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Spring hydrographs as indicators of droughts in a karst environment

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SUMMARY

Spring discharges of a large karst system (Campania, Southern Italy) have been analysed to determine if they were related to rainfall and periods of poor recharge. Due to the Mediterranean climate and hydrogeological conditions of the aquifers, the spring hydrographs are generally characterised by one annual smoothed peak during spring season and a negligible quick flow component. Insufficient recharge due to poor annual rainfall results in flat spring hydrographs (with no peak) that indicate a continuously decreasing discharge. Flat spring hydrographs reveal a drought, which is characterised by a prolonged shortage of water that induces a reduction in discharge during the following year as well. Droughts also appear to be induced by consecutive years with lower than average rainfall.

The historical data have shown that each hydrological year depends on the previous year because annual rainfall series do not have a random character and aquifers have a "memory effect", which results in spring discharges amplifying the effect of poor rainfall.

Due to a long historical series and the specific karst spring regime, a flat hydrograph can be forecast as early as winter, thereby providing a useful tool for water management. The time-lag between rainfall and spring discharges has been utilised to determine the amount of rainfall required to avoid a drought.

Introduction

Karst aquifers discharge water throughout the hydrological year, primarily in response to the climate regime, geological setting and karst conditions. The karst conditions act as a filter that regulates the groundwater paths to the springs depending on the interconnections present in the karst network. The time required for water to flow through a karst aquifer depends on surface extension and the thickness of the vadose zone and also of the development of karst conduits within the vadose and phreatic zones, varying from a several minutes to a few years. In addition, because karst aquifers act as large natural reservoirs of water, karst spring discharges reflect periods of poor or abundant rainfall, as well as long term climate change (Chen et al., 2004).

Two main types of karst aquifers can be described based on the development and interconnection of karst conduits within the system. A *conduit type* karst system is characterised by well-developed karst networks that allow rapid transit of water through the aquifer. In these systems, flow primarily occurs rapidly in large fissures through irregular conduits. Therefore, these systems are known as *quick flow* or *fast flow* systems (Atkinson, 1977; Gunn, 1986; Bonacci, 1993; Padilla et al., 1994). Because these aquifers are generally unable to store water over long periods of time, the spring hydrographs produced by these systems are characterised by many peak discharges that immediately follow rainfall events.

In a *diffuse type* karst system, the karst network is not well developed or interconnected; therefore, the groundwater requires more time to travel through the aquifer. These systems are characterised by *slow flow* (Atkinson, 1977), *diffuse flow* (Bonacci, 1993) or *dispersive flow* (Civita, 2005), which is controlled by small karst fissures and occurs in the laminar regime. These karst aquifers retain water for a much longer length of time than conduit karst systems. Therefore, the shape of the spring hydrograph produced by these systems is characterised by very few or only one smoothed peak that occurs after a time lag with regard to the rainy season. However, a smoother, less structured hydrograph may indicate that an aquifer is primarily recharged by diffuse infiltration (White, 2002). This phenomenon can be caused by mantling deposits that limit runoff and concentrated infiltration. Also the epikarst, a zone of increased weathering near the land surface, determines the distribution of recharge to a karst aquifer in both space and time (Bauer et al., 2005). Generally, karst systems contain quick flow and slow flow components that are both reflected on the hydrographs produced by the springs.

Prolonged periods of poor rainfall can reduce the response of the spring discharge, with springs characterised by a predominant quick flow component showing a diminished frequency and/or peak-value of impulses, and springs characterised by a predominant slow flow component showing a reduced annual maximum value (Fig. 1). This study was conducted to analyse spring

