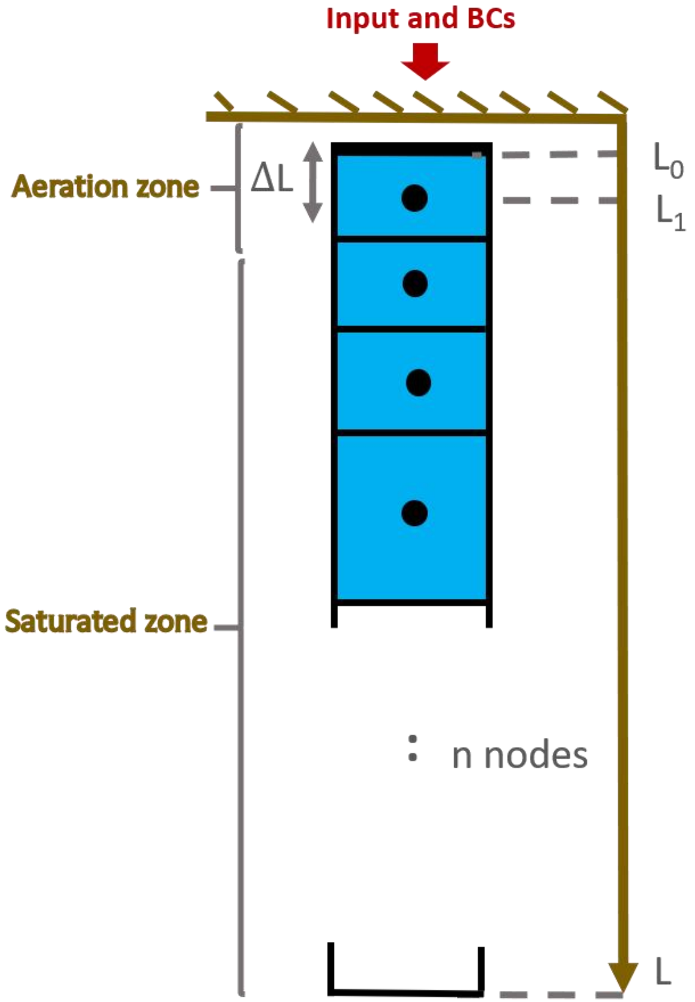


Groundwater flow model

Rödiger, Houben et al. (in prep.)

