HELMHOLTZ
Zentrum für Umweltforschung

The influence of clear-cut on nutrient dynamics in the Wüstebach catchment (Eifel, Germany)

Preliminary results from a modelling study

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17.10.2023

Relevance

Consequences of forest dieback and clear-cutting on hydrology and nutrient dynamics

Natural forest dieback and harvesting methods like clear-cutting can lead to an increased nutrient concentration in water bodies which may cause environmental deterioration and possibly even drinking water degradation

Relevant processes:

- No plant transpiration → Increased soil moisture and leakage
- Additional nutrient input from felling remains
- Increased soil moisture and soil temperature → enhancing degradation of organic matter, nitrification and denitrification
- Regeneration of vegetation → **?**

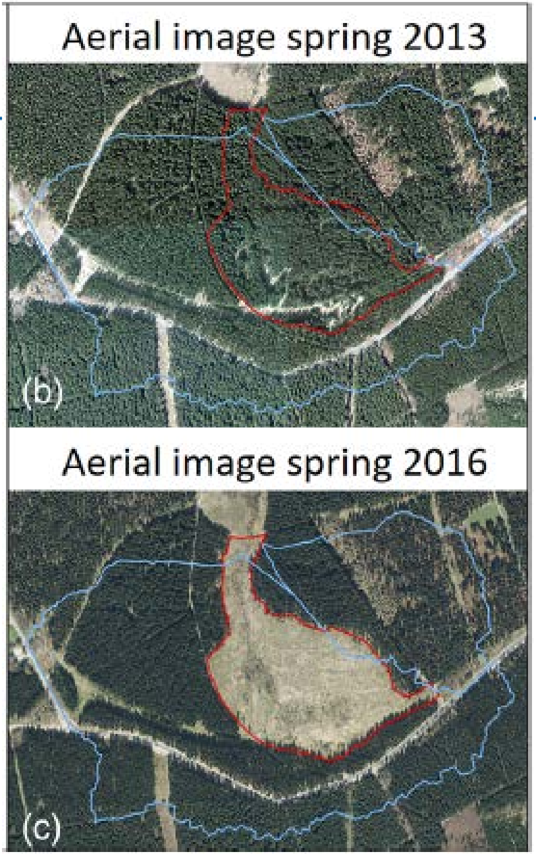


Fig. 1: Aerial image of the Wüstebach catchment before and after clear-cut. From Bogena et al. 2021.

Objectives

1. Successfully model the hydrology and dynamics of nitrogen and DOC in the Wüstebach catchment for the period 2010 to 2020, including the effect of the clear-cut in late summer 2013

2. Disentangle the influence of by clear-cut affected processes on nutrient dynamics: Hydrological fluxes, Turnover and Plant-Soil-Interaction

3. Investigate how vegetation regeneration is altering hydrology and dynamics of nitrogen and DOC after clear-cut

Fig. 2: Clear-cut area in Wüstebach catchment in 2023, Annemarie Bäthge.

Study Area and Data

The TERENO Wüstebach Catchment as study area

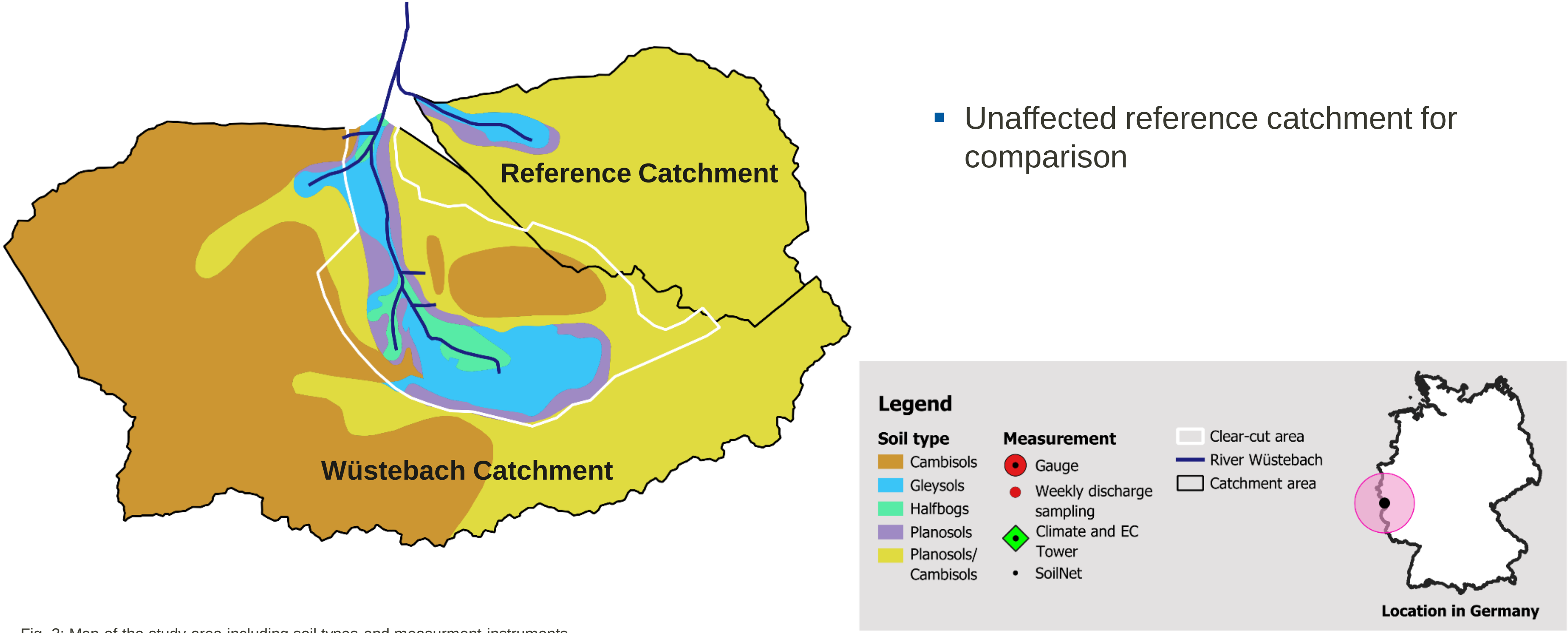


Fig. 3: Map of the study area including soil types and measurment instruments.

- Unaffected reference catchment for comparison

Study Area and Data

The TERENO Wüstebach Catchment as study area

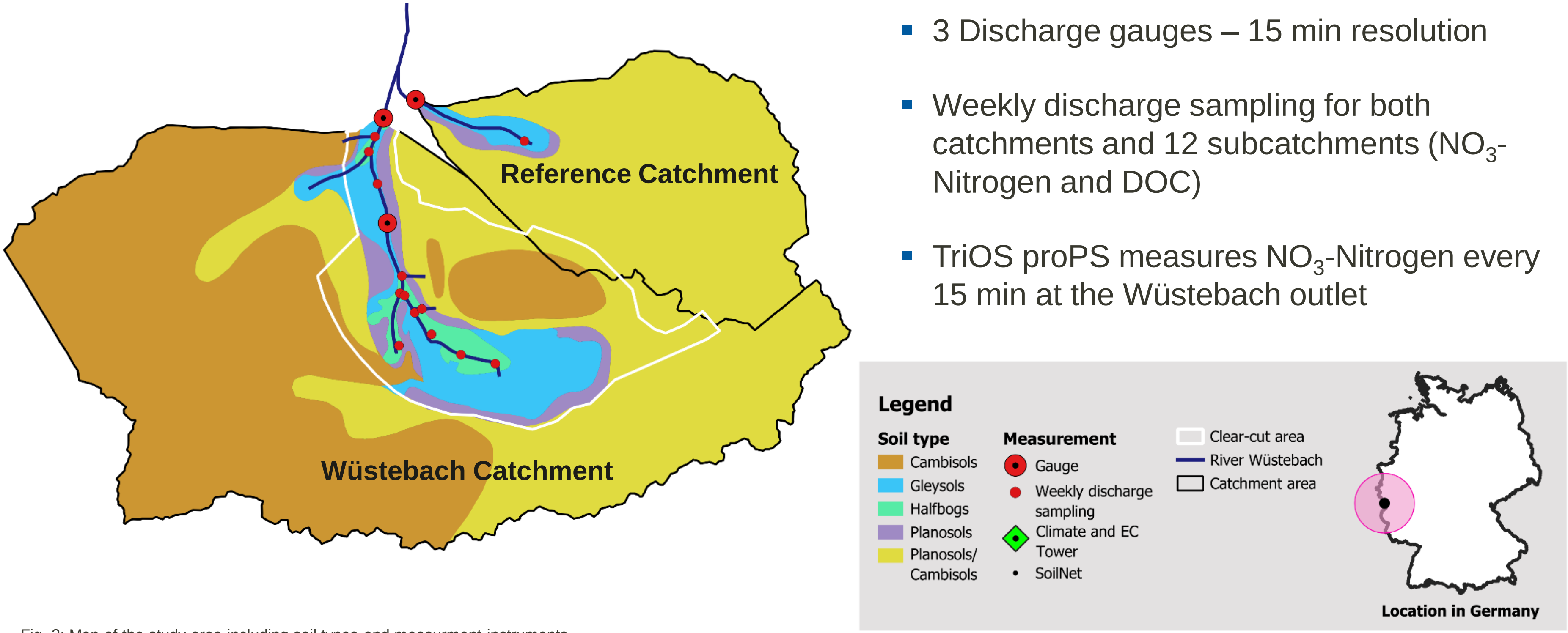


Fig. 3: Map of the study area including soil types and measurment instruments.

