Linear Model Describing Three Components of Flow in Karst Aquifers Using ^{18}O Data

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Abstract

The stable isotope of oxygen, ^{18}O, is used as a naturally occurring ground-water tracer. Time-series data for $\delta^{18}O$ are analyzed to model the distinct responses and relative proportions of the conduit, intermediate, and diffuse flow components in karst aquifers. This analysis also describes mathematically the dynamics of the transient fluid interchange between conduits and diffusive networks. Conduit and intermediate flow are described by linear-systems methods, whereas diffuse flow is described by mass-balance methods. An automated optimization process estimates parameters of lognormal, Pearson type III, and gamma distributions, which are used as transfer functions in linear-systems analysis. Diffuse flow and mixing parameters also are estimated by these optimization methods. Results indicate the relative proximity of a well to a main conduit flowpath and can help to predict the movement and residence times of potential contaminants.

The three-component linear model is applied to five wells, which respond to changes in the isotopic composition of point recharge water from a sinking stream in the Madison aquifer in the Black Hills of South Dakota. Flow velocities as much as 540 m/d and system memories of as much as 71 years are estimated by this method. Also, the mean, median, and standard deviation of traveltimes; time to peak response; and the relative fraction of flow for each of the three components are determined for these wells. This analysis infers that flow may branch apart and rejoin as a result of an anastomotic (or channeled) karst network.

Keywords: Stable isotopes; Karst aquifers; Linear systems; Aquifer response; Mathematical models; Signal processing