BIOGEOCHEMICAL PROCESSES ALONG 1D FLOW PATHS

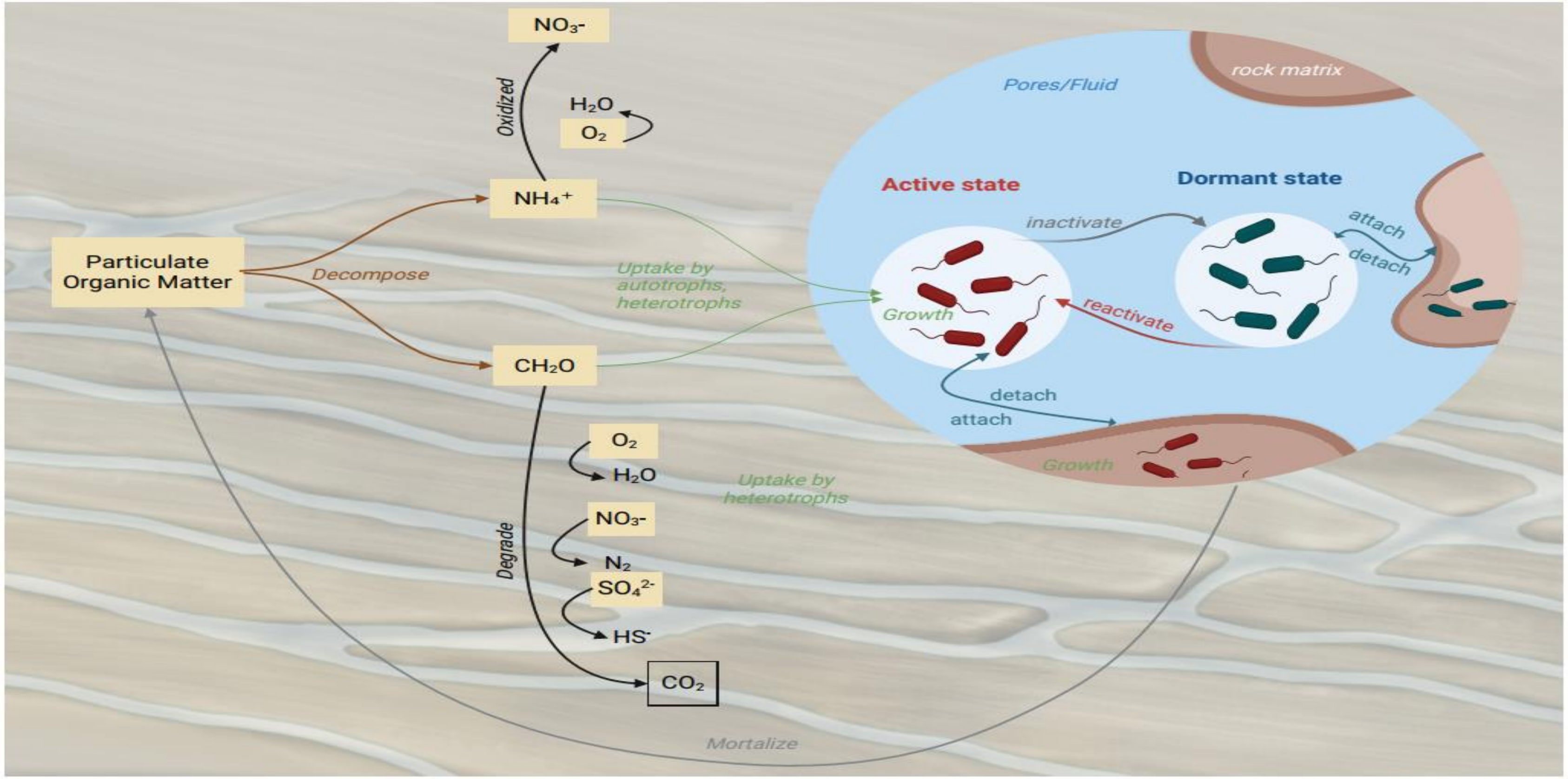




- 1D advective-dispersive-reactive transport
- Upper 50m of profile: aerobic conditions, abundant supply of oxygen
- Numerical mesh grid: non-uniform, with grid sizes ranging from fine to coarse.
- Total length (L) = 20000m
- Total time (t) = 200000 days

Biogeochemical processes along 1D flow paths

BIOCHEMICAL REACTION NETWORK



Chemical compounds:

1. dissolved organic carbon (DOC)
2. Particulate organic carbon (POC)
3. Oxygen (O_2)
4. Nitrate (NO_3)
5. Sulfate (SO_4)
6. Ammonium (NH_4)

Microbial species:

1. Aerobic DOC degraders (BO2)
2. Nitrate reducers (BNO3)
3. Sulfate reducers (BSO4)
4. Ammonia oxidizers (BNH4)

- **23 concentration variables**
- **68 microbially driven reactions expressed by modified Monod-type expressions**

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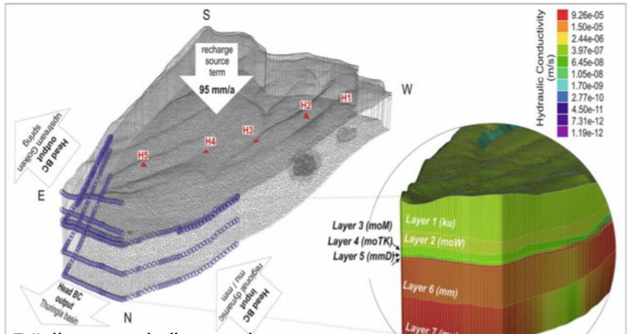

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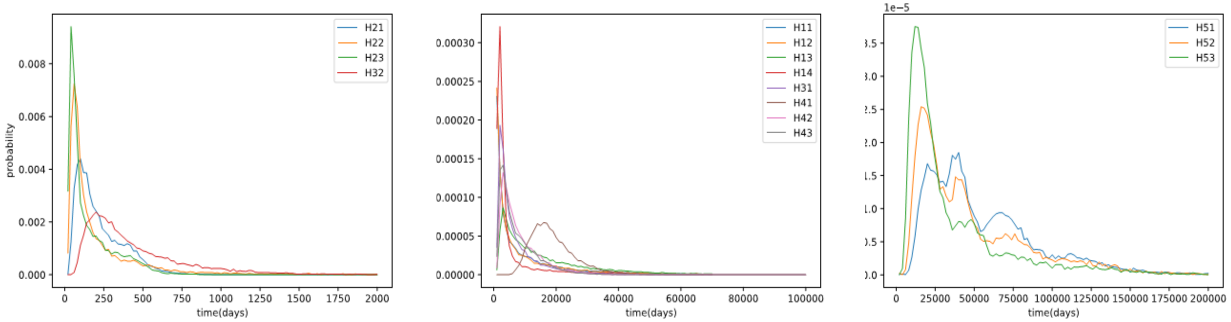

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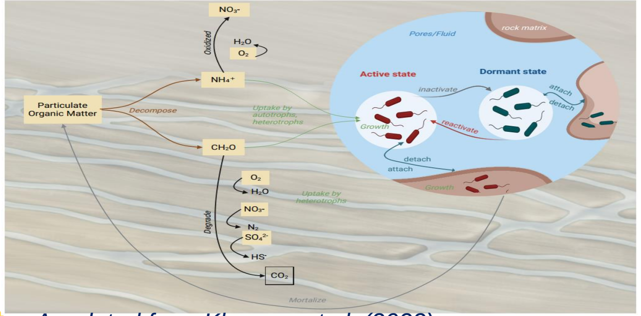

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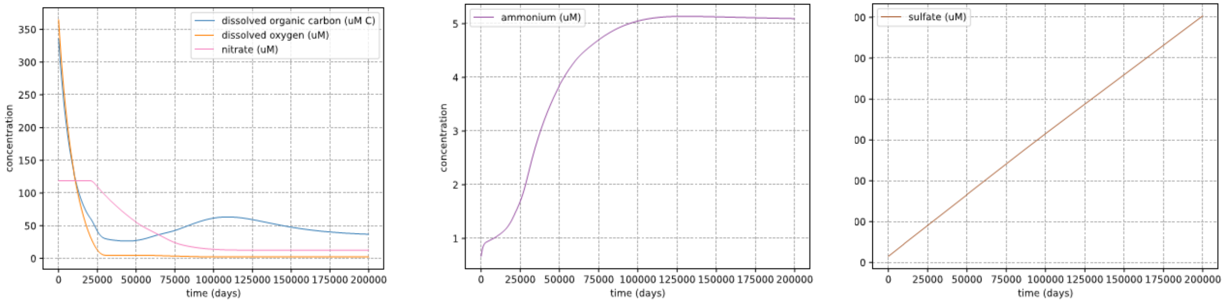

