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Biologically induced flow in sandy sediments: the ecological importance of permeability

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An interesting interaction between hydrodynamics and ecology takes place in sandy sediments. Burrowing organisms create networks that penetrate deeply into the anoxic zone of the sediment. These burrow structures are flushed with oxygen-rich water from the overlying water column, creating pore water flows in the surrounding sediment. Such bio-irrigation forms an effective transport mechanism for various solutes and fine particulate matter, but also for biological particles, such as bacteria and algae. We present a multi-dimensional (2D/3D) finite-element approach to quantify these biologically induced flow patterns, and their effect on the biogeochemistry and ecology of sandy sediments. This approach (1) describes burrow ventilating organisms as mechanical pumps (2) computes the pore flow generated by the pumping organism via Darcy's law, and (3) uses the velocity field as input for a reactive transport model of the sediment surrounding the burrow. We tested the adequacy of the model approach in a detailed case-study of the lugworms, which are dominant bio-irrigators in coastal sandy areas worldwide. Simulation of two different sets of inert tracer experiments show good agreement between model and data, indicating that our model captures the relevant aspects of lugworm bio-irrigation. A model sensitivity analysis reveals the factors that influence the lugworm's ventilation rate, leading to following ecological hypotheses. (1) Decreasing the permeability of the burrow lining greatly increases the efficiency of oxygen supply, as it prevents the re-entry of anoxic pore water. (2) The permeability of the bulk sediment constrains the lugworm's habitat. When permeability falls below a critical threshold, the sediment's resistance becomes too high, thus resulting in an insufficient oxygen supply. Overall, we show that permeability exerts an important control on resource availability in sandy sediment ecosystems.