- 3 Discharge gauges – 15 min resolution
- Weekly discharge sampling for both catchments and 12 subcatchments (NO_3-Nitrogen and DOC)
- TriOS proPS measures NO_3-Nitrogen every 15 min at the Wüstebach outlet

Study Area and Data

The TERENO Wüstebach Catchment as study area

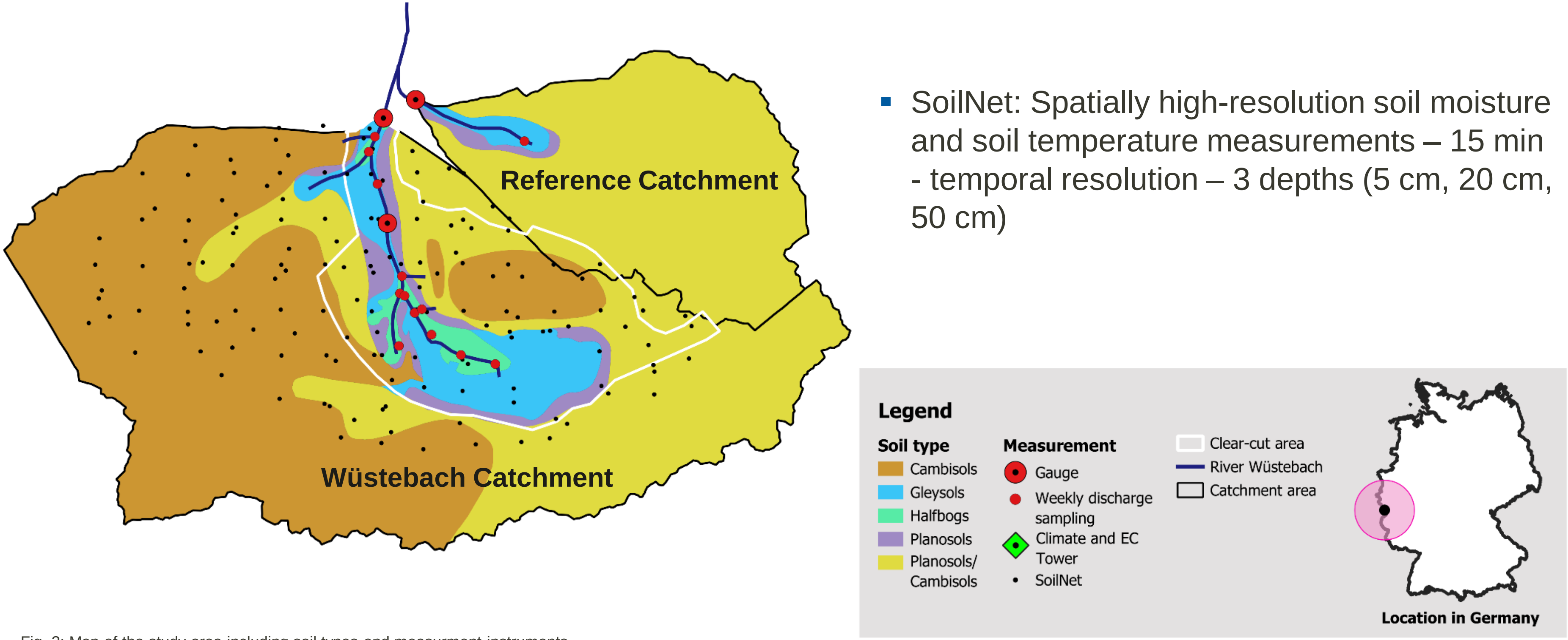


Fig. 3: Map of the study area including soil types and measurment instruments.

- SoilNet: Spatially high-resolution soil moisture and soil temperature measurements – 15 min - temporal resolution – 3 depths (5 cm, 20 cm, 50 cm)

Study Area and Data

The TERENO Wüstebach Catchment as study area

- Two climate towers with Eddy Covariance stations

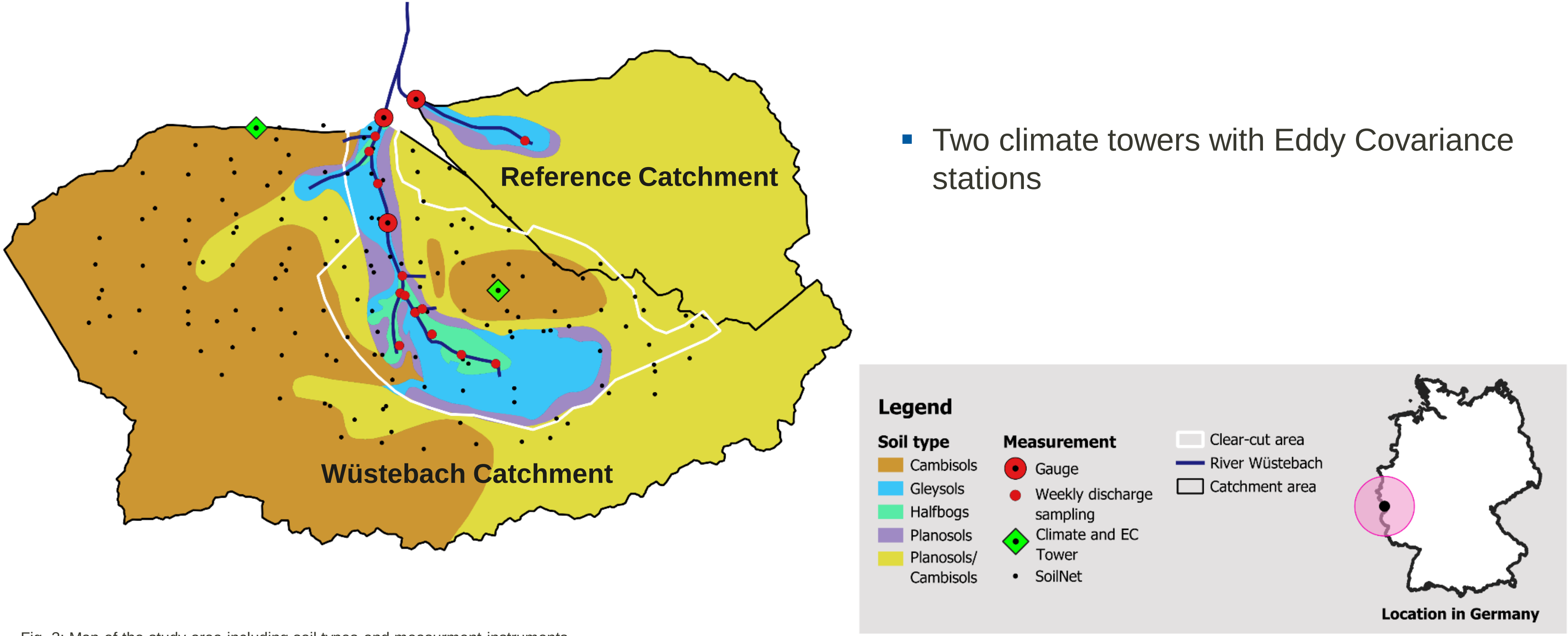


Fig. 3: Map of the study area including soil types and measurment instruments.