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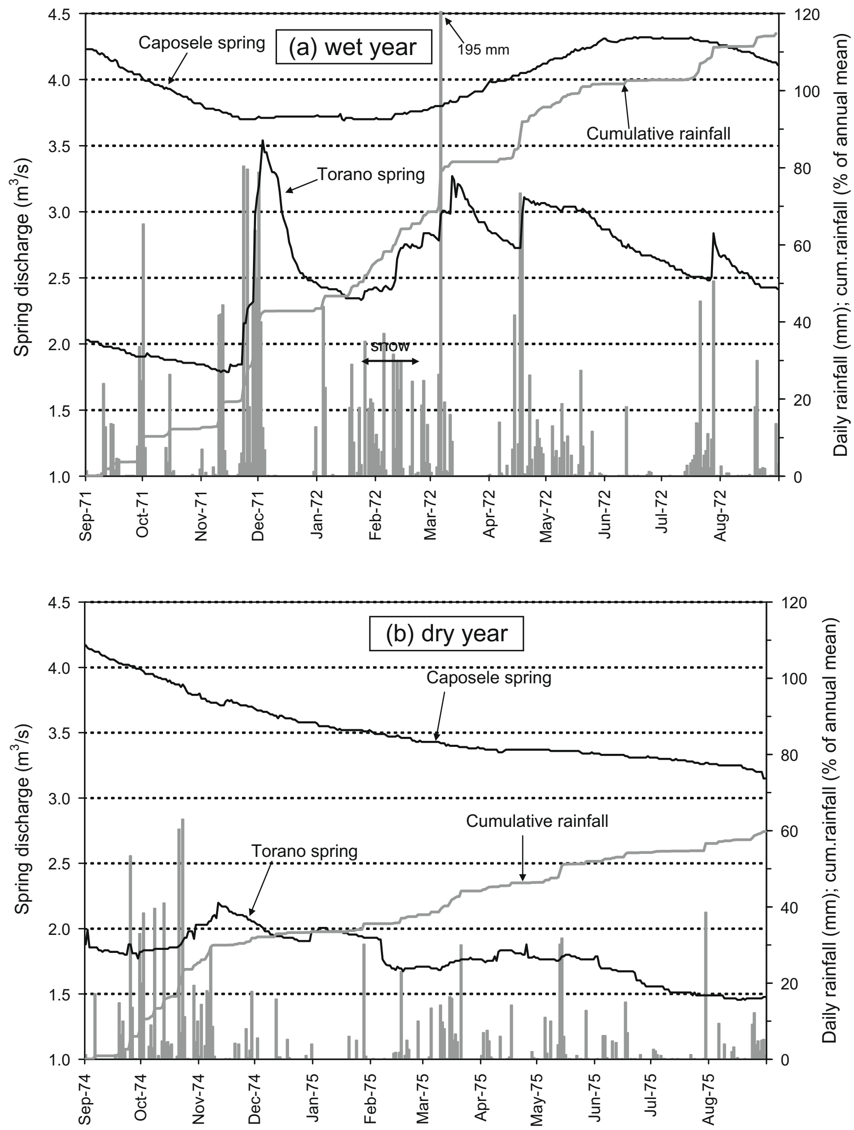

Fig. 1. Hydrographs and rainfall corresponding two Campania karst springs during a wet (a) and dry (b) hydrological year. Torano spring hydrograph (Mt. Matese, Northern Campania), which is characterised by quick flow impulses overlapping the base flow. Caposele spring hydrograph (Mt. Picentini), which is characterised by slow flow.

hydrographs characterised by one smoothed peak. The hydrographs evaluated are connected to a long period of antecedent cumulative rainfall and can be ascribed to a *diffuse type* karst system, similar to that of the Caposele spring presented in Fig. 1. The analyses focused on flat spring hydrographs that did not increase throughout a hydrological year following insufficient recharge of the karst system. During such years, the spring hydrograph presents a continuous decreasing trend, which indicates the occurrence of a wide and prolonged drought.

Based on a probabilistic approach and extension of the method described by Fiorillo et al. (2007), these flat hydrographs can be forecast several months before they occur. Therefore, probabilistic analysis can allow the amount of rainfall needed to avoid a drought to be determined. Because any prolonged drought reduces the spring discharge for a long time, the role of droughts on discharge during the following year is also discussed herein.

The data analysed in this study pertain primarily to the main karst springs in the Picentini Mountains (Campania, Southern Italy), which supply the most important aqueducts of Southern Italy. In addition, the analyses can also be applied to other karst systems characterised by "smoothed" spring hydrographs and a limited or absent quick flow component, thereby providing a useful tool for water resource management.

Geological and hydrogeological features

The karst springs are located along the northern boundary of the Picentini Mountains, a large karst system in the Campania region of Italy (Fig. 2). Morphologically, these mountains are primarily characterised by a high slope angle, greater than 20° representing more than 50% of the overall area. Flat zones are limited to endoreic areas and the karst summit landscape. In the north-eastern sector, over 70% of the catchment lies above 1000 m a.s.l., with the highest catchment being located on the top of Mt. Cervialto (1809 m a.s.l.). In the north-western sector, only 30% of the catchment lies above 1000 m a.s.l., with the highest catchment being located at the top of Mt. Terminio (1806 m a.s.l.).

Outcropping rocks in the region primarily belong to the calcareous and calcareous–dolomite series (Late Triassic–Miocene), are 2500 m thick, heavily fractured and faulted and frequently reduced to breccias. Karstic phenomena have considerably dissolved the rocks, and neotectonics activity has probably limited the connec-