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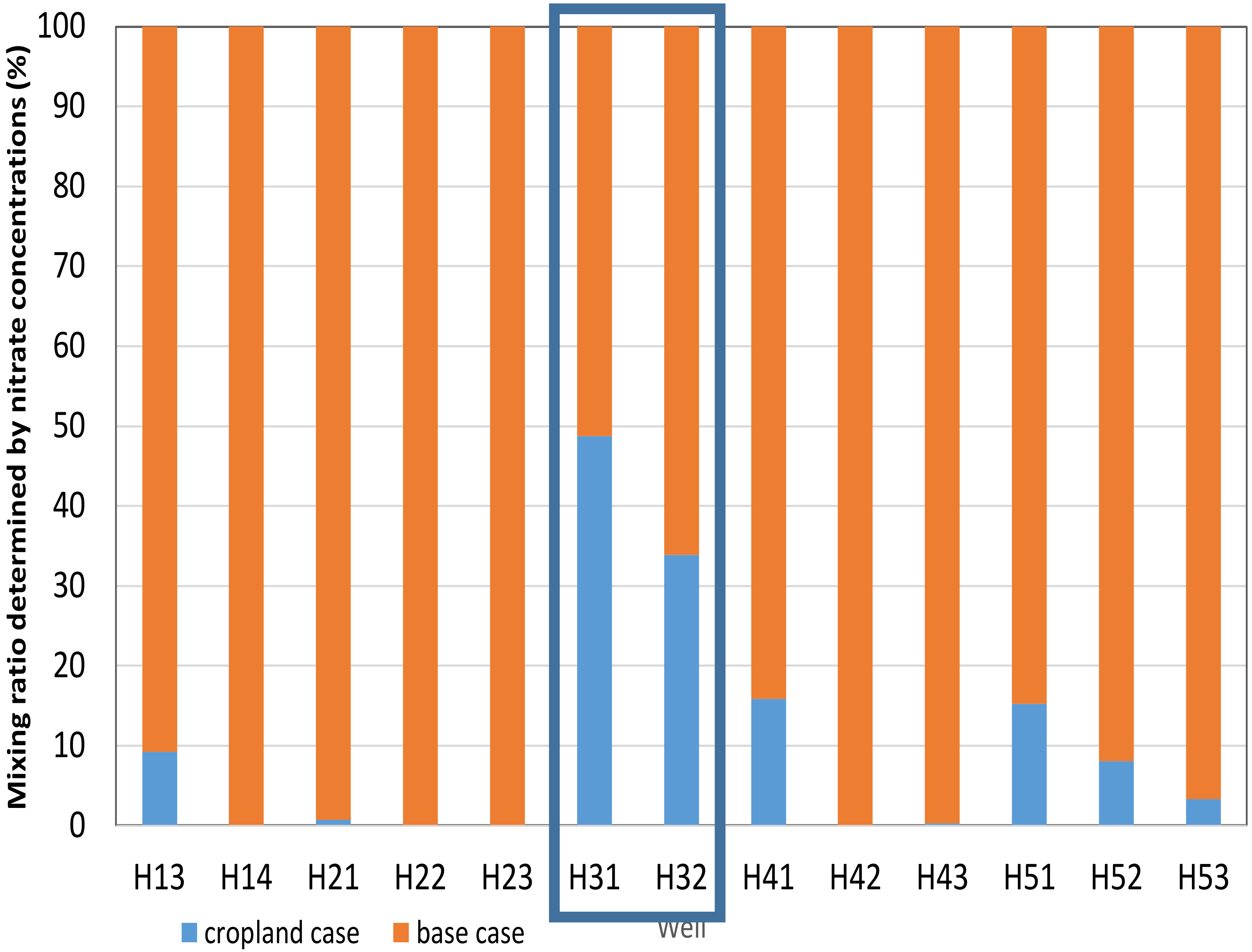
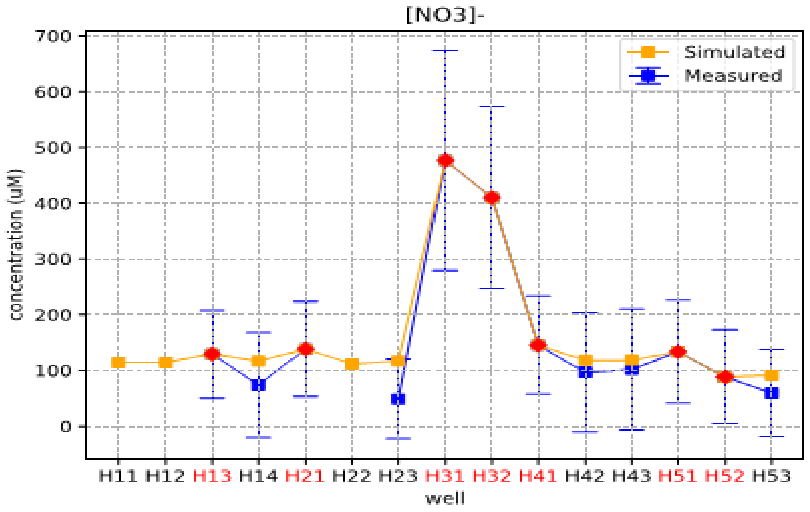
THE MIXING RATIO DETERMINED BY NITRATE CONCENTRATIONS BETWEEN THE BASE AND CROPLAND CASES

