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Global spatially explicit legacy of nitrogen in groundwater

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Background

Part of the nitrogen (N) surpluses in agricultural and natural ecosystems are lost by leaching from the root zone to subsoil and groundwater. N is stored temporarily in groundwater, a legacy store which can release N to surface water in the future. However, the magnitude of stored N in groundwater and the residence time of N at the global scale is not clear.

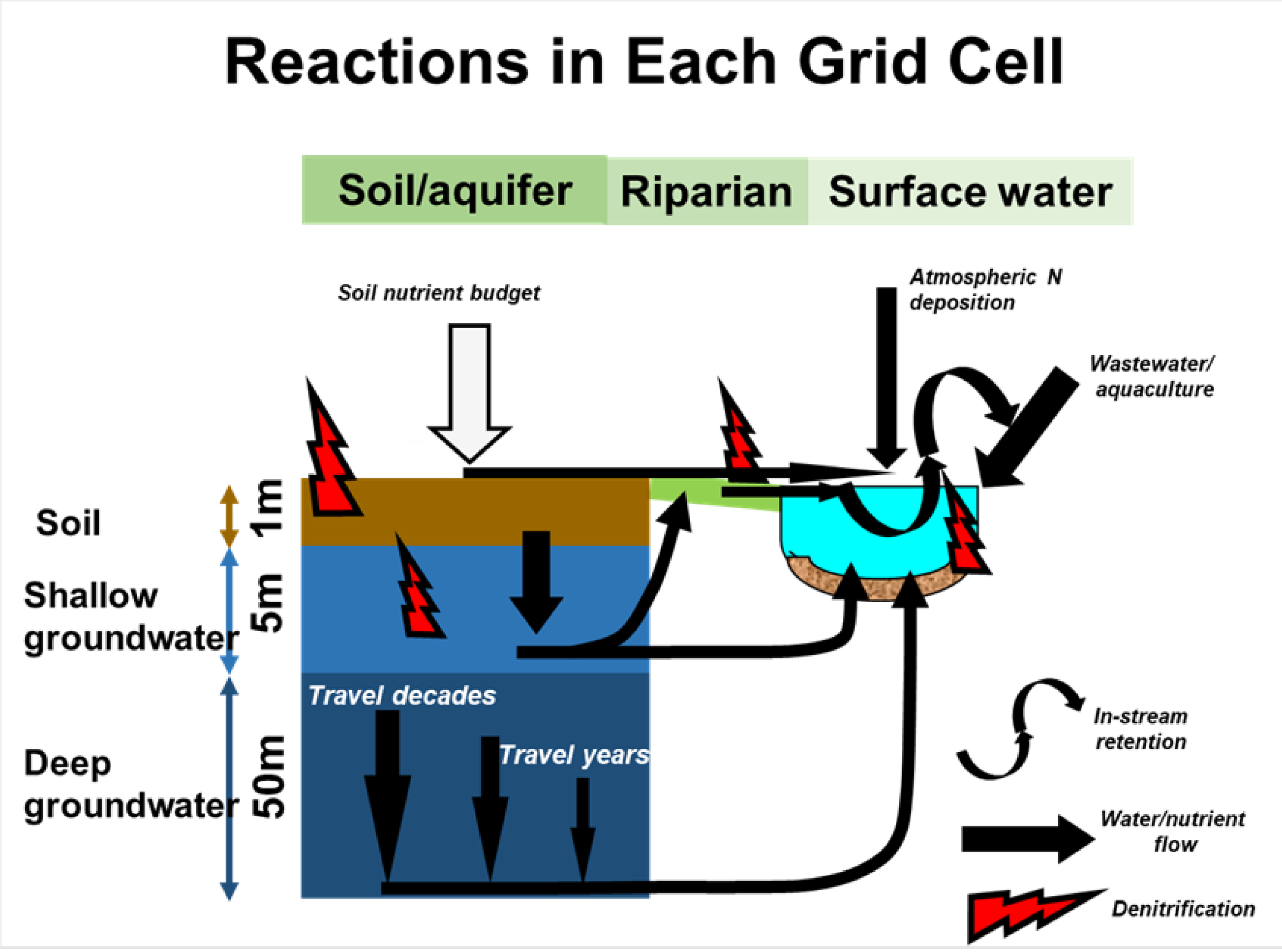

Figure 1. Scheme of the IMAGE-GNM model with all landscape components occurring in a grid cell, including soil, two groundwater layers, riparian area and surface water, and the water/nutrient flows between the compartments.

