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Modelling reaction front formation and oscillatory behaviour in a contaminant plume

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Groundwater contamination is a concern in all industrialised countries that suffer countless spills and leaks of various contaminants. Often, the contaminated groundwater forms a plume that, under the influences of regional groundwater flow, could eventually migrate to streams or wells. This can have catastrophic consequences for human health and local wildlife. The process known as bioremediation removes pollutants in the contaminated groundwater through bacterial reactions. Microorganisms can transform the contaminant into less harmful metabolic products. It is important to be able to predict whether such bioremediation will be sufficient for the safe clean-up of a plume before it reaches wells or lakes.

Borehole data from a contaminant plume which resulted from spillage at a coal carbonisation plant in Mansfield, England is the motivation behind modelling the properties of a contaminant plume. In the upper part of the plume, oxygen is consumed and a nitrate spike forms. Deep inside the plume, nitrate is depleted and oscillations of organic carbon and ammonium concentration profiles are observed. While there are various numerical models that predict the evolution of a contaminant plume, we aim to create a simplified model that captures the fundamental characteristics of the plume while being comparable in accuracy to the detailed numerical models that currently exist.

To model the transport of a contaminant, we consider the redox reactions that occur in groundwater systems. These reactions deplete the contaminant while creating zones of dominant terminal electron accepting processes throughout the plume. The contaminant is depleted by a series of terminal electron acceptors, the order of which is typically oxygen, nitrate, manganese, iron, sulphate and carbon dioxide. We describe a reaction front, characteristic of a redox zone, by means of rapid reaction and slow diffusion. This aids in describing the depletion of oxygen in the upper part of the plume.

To describe the oscillatory behaviour of the reactant concentrations deeper in the plume, we employ the dynamics of competing bacterial populations. We show that the oscillatory behaviour, characteristic of competing populations, can describe the oscillations observed among the reactants.