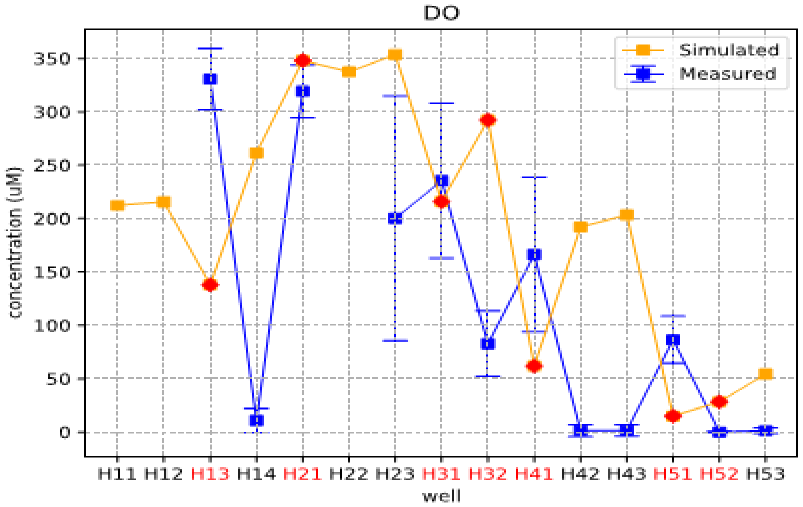


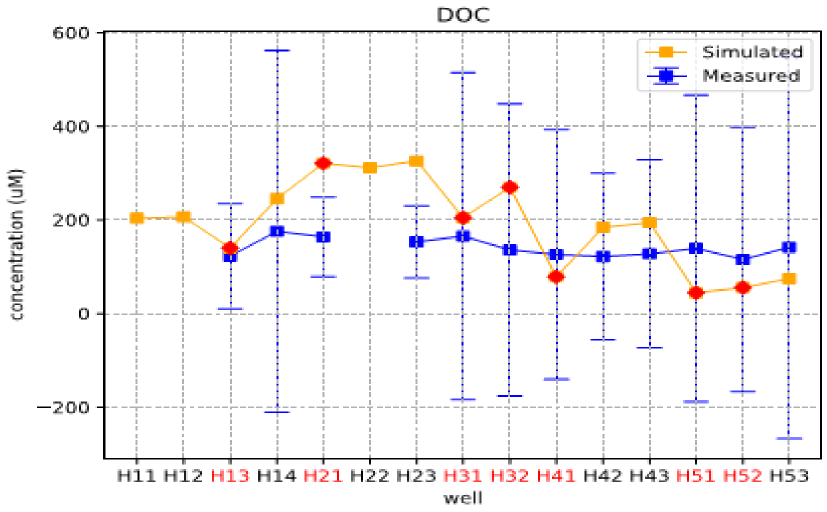
Confirmed spatial variations of land use-dependent input.

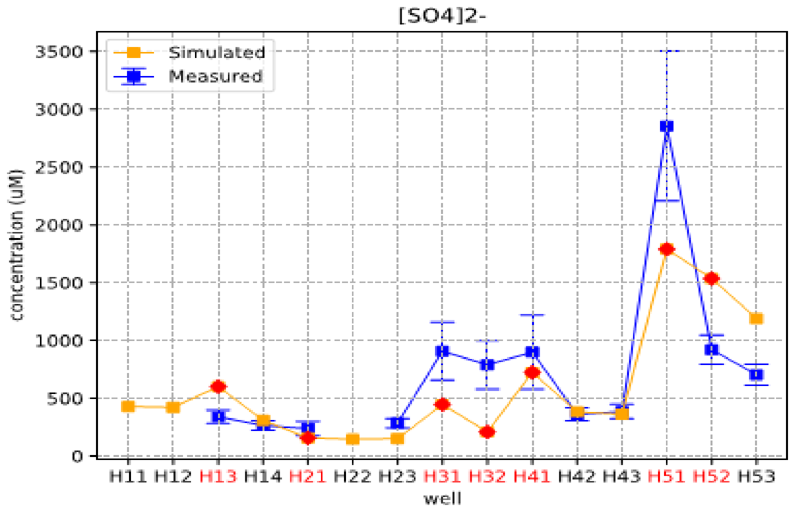
- H31 and H32 receive 30% to 50 % water from the cropland areas (which generally agrees with the origin of flow paths predicted by the flow model)