The Hydrological Predictions for the Environment (HYPE) Model

Process-based and semi-distributed model

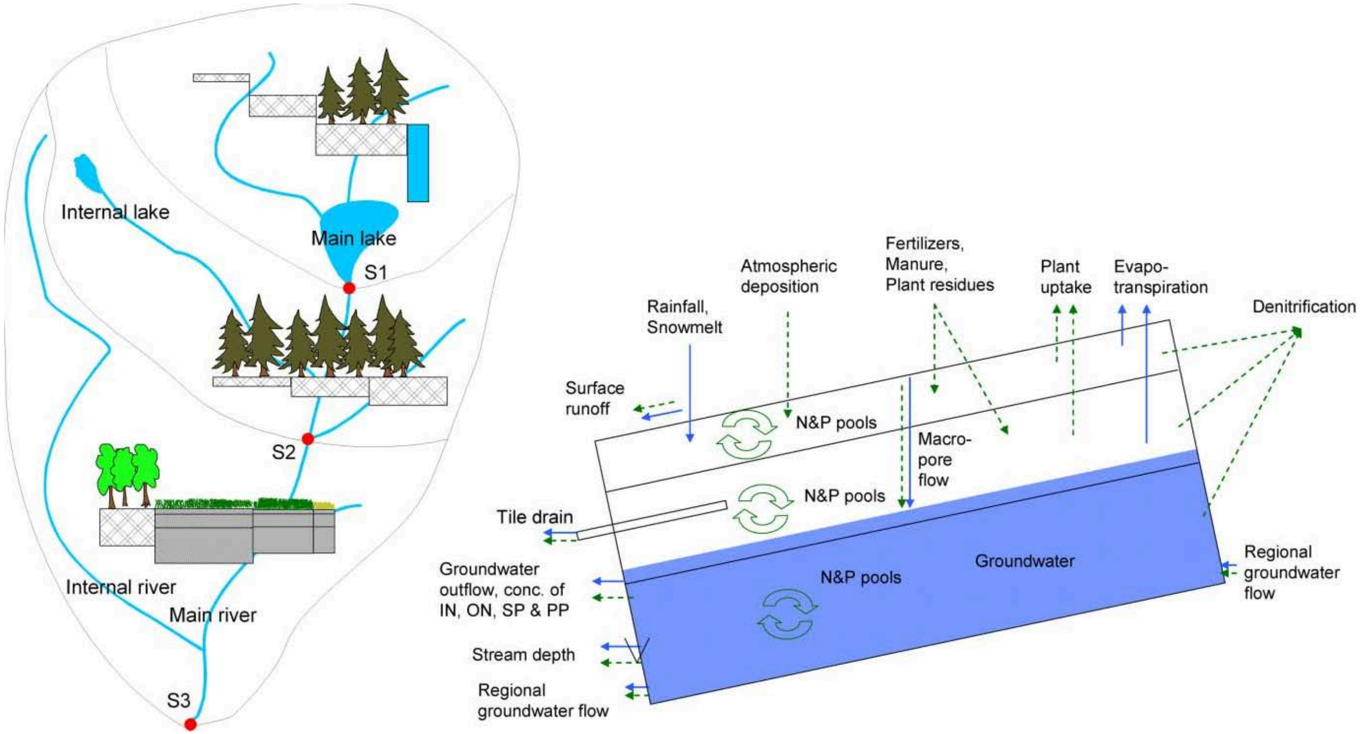


Fig. 4: Schematic model structure of subasins and hydrological response units (HRU) (left) as well as soil structure in a HRU (right). From Lindström et al. 2010.

Forcing data (daily resolution):

- Precipitation
- Air temperature
- Optional: Nitrate concentration in precipitation

Model Setup
Aggregate properties

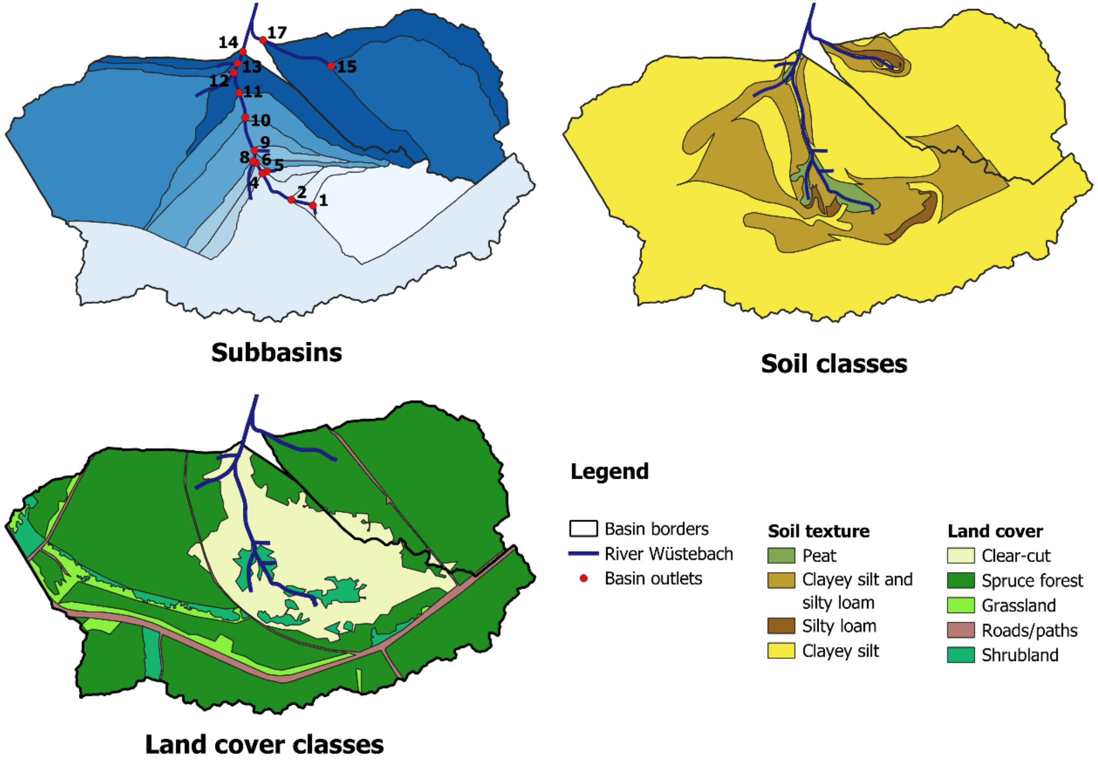


Fig. 5: Composition of subbasins and SLCs with soil and land cover classes.

Land cover change:

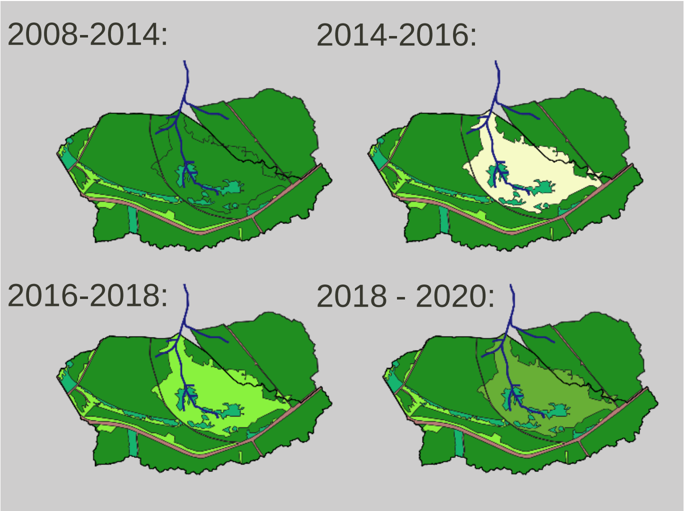


Fig. 6: Schematic illustration of land cover change in the simulation period

Model Calibration and Validation

Determine properties

Calibration period: 2010 – 2014

Validation Period: 2014 – 2020

Evaluated model results [Daily averages]:

- Discharge
- Soil moisture in root zone
- NO_3-Nitrogen concentration in discharge
- DOC concentration in discharge

Model performance criteria:

- Nash-Sutcliffe Efficiency (NSE)
- Kling-Gupta Efficiency (KGE)
- Normalized Root Mean Squared Error (NRMSE)

Results & Discussion: Hydrology
Average Daily Discharge

Wüstebach catchment

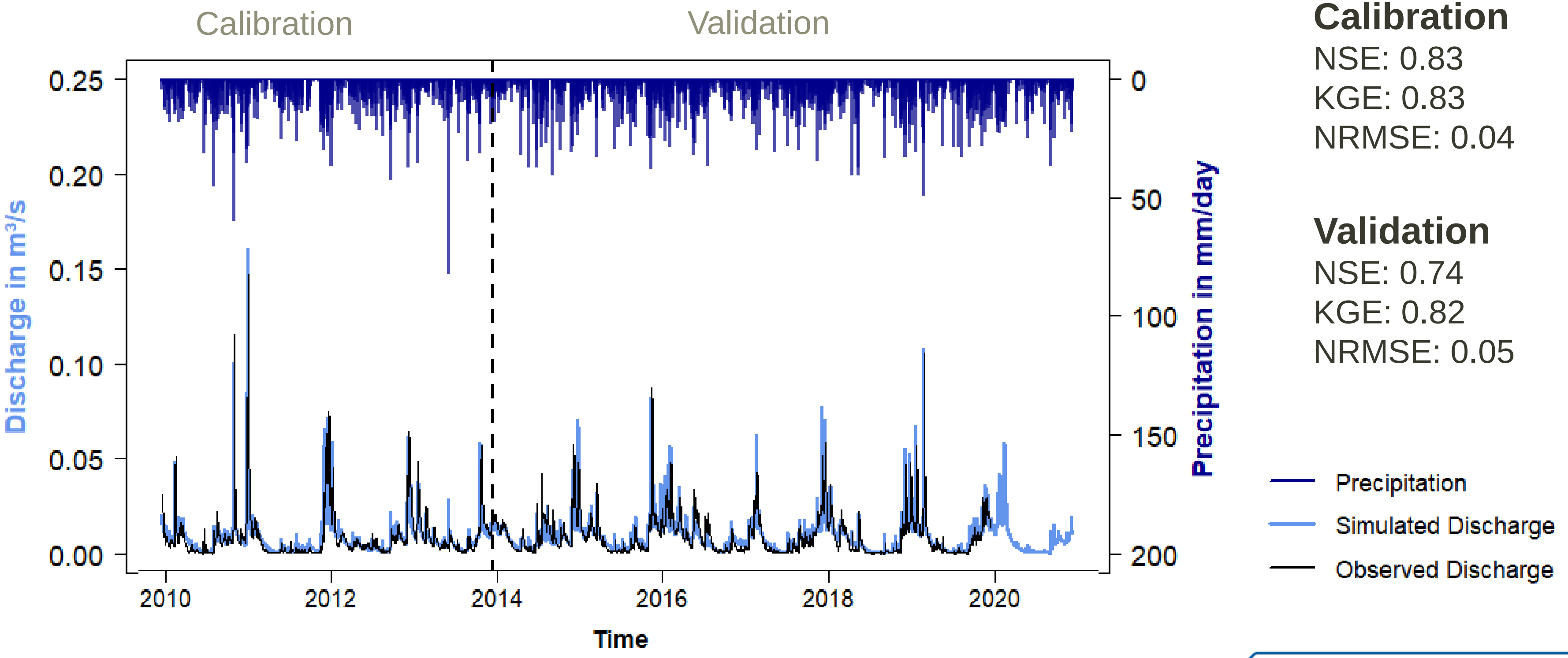


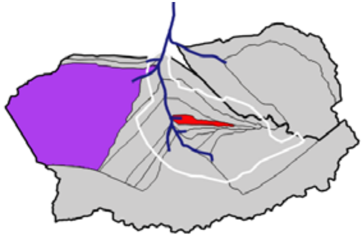
Fig. 7: Simulated and observed average daily discharge at the Wüstebach outlet and daily precipitation at DWD station Monschau-Kalterherberg.