Modelling approach

We use a modelling approach to estimate the storage of N in groundwater over the past century and assess possible future changes on the basis of scenarios. We use the spatially explicit model IMAGE-GNM (the Integrated Model to Assess the Global Environment – Global Nutrient Model) with 0.5 by 0.5 degree resolution (Beusen et al., 2015) and a combination of future climate scenarios (RCPs) and Shared Socioeconomic Pathways (SSPs) (Beusen et al., 2022).

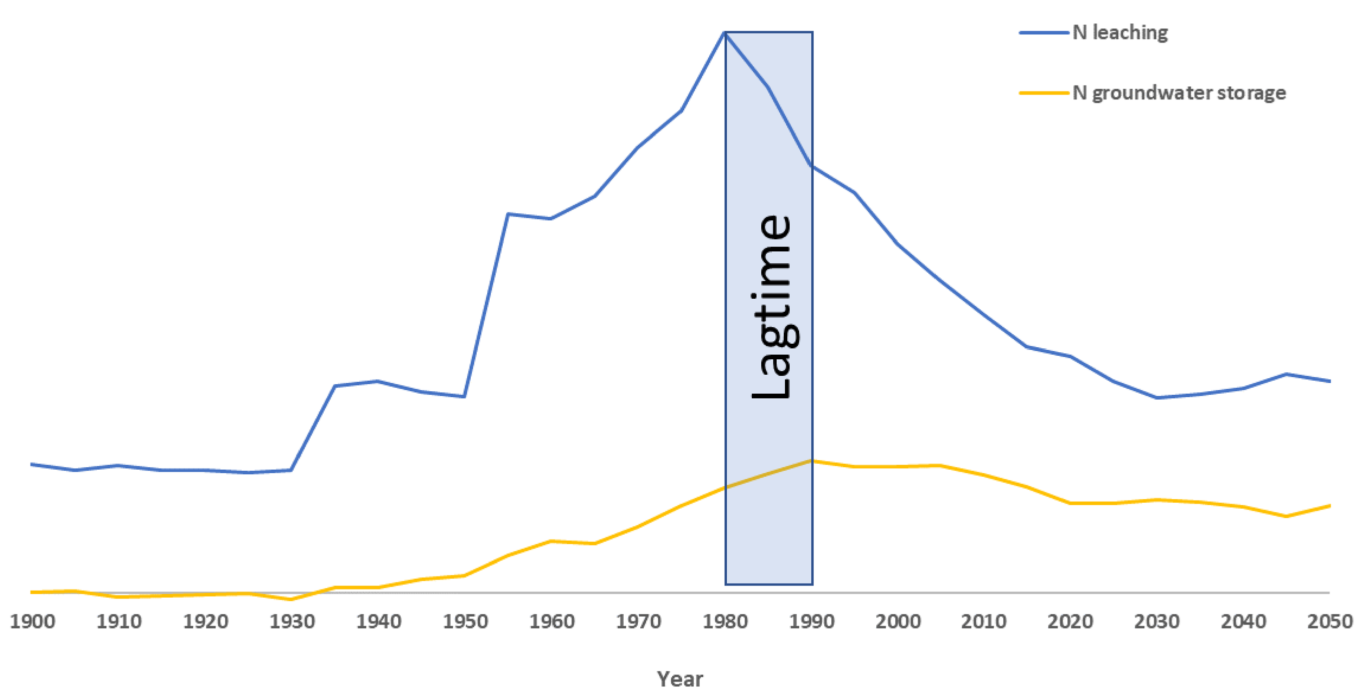

Figure 2. Lagtime as time difference between N leaching and N storage.

Scenario assumptions

- The SSPs are the set of community scenarios used to explore a spectrum of global environmental futures considering different developments in society and economy, the energy and agricultural systems, climate change and hydrology.
- **SSP1**: strive for sustainability; **SSP2**: middle of the road; **SSP3**: fragmentation; **SSP4**: inequality **SSP5**: fossil fuel-based.
- Fertilizer N is dependent on the Nitrogen Use Efficiency (NUE) and the application of animal manure, biological N_2 fixation and atmospheric N.
- Special scenario with zero leaching after 2015 to infer the year when N accumulation in groundwater will return to the level of 1970.

