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Estimation of relative recharge sequence to groundwater with minimum entropy deconvolution

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Abstract

This study applies the minimum entropy deconvolution (MED) for the estimation of the sequential groundwater recharge rate. Groundwater recharge rates have conventionally been estimated as an average value over some period of time, e.g. annual or seasonal recharge rates. Such estimates however, are not suitable for the analysis of the dynamic sequential behavior of the groundwater head fluctuation. If the sequential groundwater recharge rate is obtained, numerical groundwater models can be effectively applied to evaluate the effect of any change in the groundwater system following the change in natural or artificial components. This study successfully applies MED to estimate the sequential recharge rates. As recharge rates are obtained by relative values, a series of timed observations are necessary. The validity of the estimated sequences of relative recharge rates can be checked by cross-referencing. Cross-correlations between the applied recharge sequence and the estimated results are above 0.985 in all study cases. Through the numerical test, the suitability of MED in the estimation of the recharge sequence to groundwater is investigated.

Keywords: Groundwater; Recharge estimation; Sequential recharge; Minimum entropy deconvolution; Numerical test

1. Introduction

The estimation of groundwater recharge is a classical topic in hydrogeology. A large number of methods have been introduced for the estimation of groundwater recharge. Scanlon et al. (2002) reviewed various kinds of techniques for quantifying groundwater recharge. They subdivided techniques for estimation recharge into four types, water budget, techniques based on surface-water studies, techniques based on unsaturated studies and techniques based on saturated studies.

The former two categories are related to indirect approaches to groundwater systems. And the latter two categories are directly related to physical groundwater systems. However, from the methodological viewpoint, it is hard to distinguish the latter two cases from each other. Therefore, we tried to re-categorize these methods to estimate groundwater

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recharge into four types with the viewpoint of monitoring data types and resulting types of recharge estimate focused on whether the resulting estimate is given by dynamic time-series or a representative recharge value for some period of time. That is, the re-categorization criteria are closely related to the ranges of time period the resulting recharge estimates can represent. The four types are: (1) the water balance method, (2) baseflow/springflow recession analyses, (3) analyses of chemical or physical tracers, and (4) dynamic recharge estimation from time series data.

The first type is related to the water balance (WB) technique. WB is the most conventional method to estimate the recharge. Bradbury and Rushton (1998) estimated a runoff-recharge model using the water balance method, Finch (1998) investigated the sensitivity of direct groundwater recharge to land surface parameters with a water balance model, and Bekesi and McConchie (1999) applied the Monte Carlo technique to the water balance model to estimate the groundwater recharge.

The estimation of the groundwater recharge from baseflow/springflow recession is another type of method which has been widely employed. Many studies related to this method have been carried out (Rutledge and Daniel, 1994; Avery et al., 1999; Ketchum et al., 2000). But methods related to the baseflow/springflow recession are directly correlated with the discharge, rather than the recharge.

The third type is the method of groundwater recharge estimation by measuring the groundwater age with environmental tracers or temperature profiles (Solomon et al., 1993; Leduc et al., 1997; Bromley et al., 1997; Taniguchi, 1993; Taniguchi et al., 1999a,b). The applications included in the above-mentioned three groups are mostly concerned with the estimation of groundwater recharge as forms of seasonal average or annual recharge rates. If there are some studies related to the estimation of a daily or dynamic recharge rate, those studies are somewhat or highly related to the following fourth type.

To estimate more dynamic fluctuations of groundwater recharge, a method for sequential estimation of recharge is necessary. Unfortunately, it is not easy to find studies on sequential approaches to estimate the recharge rate to groundwater. We categorized the fourth type as methods related to the sequential estimation of groundwater recharge rate. Sometimes, the methods related to the fourth group are called 'saturated-volume fluctuation (SVF) analysis methods'. Ketchum et al. (2000) proposed the storage accumulation method calibrated with the spring discharge records. Healy and Cook (2002) tried to extend the discussion of SVF to the estimation of specific yield in fractured media. But in these studies, the local discharge, described with the recession of the hydraulic head, was not considered. The local discharge for the studied area is merely considered as the area average by dividing the spring flow discharge by the catchment area.

On the other hand, there are many studies on the estimation of the source sequence with time series data in geophysics (Broadhead, 1993; Sacchi et al., 1994; Kaaresen and Taxt, 1998; Sibul et al., 2002). But there have been only rare applications of geophysical methods to the estimation of the groundwater recharge. Even though predictive deconvolution techniques are one of the most prevalent methods for the estimation of source wavelets in signal processing, they have rarely been applied to the estimation of recharge to groundwater.

In general, the classical predictive deconvolution technique is based on the minimum phase condition. However, the minimum phase condition can hardly be satisfied in nature. On the contrary, the input signal in a natural system can be considered as a random signal. To apply the classical predictive deconvolution, some appropriate sequence satisfying the minimum phase condition must be picked up. To avoid the strong restriction of the minimum phase condition, Wiggins (1978) proposed another deconvolution technique, called the minimum entropy deconvolution (MED). Wiggins (1978) insisted that the MED process seeks the smallest number of large spikes that is consistent with the data. In other words, MED finds the simplest signals consistent with the observed data. Wiggins (1978) represented the simplicity with the varimax norm. However, the solution process with the varimax norm is non-linear. To acquire the desired digital filters for the estimation of source wavelets, some iteration is needed in the MED proposed by Wiggins. For the linearization of the MED problem, Carbrelli (1984) suggested another criterion, the D norm, instead of the varimax norm. Carbrelli (1984) showed that the behavior of the D norm is consistent with