Calibration
NSE: 0.83
KGE: 0.83
NRMSE: 0.04

Validation
NSE: 0.74
KGE: 0.82
NRMSE: 0.05

Results & Discussion: Nutrient dynamics

Share of different flows to total discharge



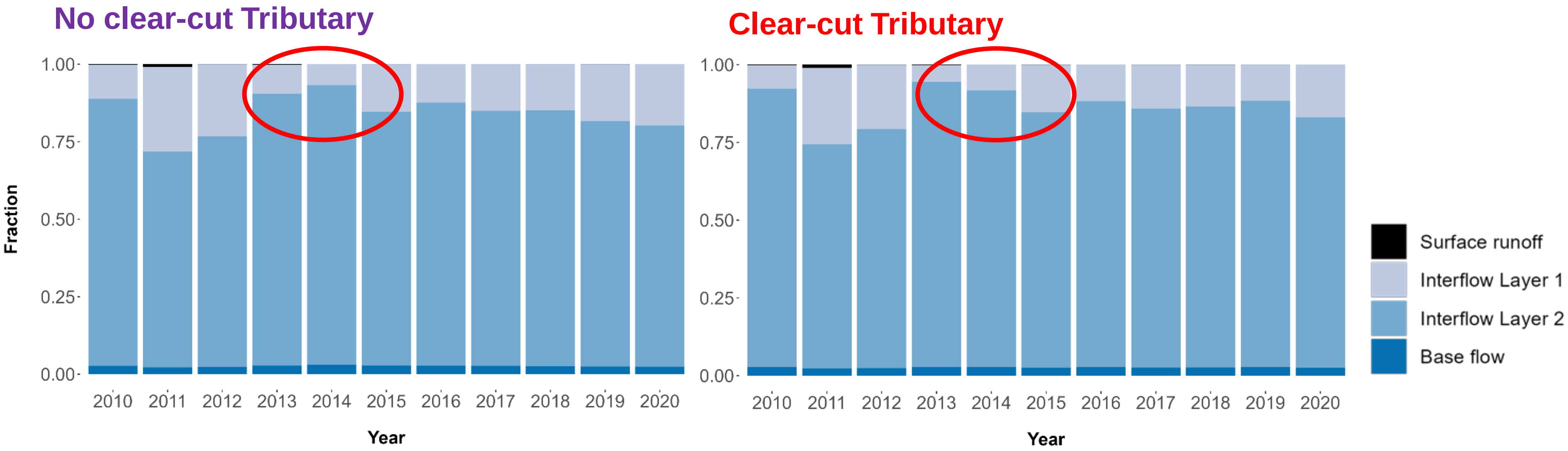


Fig. 21-22: Share of surface runoff, interflow from first and second soil layer and baseflow to total discharge in subasin 12 and 9.

→ The clear-cut causes a higher share of Interflow in the top soil in year 2014

Results & Discussion: Hydrology
Average Daily Soil Moisture in Root Zone

Wüstebach catchment

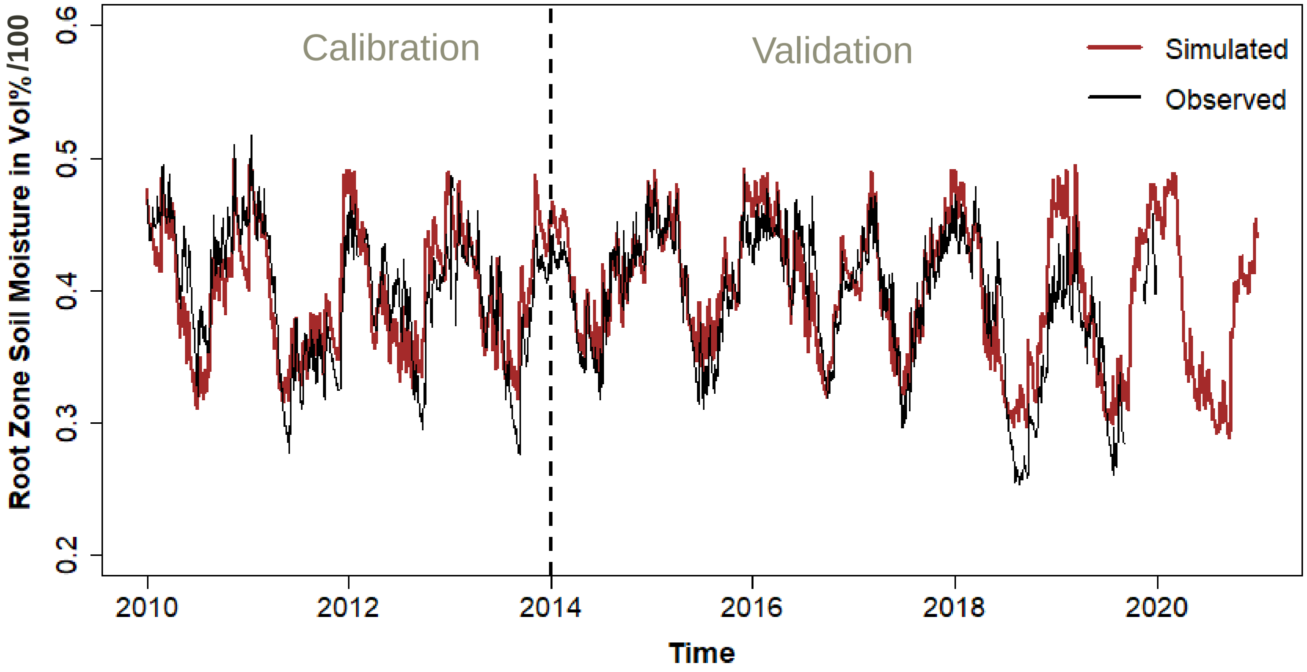


Fig. 8: Simulated and observed average daily soil moisture in root zone in the Wüstebach catchment.

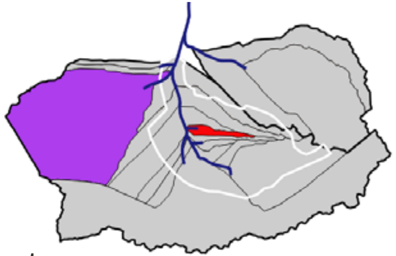
Calibration
NSE: 0.70
KGE: 0.75
NRMSE: 0.06

Validation
NSE: 0.73
KGE: 0.88
NRMSE: 0.054

→ The model could reproduce the soil moisture increase after clear-cut

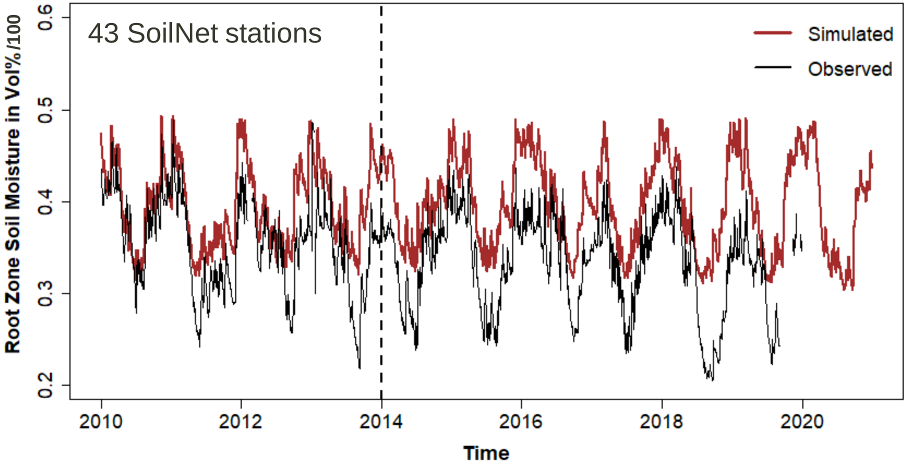
Results & Discussion: Hydrology

Average Daily Soil Moisture in Root Zone



- The model results differ more strongly from the observations in tributary subcatchments
- The general negative trend in soil moisture could not be reproduced