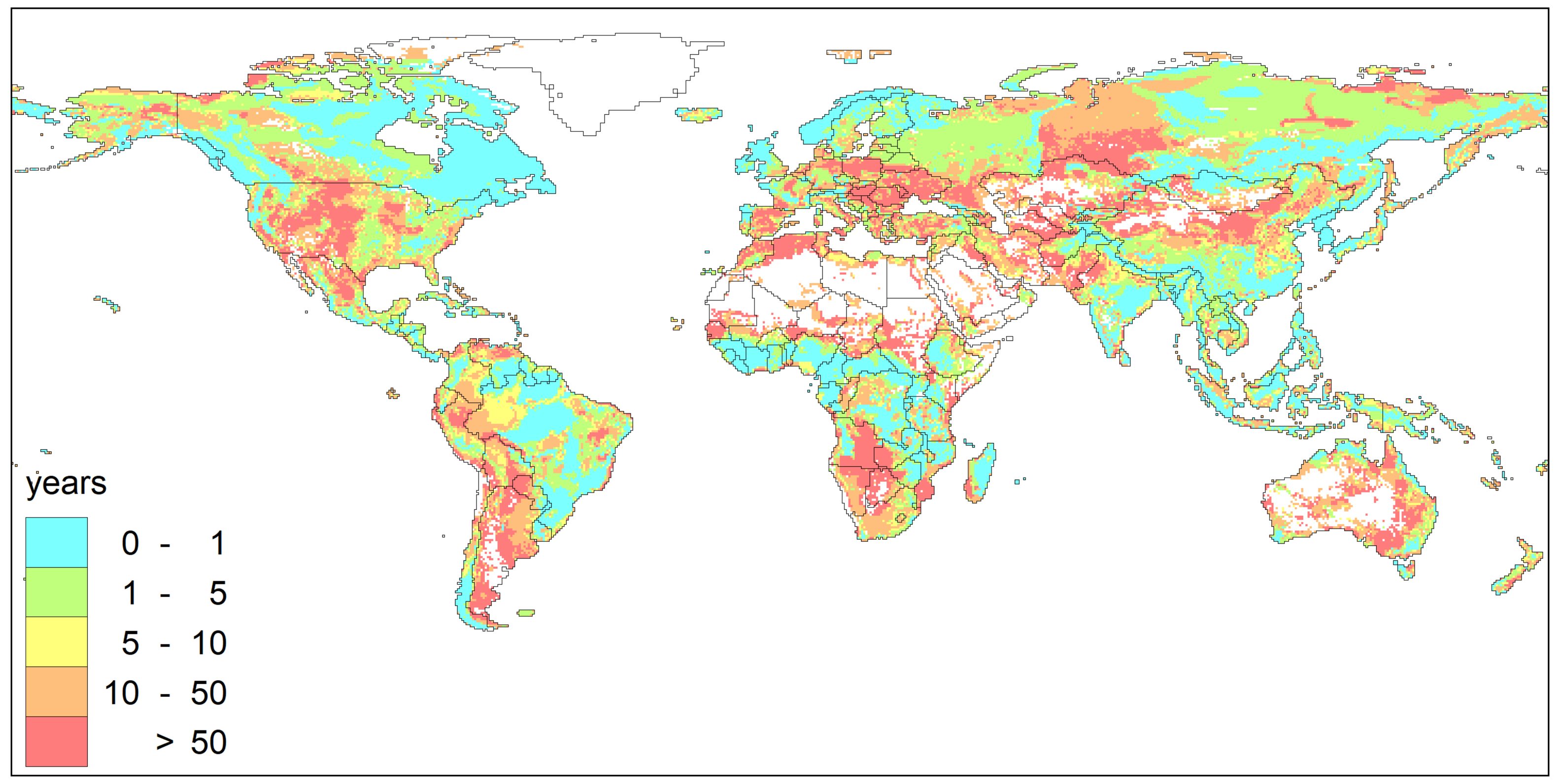

Figure 3. Median residence time in groundwater for the year 2015.