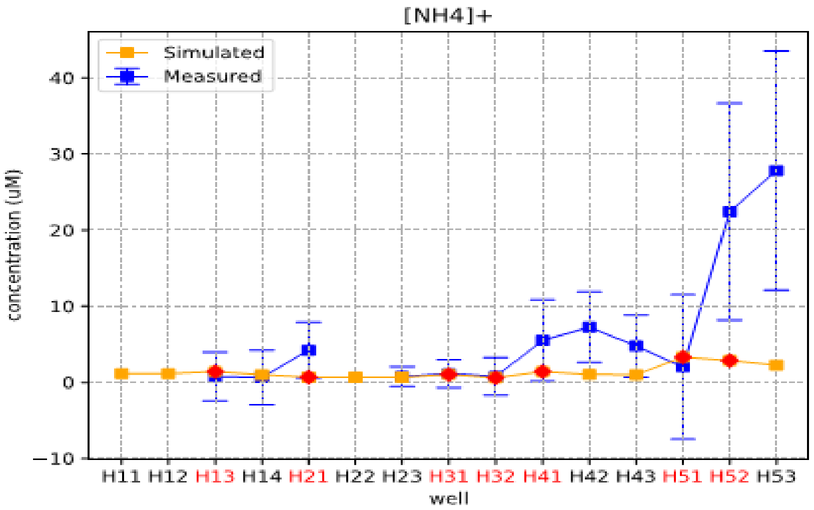
Suggesting a strong link with the surface signals.







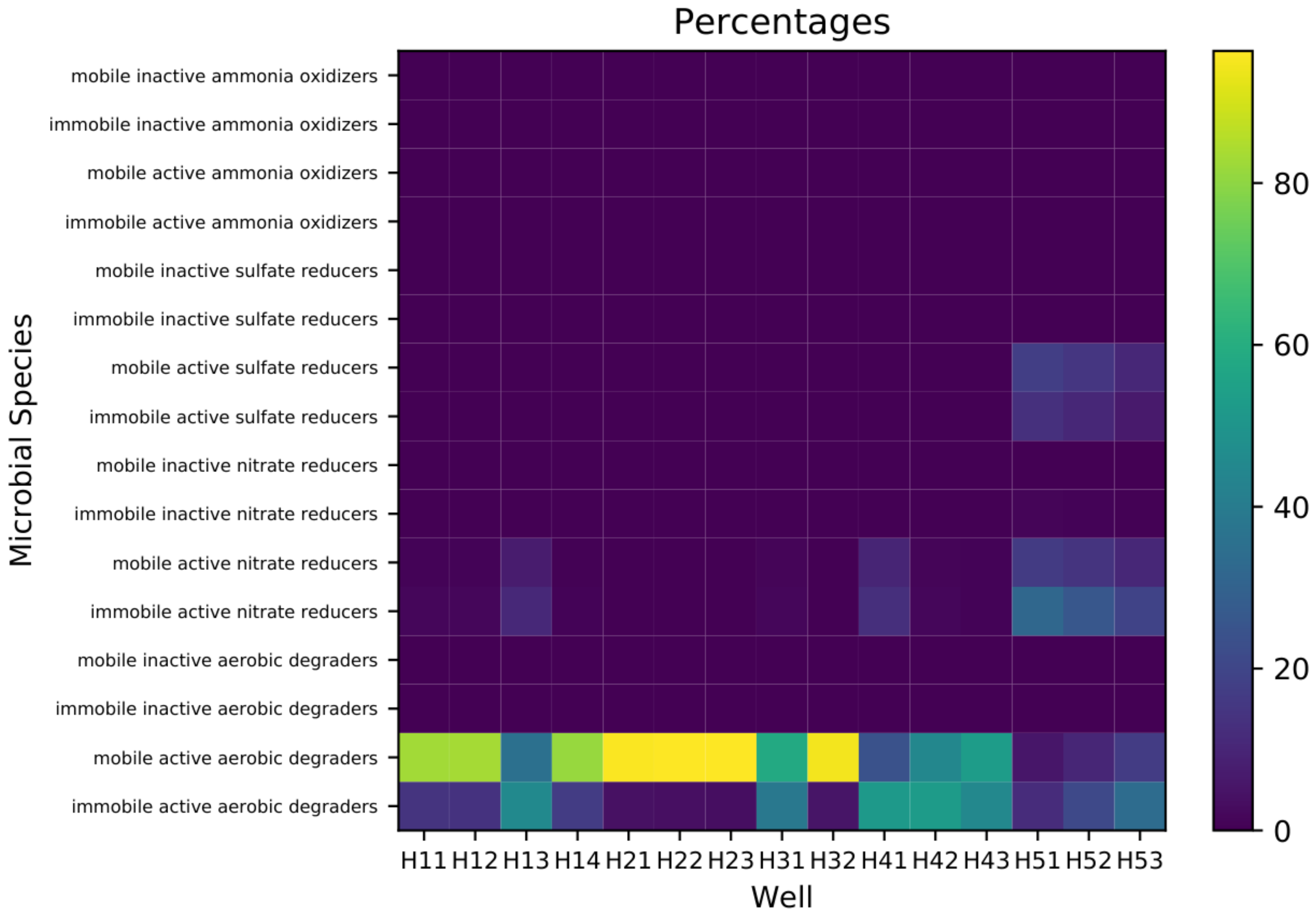




Simulated concentrations calibrated with nitrate concentrations are shown in two categories: non-mixing and mixing wells (red code).