No clear-cut Tributary



Clear-cut Tributary

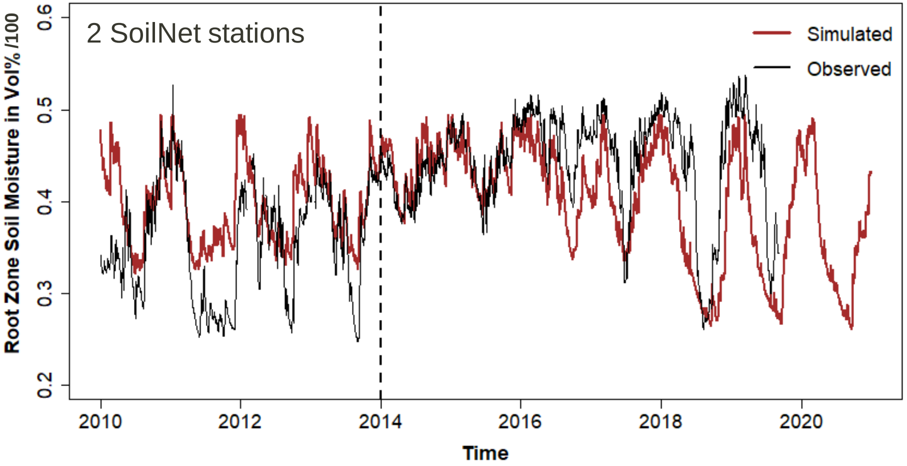
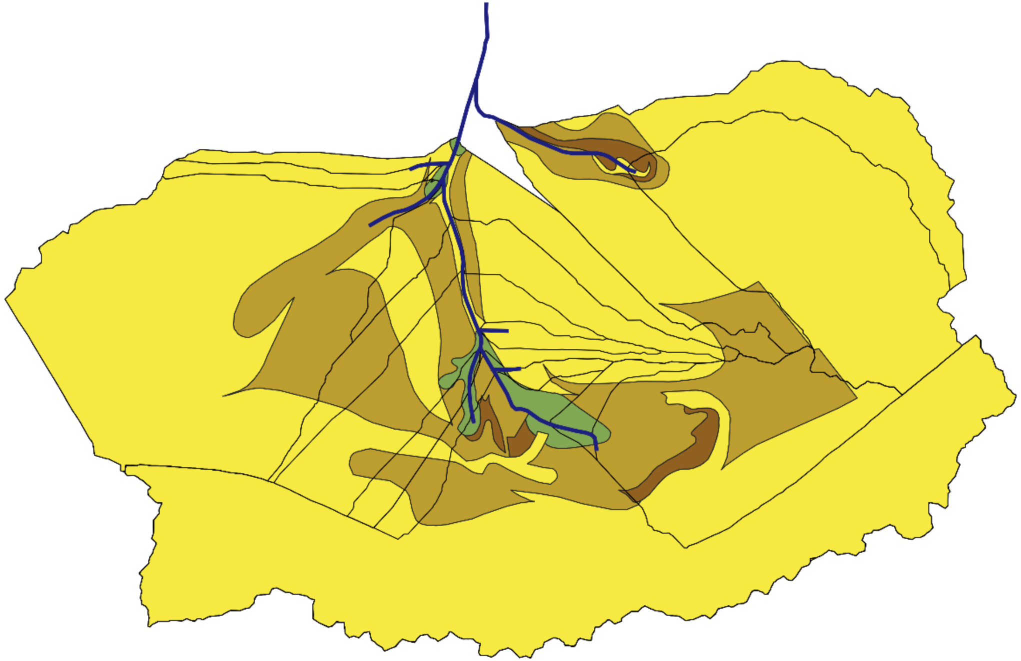


Fig. 9: Simulated and observed average daily soil moisture in root zone in subbasin 12 (left) and 9 (right).

Results & Discussion: Hydrology
Average Daily Soil Moisture in Root Zone



The soil classes in the model are not able to represent all subcatchments

→ A distinction between riparian and non-riparian zone would probably improve the model

→ More detailed measurements of soil characteristics – mainly field capacity - is necessary

Fig. 10: Map of Wüstebach catchment with subbasins and soil classes.

Results & Discussion: Nutrient dynamics
Average Daily Nitrate-N concentration in discharge

Wüstebach catchment

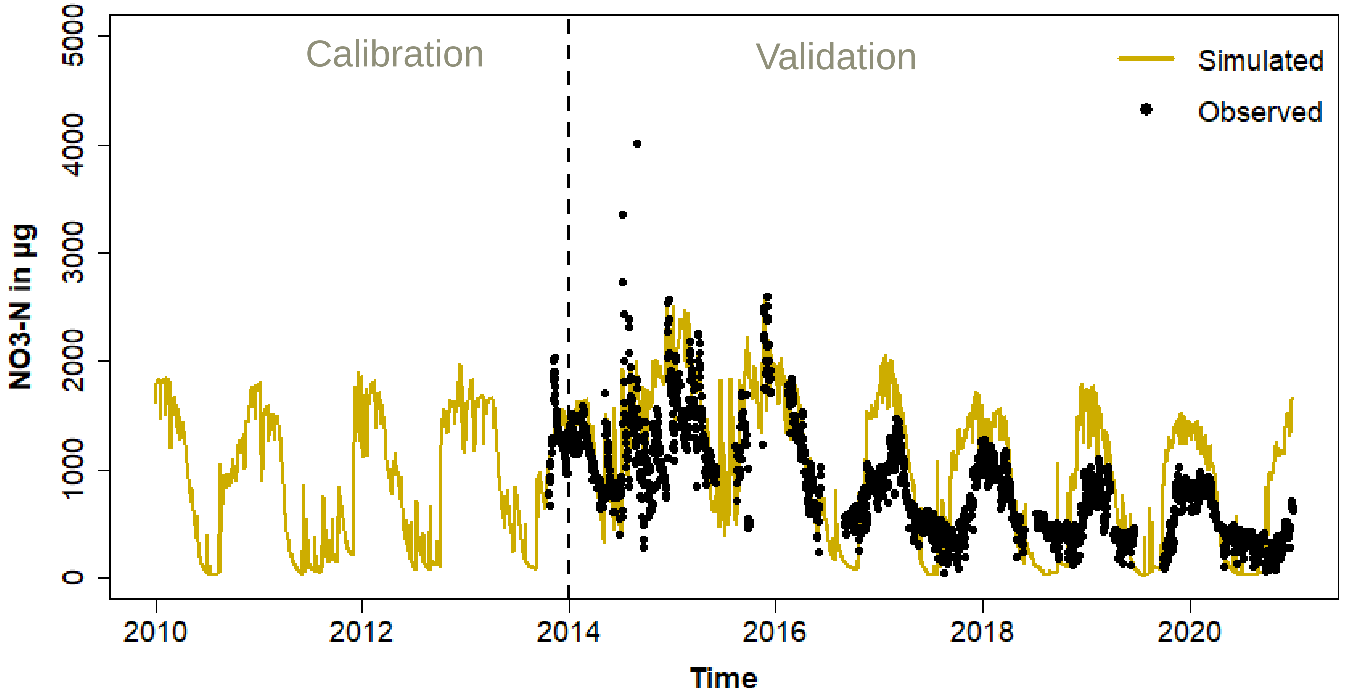


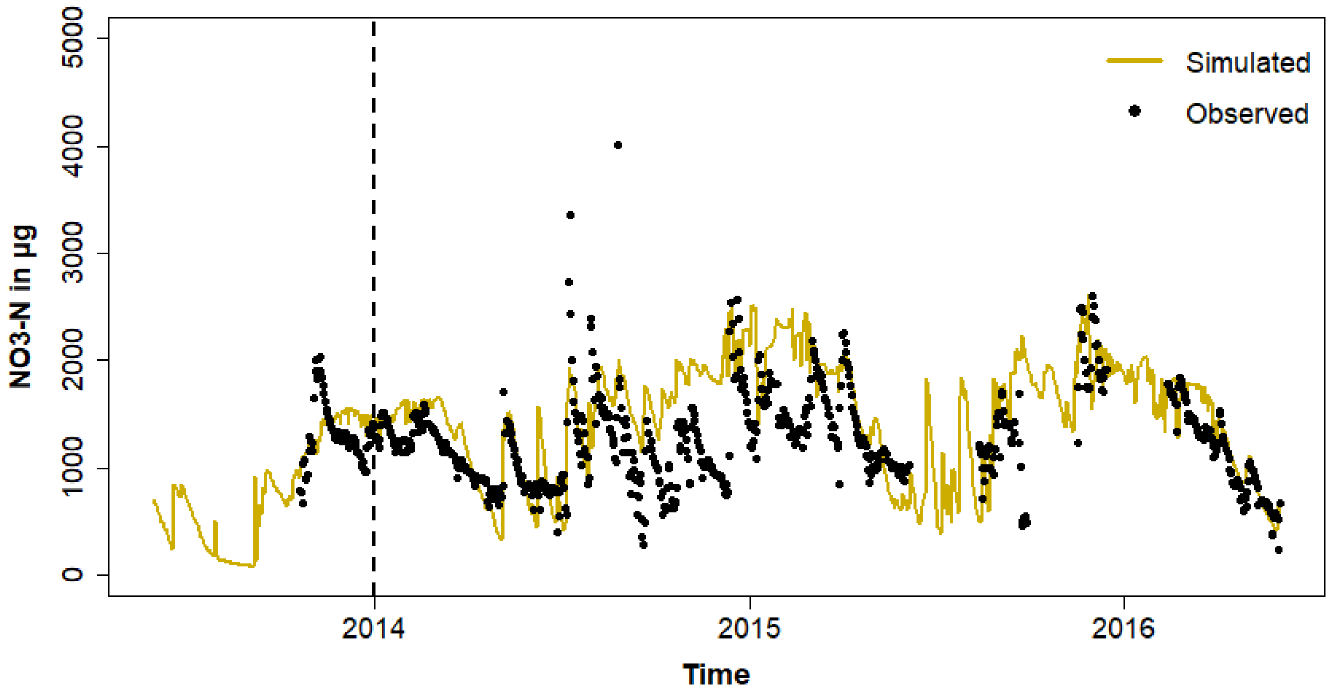
Fig. 16: Simulated average daily NO3-Nitrate concentration and daily means of observed NO3-Nitrate concentration with TriOS proPS in discharge at the Wüstebach outlet

