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Modelling the effects of bioturbation on the re-distribution of 137Cs in an undisturbed grassland soil

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Soil turnover by earthworm populations may be an important transport mechanism for contaminants that are strongly bound to soil. It is therefore quite surprising that few modelling studies to date have explicitly considered the effects of bioturbation on contaminant transport in soil. We present a general model that incorporates the effects of both 'local' and 'non-local' biological mixing into the framework of the standard physical (advective-dispersive) transport model. The model is tested against measurements of the re-distribution of 137Cs derived from the Chernobyl accident, in a grassland soil during a 21-year period after fallout. Three model parameters related to biological transport were calibrated within ranges defined by measured data and literature information on earthworm biomasses and feeding rates. Other parameters (e.g. decay half-life, sorption constant) were set to known or measured values. A physical advective-dispersive transport model based on measured sorption strongly underestimated the downward displacement of 137Cs. A dye tracing experiment suggested the occurrence of physical non-equilibrium transport in soil macropores, but this was insufficient to explain the extent of the deep penetration of 137Cs observed at the site. A simple bio-diffusion model representing 'local' mixing worked reasonably well, but failed to reproduce the deep penetration of Cs as well as a dilution observed close to the soil surface. A comprehensive model including physical advective-dispersive transport, and both 'local' and 'non-local' mixing due to the activities of both endogeic and anecic earthworms gave an excellent match to the measured depth profiles of 137Cs, with predictions mostly lying within confidence intervals for the means of measured data and model efficiencies exceeding 0.9 on all sampling occasions but the first.