SIMULATED CONCENTRATION OF REACTIVE SPECIES AT GROUNDWATER WELLS

MICROBIAL DISTRIBUTIONS AT GROUNDWATER WELLS

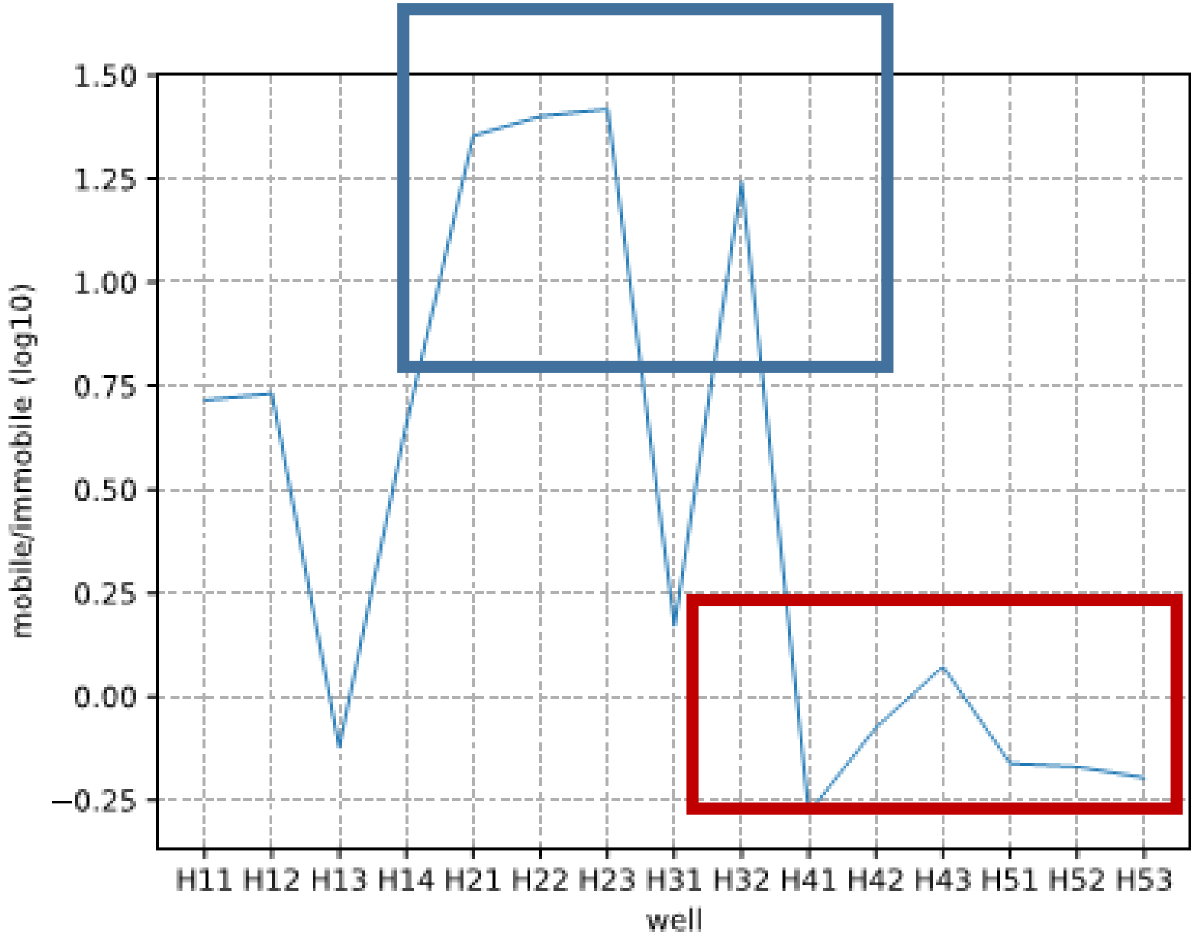


- **Aerobic degraders** dominate communities at most wells.
- **Mobile active aerobic** degraders contributed the most to microbial biomass at wells with short travel times (H21, H22, H23, H32)