Validation
NSE: -0.35
KGE: 0.39
NRMSE: 0.13

Results & Discussion: Nutrient dynamics

Average Daily Nitrate-N concentration in discharge

Wüstebach catchment

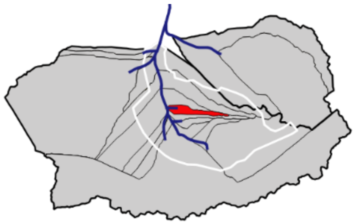


→ High outliers in summer 2014 could not be reproduced by the model

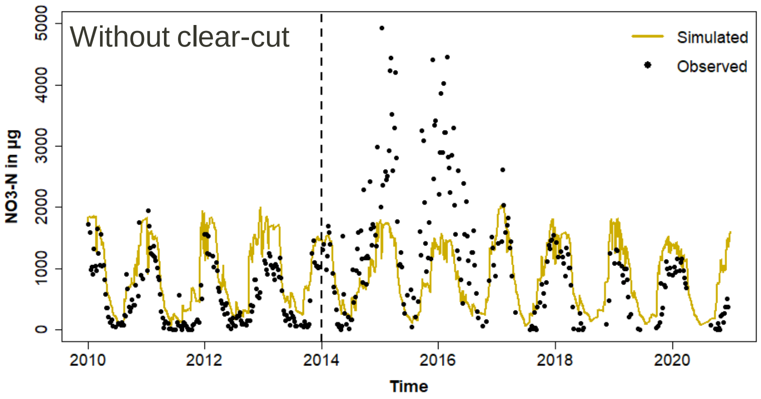
Fig. 17: Simulated average daily NO3-Nitrate concentration and daily means of observed NO3-Nitrate concentration with TriOS proPS in discharge at the Wüstebach outlet

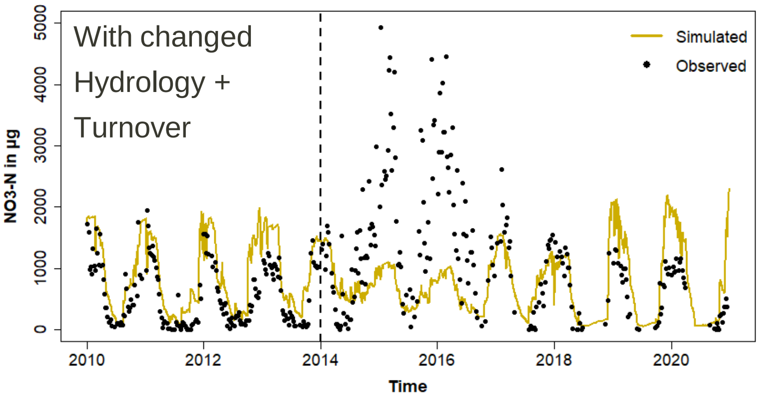
Results & Discussion: Nutrient dynamics

Average Daily Nitrate-N concentration in discharge



Clear-cut Tributary…





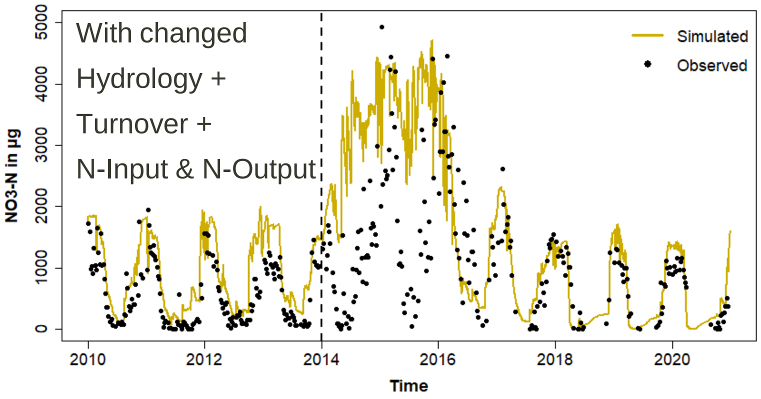


Fig. 18-20: Simulated average daily NO3-Nitrate concentration and weekly laboratory measurements of NO3-Nitrate concentration in discharge of subbasin 9 în different scenarios.

→ The increase of soil moisture and soil temperature after clear-cut even leads to a dilution of nitrogen and increased denitrification (+25 %) in HYPE

→ The increase of nitrogen can only be attributed to an increased nutrient input by the felling remains

→ An increased N-uptake by the regenerated vegetation is able to buffer N-leaching

Results & Discussion: Nutrient dynamics
Average Daily Dissolved Organic Carbon Concentration in Discharge

Wüstebach catchment

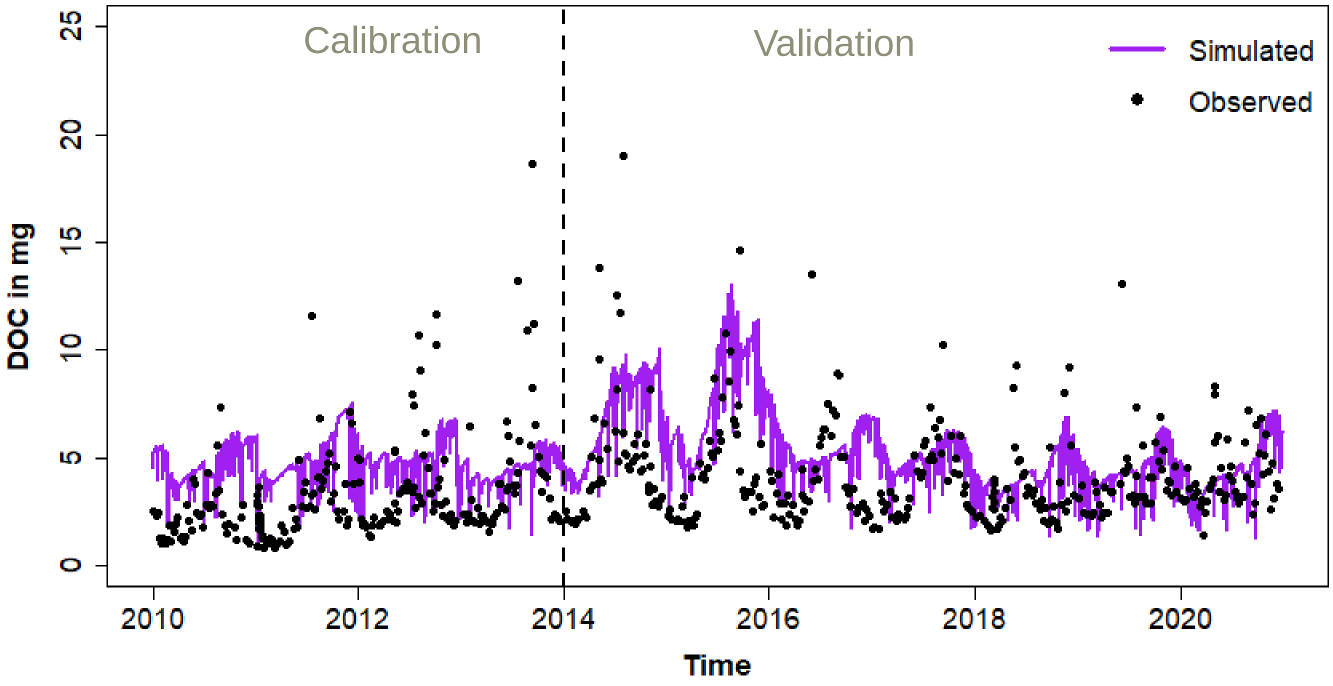


Fig. 13: Simulated average daily DOC concentration and weekly laboratory measurements of DOC concentration in discharge at the Wüstebach outlet.

