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Effective denitrification at the groundwater surface-water interface: exposure rather than residence time

Stefan Peiffer and Sven Frei
University of Bayreuth, Hydrology, BayCEER, Bayreuth, Germany (s.peiffer@uni-bayreuth.de)

Effective processing of material in aquatic systems, e. g. removal of nitrate upon denitrification, requires sufficient reaction time. This statement sounds trivial albeit its implication for biogeochemistry seems to be not fully recognized.

The time t_{eff} required for effective processing of nitrate is controlled by the underlying biogeochemical rate law. In the simplest case of a 1^{st} order reaction, t_{eff} is often calculated as the time when 63% of the initial concentration is consumed setting t_{eff} as $1/k_{reaction}$. It may, however, be more appropriate to derive $t_{eff,90\%}$ or $t_{eff,99\%}$ from the respective rate law. Hence a minimum time $t > t_{eff}$ is required that exposes a specific biogeochemical process to conditions favourable for this process, which is anoxia in case of denitrification.

This exposure time τ_{exp} is not necessarily identical to the residence time τ of water in the particular system or flow path. Rather, the exposure time can be much shorter and may even fluctuate with time. As a consequence, Damköhler numbers ($Da = \tau_{exp}/t_{eff}$) for denitrification < 1 may be the consequence even though the age of water may be comparatively high. We therefore argue that the key for understanding denitrification efficiency at the groundwater surface-water interface (or in groundwater systems in general) is the quantification of the exposure time.

This contribution therefore aims i) to estimate exposure times required for effective denitrification based on an analysis of rate constants for denitrification, ii) to relate these time scales to typical residence time distributions found at the groundwater surface-water interface and iii) to discuss implications for denitrification efficiencies.

References:

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