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Catchment low pass filter characteristics, legacy contamination and their link to variability in biogeochemical $1/f^{\alpha}$ scaling

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In spite of recent progress, hydrological processes underlying observed water quality response patterns, such as the emergence of near-chemostatic conditions and fractal $1/f^{\alpha}$ scaling of stream chemistry, are not completely understood. Analysing hydrological and Cl^- tracer data for two intensely managed, hydrologically contrasting yet biogeochemically similar catchments we tested (1) if a model can simultaneously reproduce the hydrological and biogeochemical responses, (2) if legacy stores, allowing for long-term storage of nutrient inputs can be identified and (3) if a model can reproduce $1/f^{\alpha}$ scaling. Further we analysed (4) the transit (TTD) and residence time distributions (RTD) and the associated response dynamics of legacy stores, and (5) what controls fluctuations in the scaling exponent α, establishing a process based link between $1/f^{\alpha}$ scaling, legacy stores, and age distributions. We found that the model could reproduce the variable hydrological and the stable Cl^- responses. This was possible through Cl^- accumulation in hydrologically passive legacy stores (e.g. groundwater), where Cl^- age is well above 2000 days, one magnitude above the Cl^- age in other components, such as the root zone (200d). The results indicate that legacy stores can cause stable nutrient concentrations in streams for several decades after the end of nutrient input. It was further found that the model could reproduce fractal scaling of stream Cl^- in both catchments, with higher values of α for the catchment with the smaller legacy store and faster response (α=-0.88 vs. -1.29). Further analysing the spectral properties of model components, it was found that the parts of the system with less storage are characterized by higher values of α. This suggests a plausible processes-based link between the fluctuations of α, legacy stores and RTDs: the smaller the legacy store and the higher the flow contribution from faster responding system components, the higher α, suggesting that fractal scaling may potentially not be a universally emerging property of the biogeochemical response in streams.