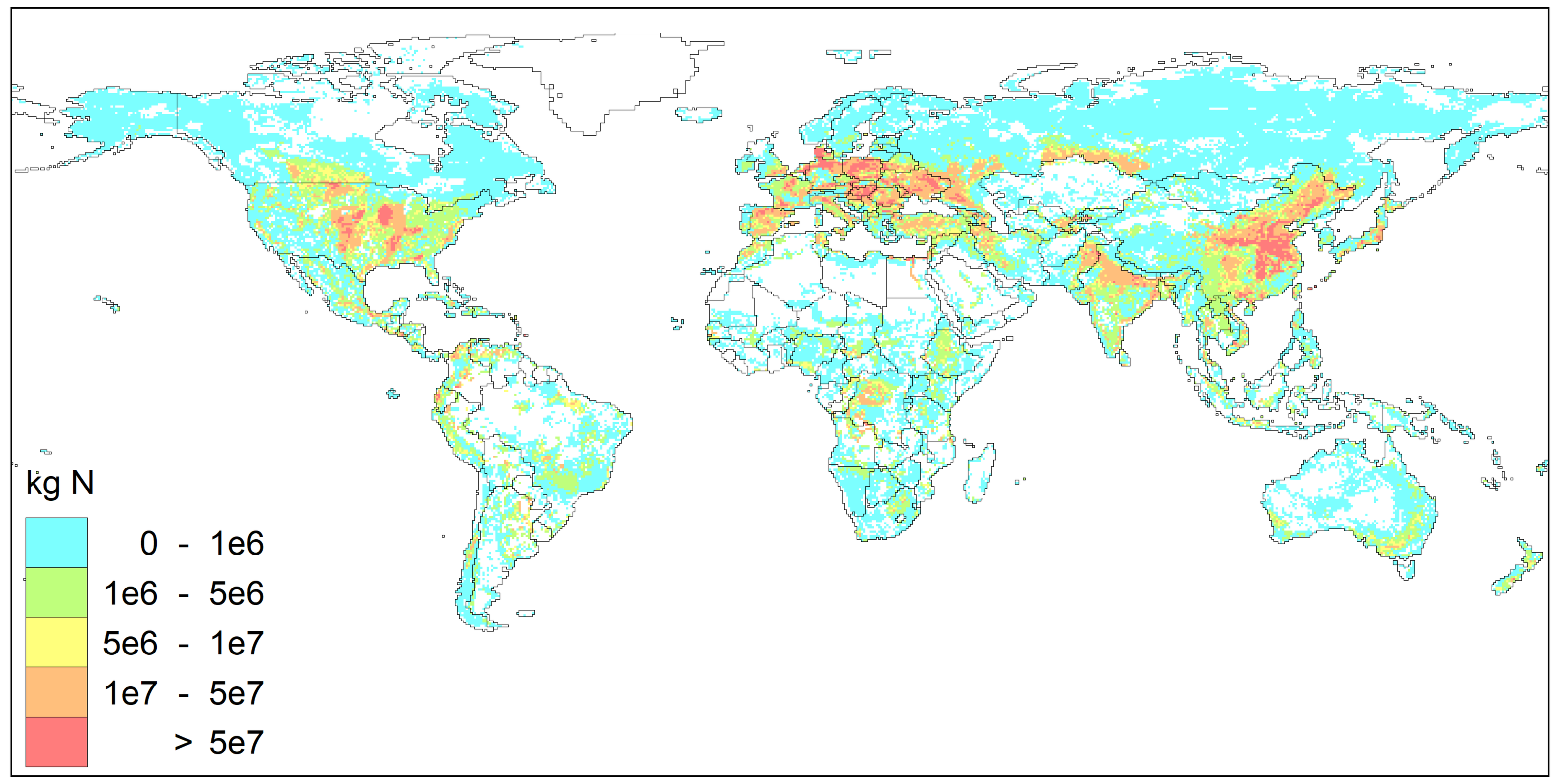

Figure 4. Cumulated N storage in groundwater since 1900.

Table 1. a) Median residence time of groundwater and b) the year N accumulation returns to the level of 1970 under zero leaching scenario.

	Rhine	Mississippi	Yangtze	Pearl
a. Residence time (min-max)	12 (6 – 18)	15 (6 - 46)	4 (2 - 5)	3 (2 – 4)
b. Year	**2024**	**2035**	**> 2050**	**> 2050**