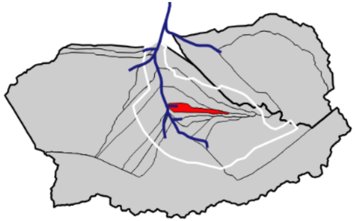
Calibration
NSE: -0.58
KGE: -0.33
NRMSE: 0.16

Validation
NSE: -0.70
KGE: -0.27
NRMSE: 0.16

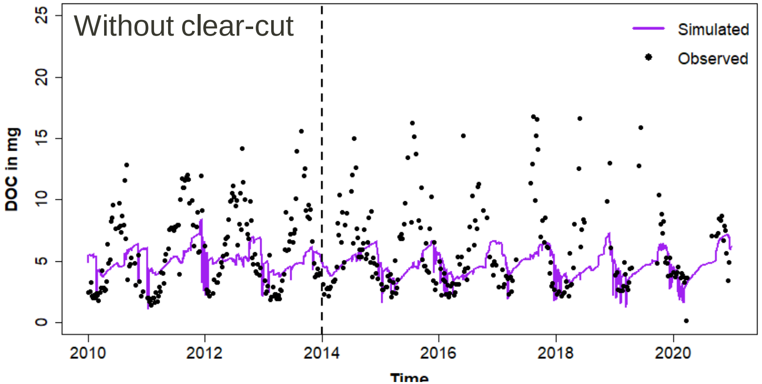
→ In HYPE: Delayed peaks can be attributed to turnover processes in soil

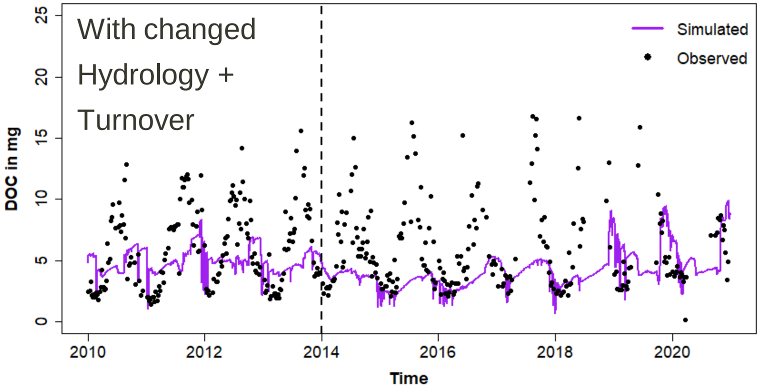
Results & Discussion: Nutrient dynamics

Average Daily Dissolved Organic Carbon Concentration in Discharge



Clear-cut Tributary…





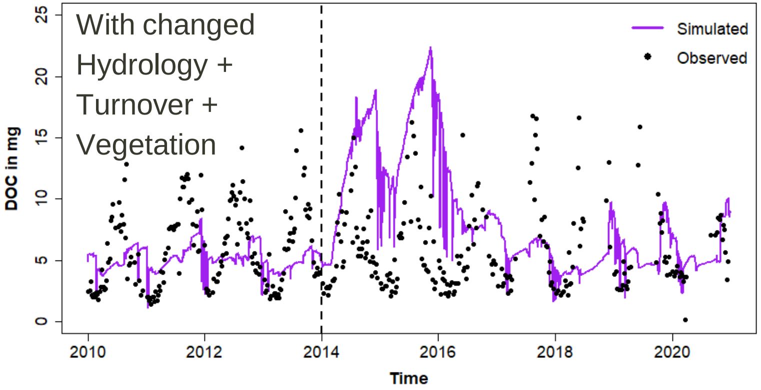


Fig. 24-26: Simulated average daily DOC concentration and weekly laboratory measurements of DOC concentration in discharge of subbasin 9 în different scenarios.

→ Analogous to Nitrogen, similar pattern can be observed for DOC

Conclusion

1. Except DOC simulation, the HYPE model was able to reproduce average catchment characteristics. But detailed processes in subcatchments were not well represented.

In the model:

2. The increased nutrient input from felling remains was mostly responsible for the catchment‘s response to clear-cut regarding nutrient dynamics.

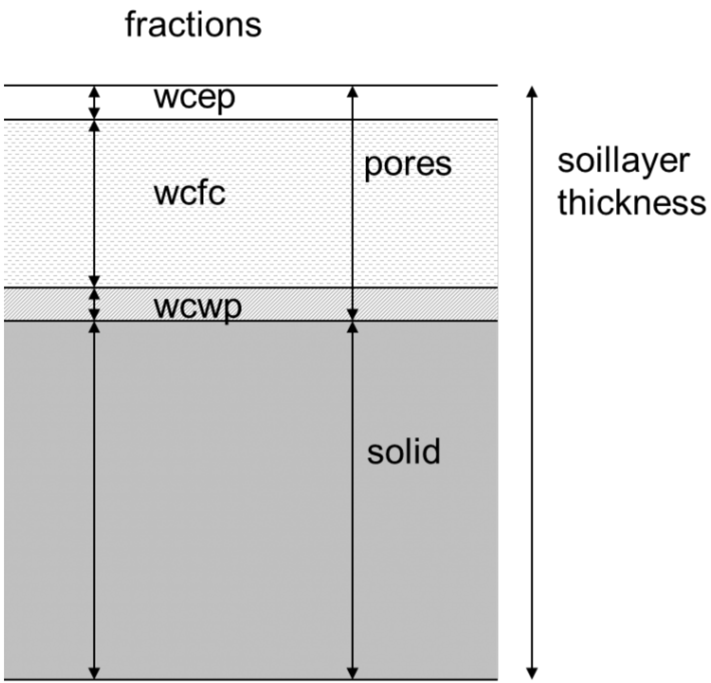
3. The regenerated vegetation is buffering the nutrient leakage very quickly by a high nitrogen uptake.

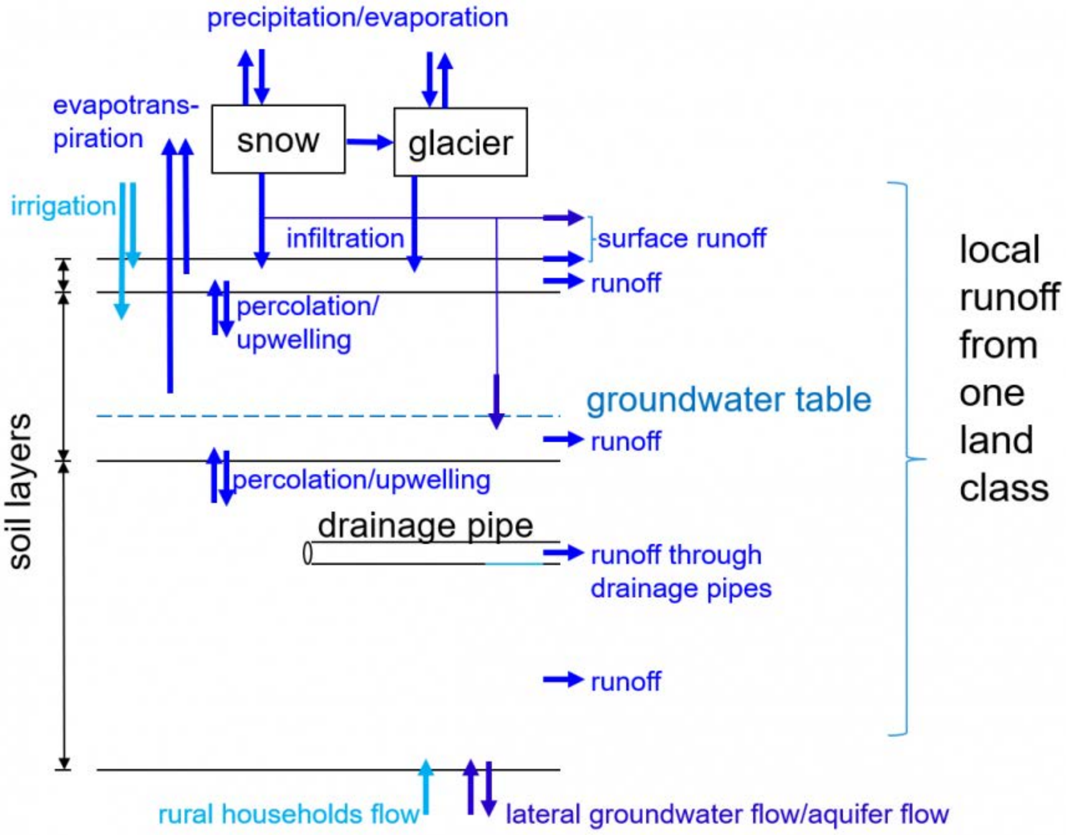
References

Bogena, Heye R.; Stockinger, Michael P.; Lücke, Andreas (2021): Long-term stable water isotope and runoff data for the investigation of deforestation effects on the hydrological system of the Wüstebach catchment, Germany. In: *Hydrol. Process.* 35 (1), Artikel e14006. DOI: 10.1002/hyp.14006.

