Project: 1534

Project title: Tracer-Aided Water Quality Modelling across Spatial Scales in Europe

Principal investigator: Songjun Wu

Allocation period: 2027-01-01 to 2027-12-31

1. Development of EcoTWIN v2.0

During the 2026 allocation period, our research primarily focused on the development of EcoTWIN v2.0, a fully distributed, process-based ecohydrological model integrating water, stable isotopes, carbon, and nitrogen cycling.

The development builds upon EcoTWIN v1.0, which tracks the coupled water-nitrogen cycling using stable water isotopes. The model supported our recent publication in Science (Wu et al., 2026) based on EcoTWIN v1.0 simulations across 3,832 European catchments, and demonstrated the importance of landscape water velocities in regulating nitrogen cycling. This provides an important scientific foundation for extending the model to coupled water–carbon–nitrogen processes.

Compared with v1.0, EcoTWIN v2.0 further incorporates carbon cycling, including vegetation carbon uptake, litter decomposition, soil organic carbon dynamics, dissolved organic carbon (DOC) production and transport, and coupled carbon–nitrogen transformations. These developments enable a more comprehensive representation of the interactions between hydrological transport, ecosystem carbon cycling, and nutrient dynamics.

Considerable effort has been devoted to integrating the new modules, improving numerical stability, ensuring mass conservation, and developing long-term spin-up procedures for carbon and nitrogen pools. In particular, the slow turnover of soil organic carbon requires long spin-up periods to establish reasonable initial conditions. These development and testing activities occupied a substantial proportion of the project period, resulting in fewer production-scale simulations and lower computing resource utilization than initially anticipated.

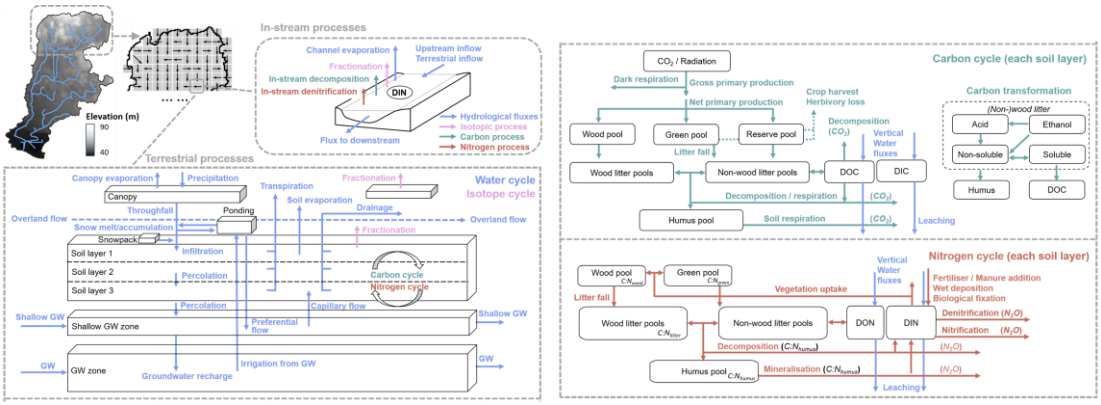


Figure 1. Model structure of EcoTWIN v2.0.

2. Preliminary simulations and model evaluation

Following the development of EcoTWIN v2.0, preliminary historical simulations have been conducted across European catchments at 5 km spatial resolution covering the period 1980–2024. The model has been evaluated against extensive observations of discharge, stable water isotopes, dissolved organic

carbon (DOC), and nitrate concentrations, providing an initial assessment of its capability to reproduce coupled hydrological and biogeochemical processes.

The preliminary results show encouraging performance in simulating discharge and stable water isotopes across European catchments, indicating that the model can reasonably capture major hydrological dynamics and water transport processes. Nitrate simulations also show promising results, suggesting that the model can represent important aspects of nitrogen transport and transformations. In contrast, DOC simulations remain more challenging, primarily due to the strong spatial heterogeneity of carbon sources, soil properties, vegetation, and biogeochemical processes across Europe. These results highlight the difficulty of simultaneously reproducing hydrological dynamics, isotope signatures, and carbon and nitrogen transport within a unified modelling framework.

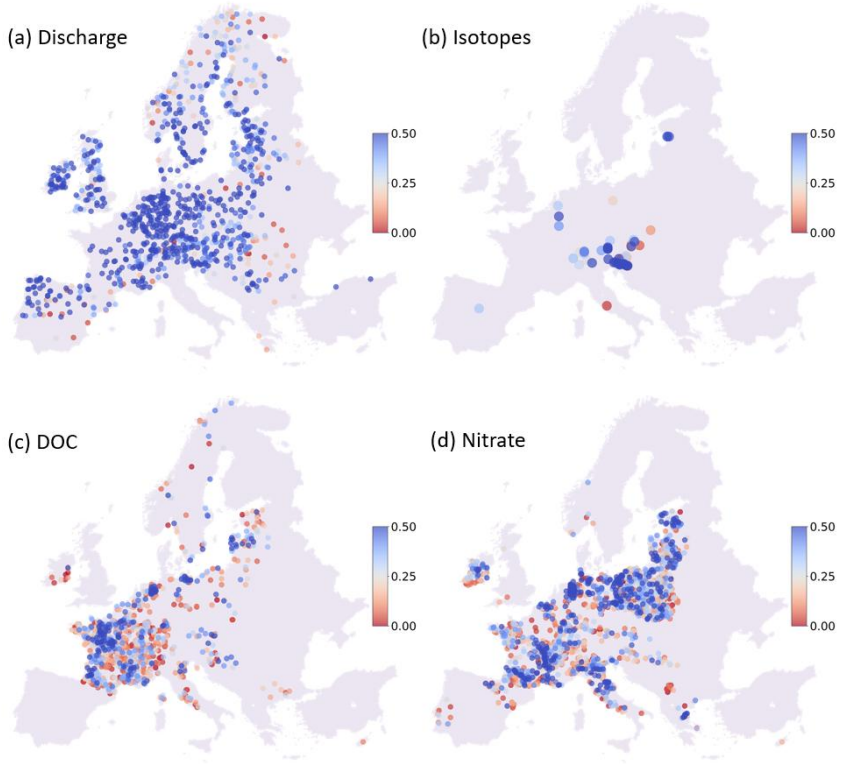


Figure 2. Spatial distribution of EcoTWIN v2.0 model performance across European monitoring stations for (a) discharge, (b) stable water isotopes, (c) DOC, and (d) nitrate, evaluated using Kling–Gupta Efficiency (KGE).

Overall, the preliminary simulations demonstrate the potential of EcoTWIN v2.0 for integrated water–carbon–nitrogen modelling across Europe, while highlighting the need for further improvements in spatial parameterization, particularly for DOC dynamics. The next phase will focus on systematic multi-scale calibration and validation, using detailed catchment-scale observations to improve process representation and parameter transferability at continental scales. This will provide the foundation for subsequent land-use scenario experiments and climate change projections to 2100.

Reference

Wu, S., Soulsby, C., Zheng, Y., Musolff, A., & Tetzlaff, D. (2026). Divergent evolution of nitrogen cycling along gradients of landscape water velocities. Science, 392, 1188–1193. https://doi.org/10.1126/science.aed0399