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Optimization of multi-tracer vectors for residence time analysis

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It is proposed to use a multi-model and multi-tracer approach applying several mixing models and a series of environmental tracers simultaneously and in comparison, to estimate groundwater residence time. Most of the commonly used tracers for groundwater with residence times of less than 50 years have short-comings: CFCs are decreasing since the 1990ies, SF6 and SF5CF3 are highly affected by excess air and 3H signals have reached natural levels in precipitation. A combined quantitative analysis based on several tracers and applying a series of possible mixing models is used to derive residence times based on an optimization of a multi-tracer sample vector compared to a multi-model data vector. This approach provides a range of residence times and hence indicates the dependence of the analysis on model or tracer selection and uncertainty. Residence times are given in a probabilistic manner with confidence intervals corresponding to tracer and model selection. The analysis is facilitated by the use of an algorithm to find the minimal distance of the multi-tracer data array to calculated mixing curves. The analysis is supported by a new type of normalized residence time graph integrated empirical and model data. The approach can be constrained to a sub-set of tracers and models. The application of the approach to several case studies in groundwater residence time analysis indicates that uncertainty and dependence of residence time analysis on the choice of tracers of models depends on hydrogeological conditions: In some cases results are very sensitive to the choice of tracers or models, in other cases residence time analysis converges to similar results over a range of tracers and models.