RATIOS BETWEEN MOBILE/IMMOBILE AND ACTIVE /INACTIVE BACTERIA

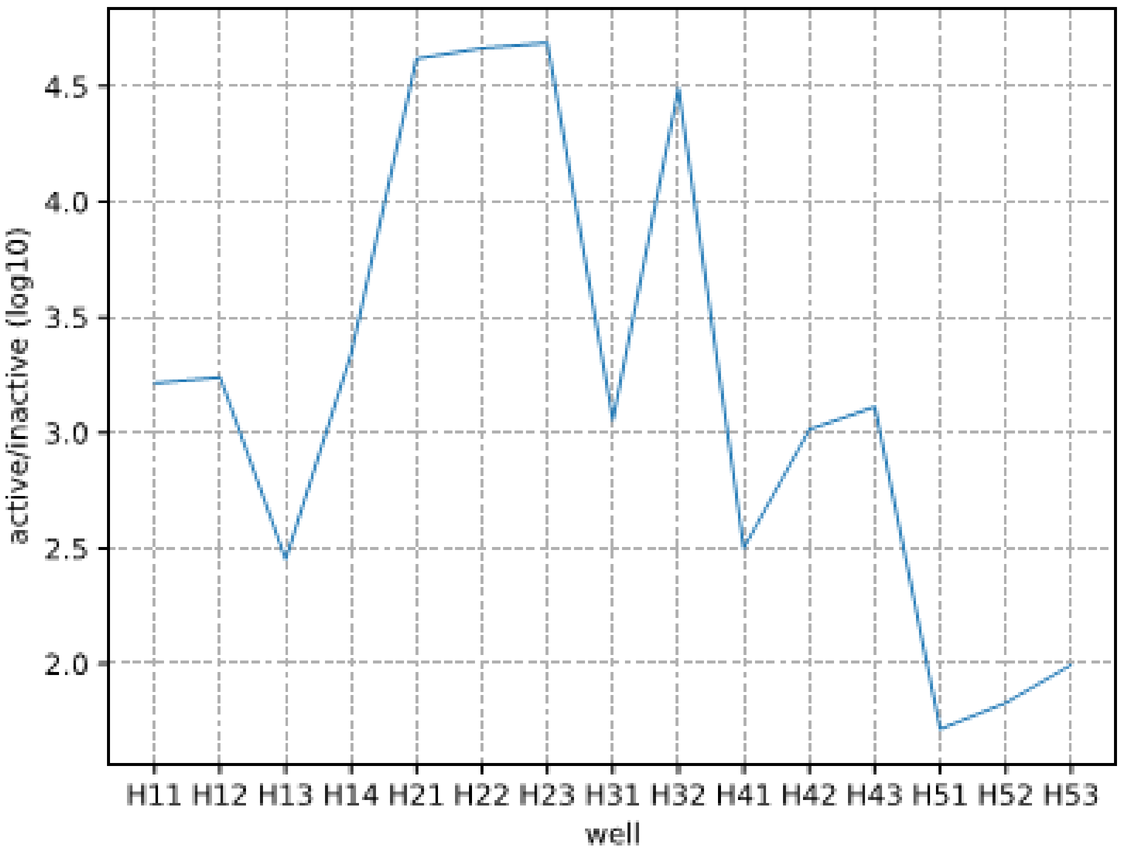
Mobile bacteria

Short travel time



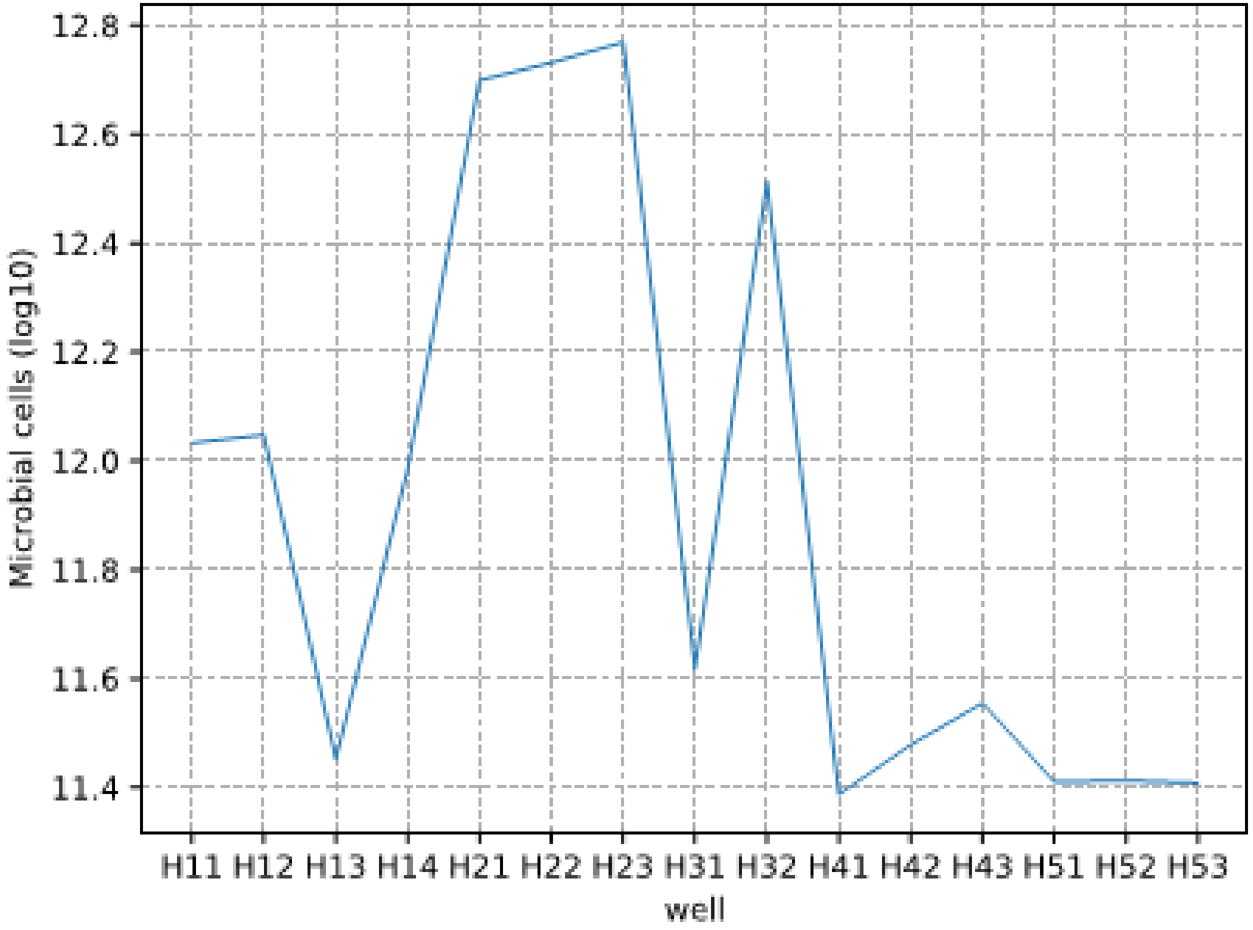
Immobile bacteria

Active



Travel time is XXX years

MICROBIAL ABUNDANCE: total biomass varies from 10^{11} to 10^{12} cells



- Highly abundant in groundwater wells strongly linked to surface inputs
- Relatively stable at deep wells with long travel times (H51, H52, H53)