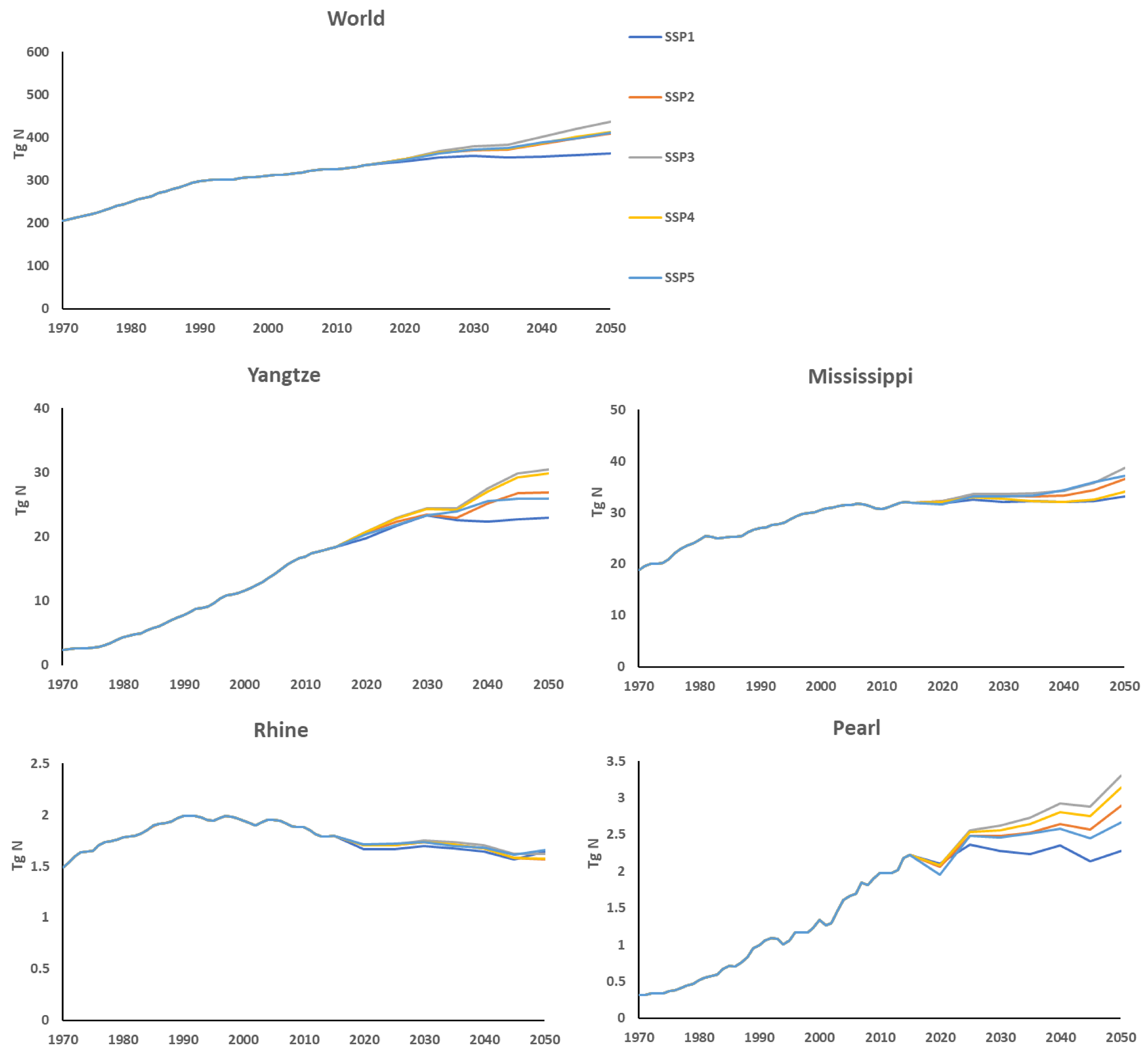

Figure 5. N storage in groundwater of four river basins and the world for the period 1970 – 2100 for the five SSP scenarios.

Results

Our results indicate that the current temporary storage in groundwater systems has been increasing considerably since 1970 by an amount comparable to global annual N fertilizer use. As the rate of N input to the groundwater system exceeds the rate of release, all SSP scenarios show a continued global N accumulation in groundwater. There are large differences between river basins, and we present scenario outcomes for 4 rivers, i.e. the Rhine, Mississippi, Yangtze and Pearl. The N storage in groundwater is expected to increase in Mississippi, Pearl, and Yangtze in all SSPs except for a stabilization in the sustainability scenario SSP1. The N legacy in the Rhine is predicted to decline under all the SSPs. Results of the zero leaching scenario shows large differences between rivers. Time needed to return to the 1970 level are especially long in the Yangtze and Pearl, river basins that are still in an accumulation phase, while Rhine and Mississippi are already in the depletion phase.

References

Beusen, A.H.W., Doelman, J.C., Van Beek, L.P.H., Van Puijenbroek, P.J.T.M., Mogollón, J.M., Van Grinsven, H.J.M., et al. (2022). Exploring river nitrogen and phosphorus loading and export to global coastal waters in the Shared Socio-economic pathways. Global Environmental Change 72, 102426. doi: https://doi.org/10.1016/j.gloenvcha.2021.102426.

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