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Karst flash flooding in a Mediterranean karst, the example of Fontaine de Nîmes

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Abstract

Karst flash flooding, identified as one of the hazards in karst terrains, is directly linked to the structure and hydraulic properties of karst aquifers. Due to the characteristics of flow within karst aquifers, characterized by a dual flow – diffuse flow within fissured limestone and conduit flow within karst conduits networks – flash flooding may be important in volume and dynamics. Such phenomenon may cause serious damages including loss of lives, as it occurred on 3rd October 1988 in Nîmes (Gard, South France). Flash floods there have been considered to be the result of very intensive rainfall events conjugated to runoff due to the geomorphologic context of the city located down hill. However, preliminary results of recent studies of the hydrologic behaviour of groundwater and surface water for a specific event (September 2005) show that the karst plays an important role in the flood genesis. The main characteristics of the Nîmes karst system leading to karst flash flooding are presented in this paper. A methodology comprising modelling of the karst system allowed proposing simple warning thresholds for various part of the karst (water level threshold for the karst conduits and cumulative rainfall threshold for the overflowing fissured karst). These thresholds can be included in the flash flood warning system of the Nîmes city.

Keywords: Flash-flood; Groundwater; Hazard; Karst; Spring; Water table

1. Introduction

Four main geologic hazards are generally associated with karst: cover-collapse sinkholes (Kaufmann and Quinif, 1999), sinkhole flooding (Lolcama et al., 2002), high concentrations of radon in basements and crawl spaces of houses (O'Connor et al., 1993) and groundwater vulnerability (Andreo et al., 2006). Recently, karst flash flooding has been identified as a new kind of hazard in karst terrains (Bonacci et al., 2006). A flash flood is defined as a flood which follows shortly (i.e. within a few hours) after a heavy or excessive rainfall event (Georgakakos, 1986).

Karst aquifers are characterized by a dual flow system (Kiraly, 1994) consisting of a fissured system which represents the bulk mass of limestone storing water with Darcyan flow, and a conduit system with the karst conduit network transmitting water by turbulent flows (Atkinson, 1977). Exchange between the two systems is controlled by hydraulic head differences as well by the hydraulic conductivities and the geometric setting (Atkinson, 1977).

Due to the characteristics of groundwater circulation in karst terrains, flash flooding in such context is strongly different than in non karst terrains: the volume of water during a karst flash flood is much more important than flash floods on other terrains. The main cause is the rapid circulation of large quantities of infiltrated water through karst conduits with a dynamic very close to surface water runoff.

The Nîmes city has been forever subject to catastrophic floods events. History of the city mentions about 42 flood events from 1334 to 2005, about one flood every 16 years as an average. Almost 60% of the events happen during the three months between September and November. In the recent past, the most important one occurred on 3 October 1988 and killed

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9 people among 45,000 disaster victims (Fabre, 1990). Damages were about 600×10^6 euros. The specific maximum outflow discharge (q_M) of the Cadereaux rivers, defined as $q_M = Q_M/A$, where A is the catchment area (42 km^2) and Q_M is maximum estimated discharge (1600 m^3 s^{-1} in 1988), is equal to 38.1 m^3 s^{-1} km^{-2}, the highest in a comparative study done by Stanescu and Matreata (1997) on flash floods along rivers in five European countries. These flash floods have been for a long time considered to be the result of very intensive rainfall events from Cevennes climate influence conjugated with the geomorphologic context (Ballais et al., 2005) of the city which is located at the bottom of a hill. Usually, overland flow tends to play the dominant role in flash flood formation and low infiltration capacity is the most important factor for overland flow development (Smith and Ward, 1998). However, with a very scarce and thin soil cover of high infiltration capacity, karstified limestone of Nîmes hills are in theory favourable to the infiltration of a part of rainwater, reducing the potential overland flow genesis. Therefore, soils characteristics and geological conditions in the watershed are apparently such that flash flood should not happen in Nîmes city.

An extensive monitoring of the karst system has been coupled to a classical runoff monitoring during a recent event which occurred in September 2005. The preliminary results show that the role of the karst system in the flood genesis is very important and that the flash floods at Nîmes can be related to a phenomenon of karst flash flooding. This paper presents the main characteristics of the Nîmes karst leading to karst flash flooding.