TAKE-HOME MESSAGES

- **Travel time-based approach** untangles **field-scale reaction transport processes**.
- The results confirmed the **spatial variations of land use-dependent input.**
- **The majority of microbes are mobile**, which agrees with the observation at the Hainich site.
- Aeration zone is crucial for surface DOC degradation.
- Groundwater organic carbon mainly originates from subsurface release rather than surface sources.

OUTLOOK

- Analysis of main factors controlling concentrations at the Hainich CZE

  Relevance of surface signals for observations in the subsurface.

- Extrapolation to the catchment scale

  Assessment of the applicability of the used travel time-based approach

  Analysis of carbon and nitrogen turnover for different climatic projections

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Hall A | A.105

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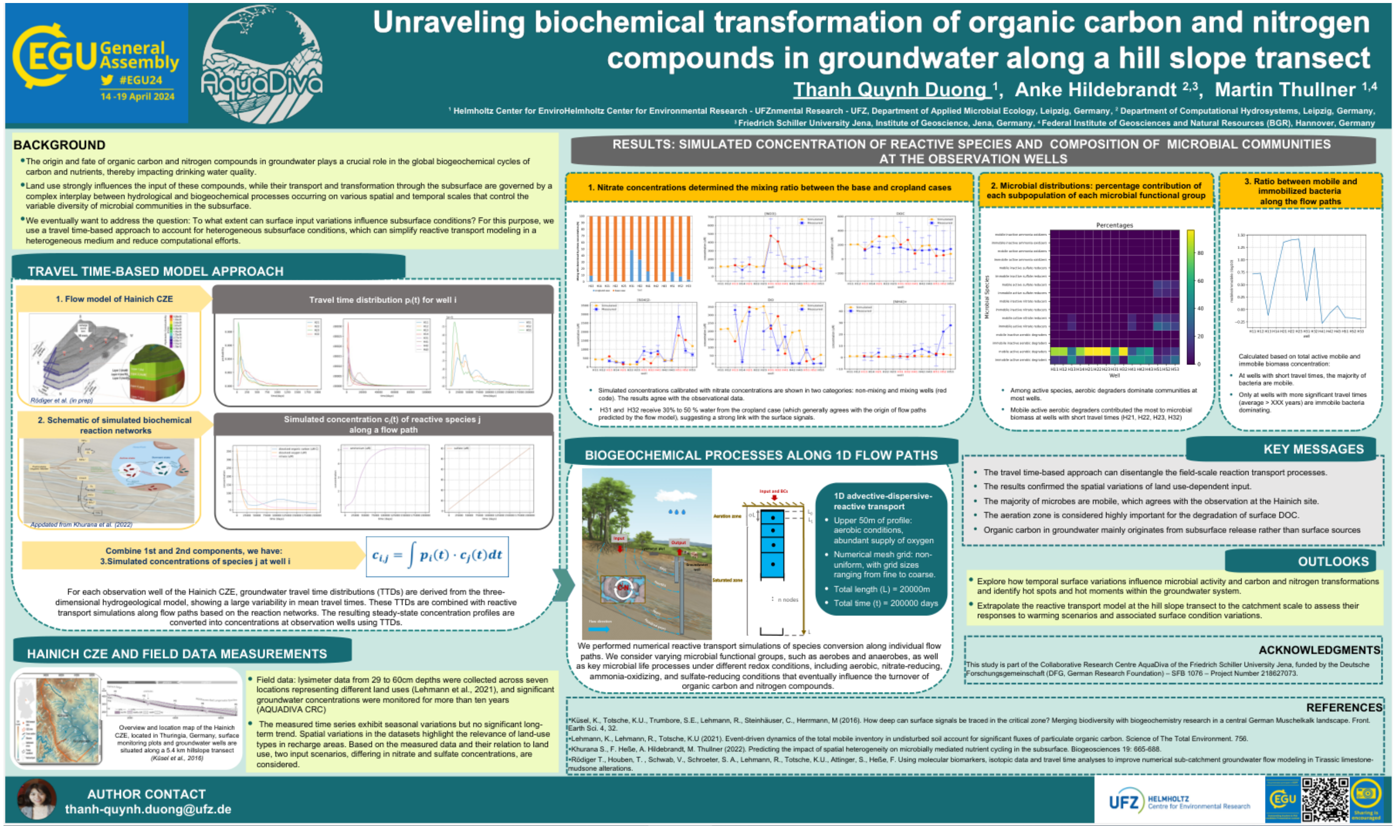

Interesting?

X **YES**

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA | Leibniz ipht | Max Planck Institute for Biogeochemistry | UFZ HELMHOLTZ Centre for Environmental Research | DFG Deutsche Forschungsgemeinschaft

Thank you!

UFZ HELMHOLTZ
Centre for Environmental Research

DFG Deutsche Forschungsgemeinschaft