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Nonlinear kernel functions for karst aquifers

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Summary This paper presents a form of kernel function for karst aquifers derived from the time-invariant and non-anticipatory Volterra series. The shape of the kernel function depends on the current value of an index of antecedent recharge that is considered as an indicator of groundwater levels and vadose zone saturation. The proposed nonlinear form preserves specific characteristics of instantaneous unit hydrographs. By using analogies with the conceptual model of nonlinear reservoir, it is shown that the second component of the kernel function characterizes the prevailing type of groundwater flow. If the second component is positive, the free-surface flow is dominant, whereas the negative value indicates that the flow under pressure prevails. Groundwater recharge rates are calculated by using a groundwater recharge model based on the Palmer's soil-moisture balance method. The values of parameters of the groundwater recharge model are estimated by the spectral method which is modified to avoid the assumption about exponential forms of autocorrelation functions of input and output time series. This paper analyzes also the practical applicability of nonlinear kernels for the preliminary characterization of karst aquifers and the karst springs discharge modeling. The results of applications on the springs zones of the rivers Krka and Krčić are in accordance with previous assumptions that the Main Krka Spring is an ascending karst spring which aquifer is situated deeply inside the karst underground, whereas the Main Krčić Spring function as a descending karst spring.

Introduction

Karst areas comprise specific surface and underground hydrographic networks resulting from the water circulation and its aggressive chemical and physical action in soluble rocks, such as limestone, chalk and dolomite as well as gypsum and salt (Bonacci, 1987). Consequently, the main hydrogeologic characteristic of the karst underground is the existence of networks of pores, fissures, fractures and conduits of various size and forms. Such irregular structure with significant spatial and temporal variability and discontinuity of hydraulic and geometric parameters creates complex hydrogeologic conditions for the groundwater flow. The dualities of the infiltration processes, groundwater flow fields and discharge conditions are direct consequence of this structure (Király, 2002). The main flow directions are usually predetermined by positions of fractures and con-

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duits or underground channel networks through which the groundwater is transported quickly by the turbulent flow. The laminar flow usually prevails in pores and fine fissures, which are more important from the water management aspects because of larger storage capacities and longer retention times. In addition to the different flow characteristics, the groundwater appearing in pores and fissures has also different flow directions. A schematic presentation of differences between the water circulation in underground karst channels and the water circulation in cracked blocks with networks of fine fissures is given in Fig. 1 (Drogue, 1980). After heavy rainfalls, the water level in the channels rises more rapidly than the water level in the surrounding karst mass, which exerts a flow from the channels into the pores and fissures of cracked blocks. During dry periods, the water level in the channels decreases faster, which produces a slow laminar drainage of the pores and fissures.

Karst springs present natural exits for the groundwater to the surface of the lithosphere. It is very difficult to precisely classify karst springs because there are always certain exceptions which deny or at least make the classification uncertain (Bonacci, 1987). However, Bögli (1980) classified karst springs according to origin of water, outflow hydrographs and geologic and tectonic conditions. Taking into account the origin of water appearing at springs; emergence, resurgence and exsurgence springs are distinguished. Regarding outflow hydrographs, karst springs can be perennial or temporary where a subdivision to periodic, rhythmically flowing and episodical springs exists. According to geologic and tectonic conditions, four types of karst springs are distinguished: bedding springs, springs emerging from fractures, overflow type of springs and ascending springs. This classification implies indirectly that karst springs can be ascending or descending (Bonacci, 1987). A schematic presentation of typical ascending and descending karst springs is given in Fig. 2. The main characteristic of the ascending karst springs is that a significant part of aquifer is located deeply inside karst massif below the spring level and spring emerges from a saturated vertical channel. The aquifer of the descending karst spring is located mainly above the spring level and spring emerges usually from a horizontal channel that can be permanently or temporarily unsaturated.

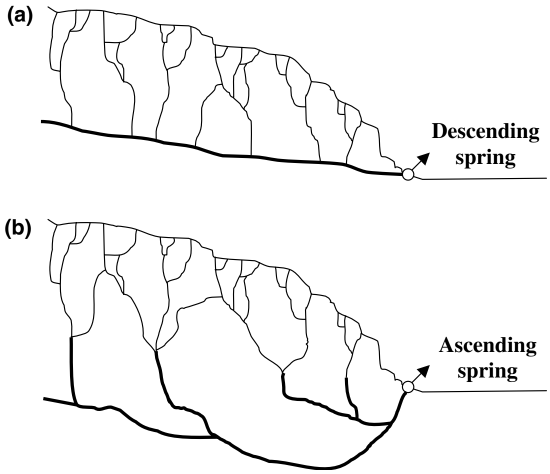

Figure 2 Schematic presentation of descending (a) and ascending (b) karst springs.

Karst springs discharges have been simulated with theoretical, conceptual and black-box models. The theoretical or physical models are based on hydraulic laws valid for the turbulent and laminar type of flow in porous media (e.g., Eisenlohr et al., 1997a,b; Teutch and Sauter, 1997) so the definition of realistic hydraulic and geometric parameters is essential, which means that extensive hydrologic, geologic and hydrogeologic investigations are needed. Because of the lack of such investigations, the simulations of karst springs discharges have been usually directed to the development of less complex mathematical models. The conceptual models are based on very simplified physical interpretations of the process of transforming input into output. Among them, the series of linear or nonlinear reservoirs are the most common (e.g., Barrett and Charbeneau, 1997; Halihan et al., 1998; Halihan and Wicks, 1998). The simplest models are black box models which do not need

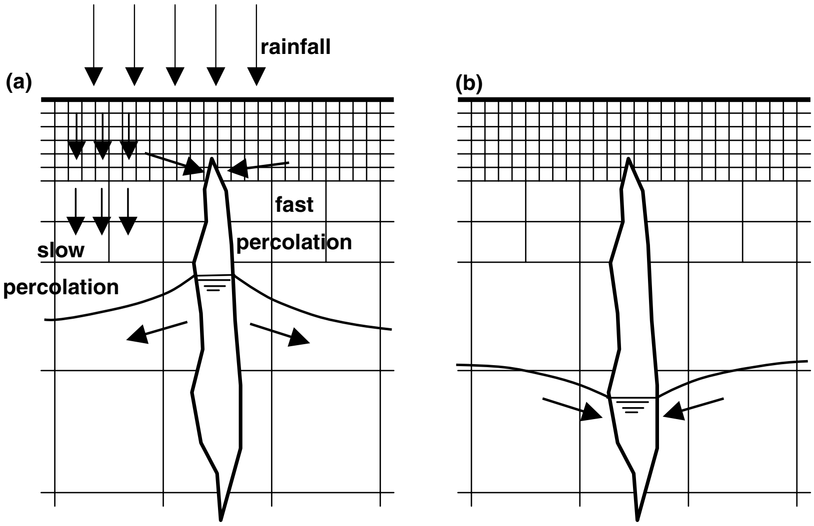

Figure 1 Water circulations between the underground channels and the cracked blocks with a network of fine fissures; case of low water levels (a) and case of high water levels (b), (Drogue, 1980).