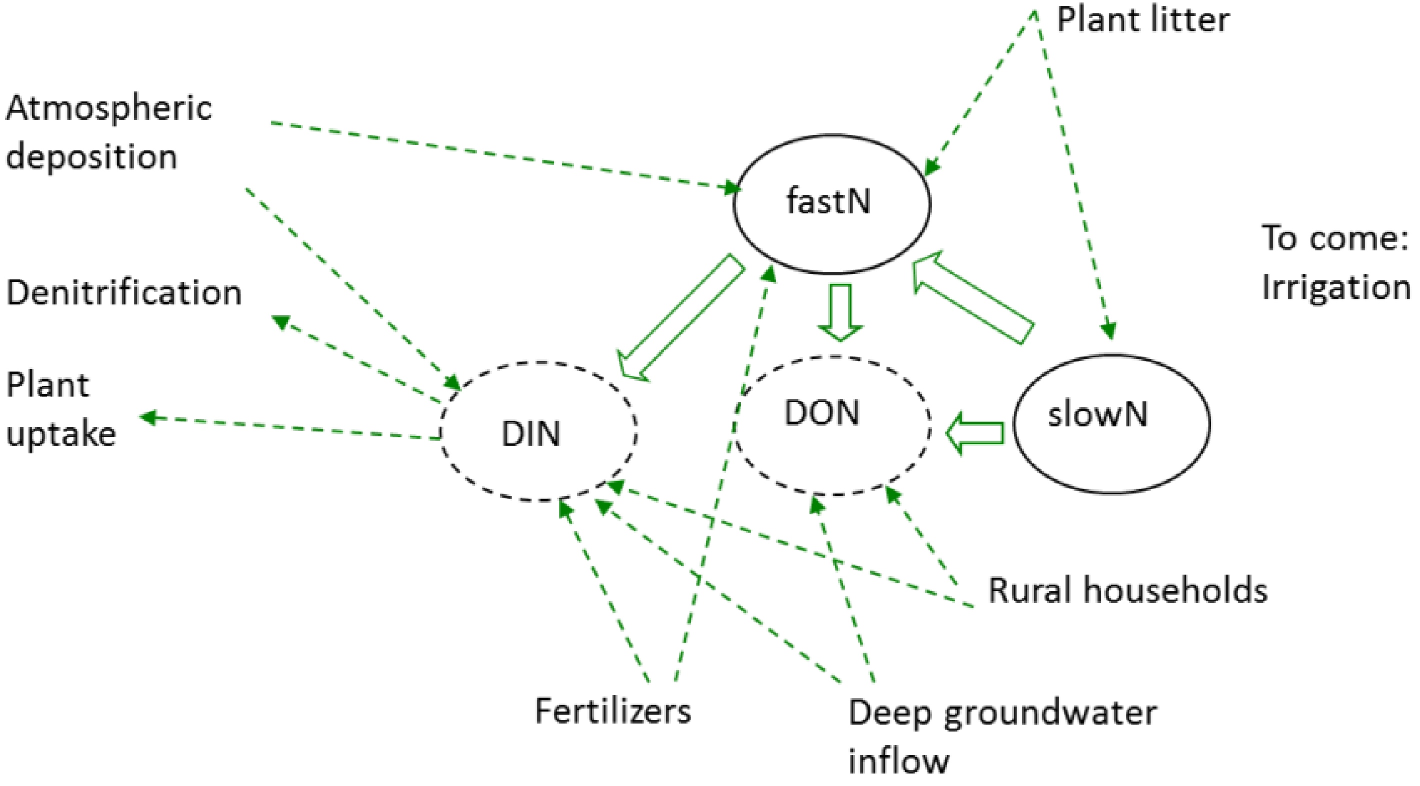
Lindström, Göran; Pers, Charlotta; Rosberg, Jörgen; Strömqvist, Johan; Arheimer, Berit (2010): Development and testing of the HYPE (Hydrological Predictions for the Environment) water quality model for different spatial scales. In: *Hydrology Research* 41 (3-4), S. 295–319. DOI: 10.2166/nh.2010.007.

Soil model and flows in HYPE

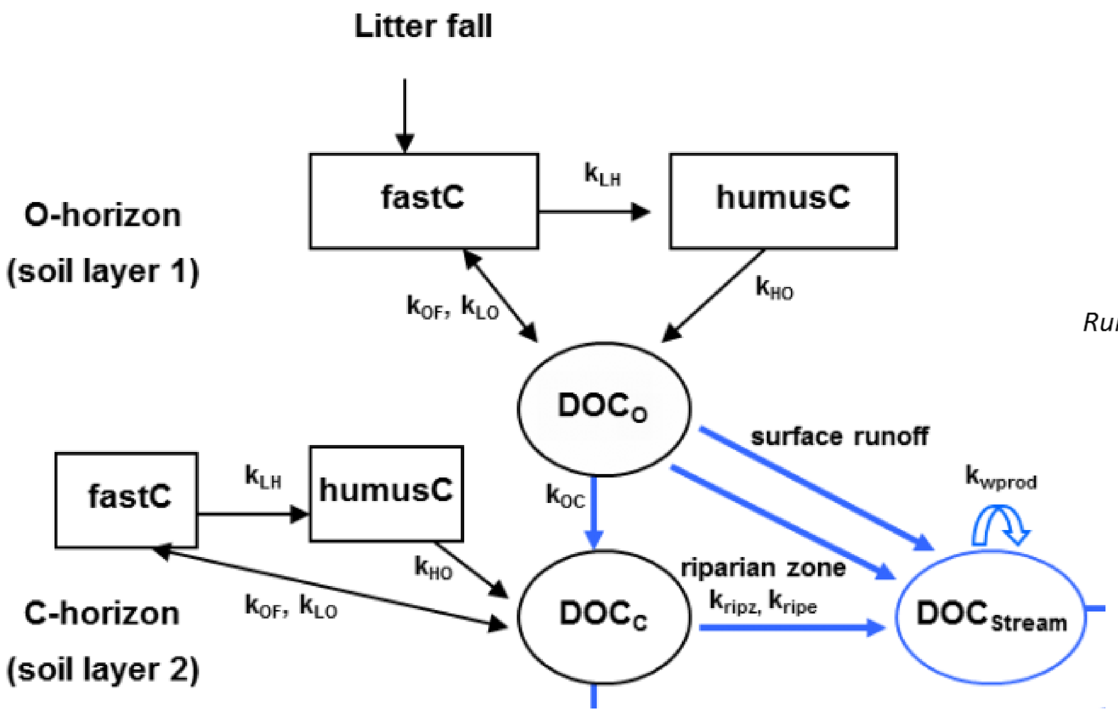


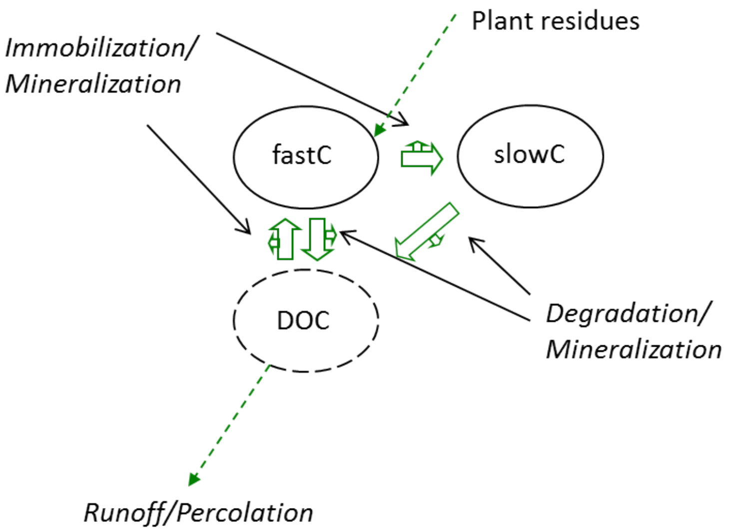


Nitrogen Pools and Turnover in HYPE

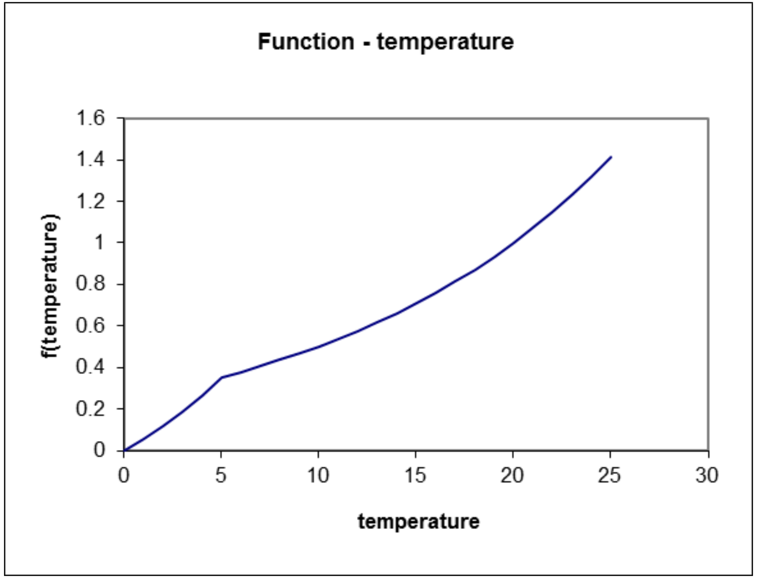


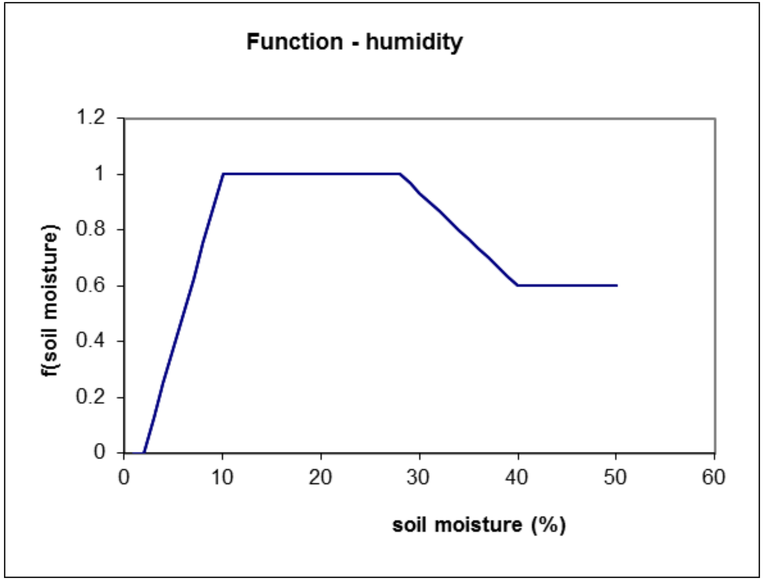
DOC Pools and Turnover in HYPE





Soil Moisture and Temperature Function Turnover in HYPE





Humidity Function Denitrification in HYPE