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An improved neural network approach to the determination of aquifer parameters

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Abstract

In this paper, an artificial neural network (ANN) approach to the determination of aquifer parameters is developed. The approach is based on the combination of an ANN and the Theis solution. The proposed ANN approach has advantages over the existing ANN approach. It avoids inappropriate setting of a trained range. It also determines the aquifer parameters more accurately and needs less required training time. Testing the existing and the proposed ANN approaches by 1000 sets of synthetic data also demonstrates these advantages. As to the comparison between the proposed ANN approach and the type-curve graphical method, an application to actual time-drawdown data shows that the proposed ANN approach determines the aquifer parameters more precisely. The proposed ANN approach is recommended as an alternative to the type-curve graphical method and the existing ANN approach.

Keywords: Aquifer parameters; Artificial neural network; Back-propagation algorithm; Aquifer test

1. Introduction

The determination of aquifer parameters has always been a challenging task for groundwater resources engineers and managers (for example, Jacob, 1940; Hantush, 1956; Walton, 1962; Wikramaratna, 1985; Aziz and Wong, 1992; Zhan et al., 2001; Chen and Chang, 2002; Balkhair, 2002; Chen and Chang, 2003), because it holds a central position in groundwater modeling. The aquifer parameters obtained by the type-curve graphical method (Jacob, 1940) are of questionable reliability (Aziz and Wong, 1992; Balkhair, 2002). In recent years, some convenient and reliable approaches based on artificial neural networks (ANNs) have been developed.

Neural networks, which were devised via imitating brain activity and are capable of modeling and identifying complex systems, provide an alternative approach to the determination of aquifer parameters. Artificial neural networks (ANNs) were first developed in the 1940s (McCulloch and Pitts, 1943). Generally speaking, neural networks are information processing systems. In recent decades, considerable interest has been raised over their practical applications, because the current algorithms can overcome the limitations of early networks. Bypassing the model construction and parameter estimation phases

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adopted by most of the conventional techniques, ANNs can be automatically developed through a simple training process. Such a training process enables the neural system to capture the complex and nonlinear relationships between the known input data and the desired output data that are not easily analyzed using conventional methods.

ANNs have also found increasing applications in various aspects of hydrology because of their ability to model and to identify both linear and nonlinear systems. Previous studies have shown the potential of ANNs for analyzing hydrology and water resource problems (for example, Coulibaly et al., 2001; Hsu et al., 1995; Clair and Ehrman, 1996; Poff et al., 1996; Gumrah et al., 2000; Lin and Chen, 2004a,b). As to the determination of aquifer parameters, Aziz and Wong (1992) and Balkhair (2002) determined aquifer parameters from aquifer test data by an ANN approach, which is referred to as the existing ANN approach herein. They trained their networks through a supervised learning scheme known as back-propagation (Rumelhart et al., 1986).

However, the existing ANN approach has its drawback. It is not capable of producing aquifer parameter values accurately when the desired values are out of the trained range. Hence, the performance of the existing ANN approach is largely determined by the selection of a range of aquifer parameter values in the training phase. However, there is no established methodology for selecting an appropriate trained range especially when there is no prior information of the aquifer parameters available. Such a limitation has prompted a search for an improved ANN approach to estimating aquifer parameters. In this paper, an alternative ANN approach is proposed. The proposed ANN approach has three advantages over the existing ANN approach. First, it avoids the aforementioned problem regarding the selection of an appropriate trained range. Second, it determines the aquifer parameter values more accurately. Finally, the proposed ANN has a simpler structure and is trained more rapidly.

This paper is organized as follows. First, an alternative ANN approach is proposed which is capable of determining the aquifer parameters from aquifer test data. Then two applications are performed and their results are presented to demonstrate the advantages of the proposed approach. Finally, conclusions are drawn.

2. The proposed ANN approach

The proposed ANN approach is developed based on the combination of an ANN and an analytical solution that can calculate the drawdown from known aquifer parameters. Theis (1935) presented an analytical solution to calculate the drawdown s at a distance r from the transmissivity T, the storage coefficient S and the discharge Q. The Theis solution can be written as

$$s = \frac{Q}{4\pi T} W(u) \tag{1}$$

where

$$W(u) = \int_u^\infty \frac{1}{y} \exp(-y) \mathrm{d}y \tag{2}$$

and

$$u = \frac{r^2 S}{4Tt} \tag{3}$$

The type-curve graphical method is developed based on the Theis solution. In the type-curve graphical method for the determination of aquifer parameters, one has to fit observed time-drawdown data to a type curve of $W(u)$ versus $1/u$ and find a match point. In this paper, the above procedures are done by a three-layered ANN (Fig. 1). An ANN is composed of a number of interconnected processing elements. These elements, called neurons, are joined

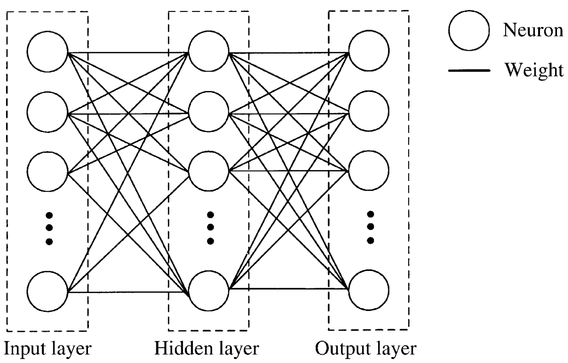

Fig. 1. Architectural graph of a three-layered ANN.