2. Study area

The Fontaine de Nîmes (FdN) spring is located in the South-Eastern France, in the city of Nîmes. Most of the time, it constitutes the only discharge point of a karst system which is famous for its rapid reaction to rainfall events. The unsaturated zone is maximum 10 m thick and the saturated zone is limited to a few tens of meters. A well developed karstic network drains the aquifer to the FdN spring (Fig. 1). A part of these drains has been mapped by speleologists during several diving explorations. Except for two publications (Fabre and Guyot, 1984; Fabre and Guyot, 1988), the hydraulics of the system is poorly known.

The area receives around 740 mm annual precipitation that recharges the karst aquifer mainly by diffuse infiltration and swallow holes. The springs of the system consist of the FdN spring, with a discharge comprised between 0.01 and 18 m^3 s^{-1}, and several intermittent springs discharging only during flash floods.

The karst basin (Fig. 1), defined by numerous tracing experiments (Fabre, 1997) and a water budget calculation (Pinault, 2001; Maréchal et al., 2005), is estimated to be on the order of 55 km^2. The area is quite a lot urbanised in the southern part and covered by natural Mediterranean vegetation (Garrigues) in the north. The catchment area is mainly composed of limestone from Hauterivian, Cretaceous.

The city is at the bottom of the hill at the convergence of three temporary streams called “cadereaux”, which is a local

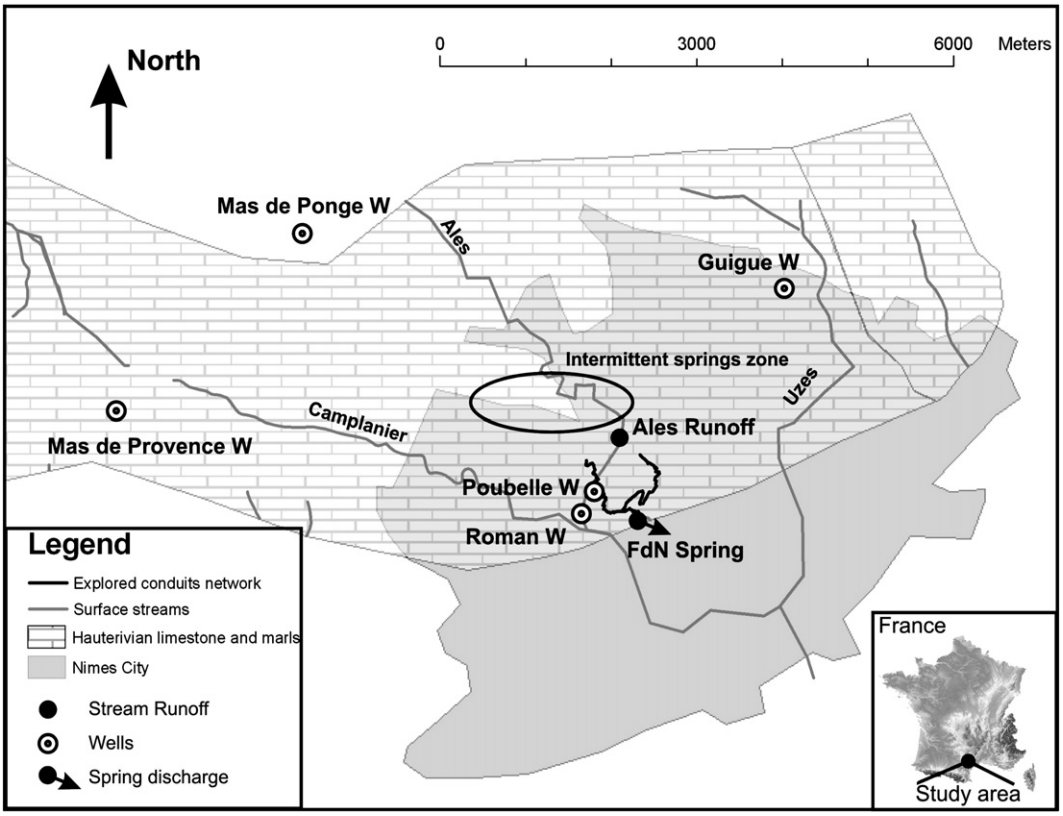

Fig. 1. Location of the Eastern part of Nîmes karst basin and Nîmes city area. Location of monitoring network.