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Bioclogging of dune sediments by coupled nutrient transport and microbial evolution: a numerical modeling study

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Streambeds are biogeochemical hotspots for a number of reactions that influence the fate of nutrients in streams and groundwater and that are performed by microorganisms attached to the hyporheic sediments. It is well known that in nutrient-enriched streams the metabolic activity of hyporheic microbes relies on water-borne solutes that are supplied by water exchanged with the stream. However, microbes also exert feedbacks on nutrient fluxes through the process of bioclogging, i.e. the reduction of water-filled pore volume and sediment permeability caused by biofilm growth and gas production. Unfortunately, the present understanding of this process is limited by the difficulty of data collection within streambed sediments.

In order to better understand the dynamics of bioclogging, we have performed a numerical modeling study on the coupling between water fluxes, nutrient reactions, and permeability variations due to microbial growth. We have updated a previously published hydro-biogeochemical model with the addition of two microbial components representing autotrophic (nitrifying) bacteria and heterotrophic (facultative aerobic) bacteria. We assume that biofilm grows and occupies pore space, thus altering hydraulic conductivity and modifying the fluxes of water and nutrients which support microbial metabolism.

The simulation results show that the system eventually attains an equilibrium between microbial growth and nutrient fluxes that is characterized by a vertical stratification of the microbial species and by a strong reduction of permeability near the stream-sediment interface. These findings denote the existence of an equilibrium configuration and provide insights on how microbial reaction rates are constrained by sediment properties, hydrodynamic factors, and nutrient availability.