Flood Hazard in the Classical Karst: The Case of Mucille Polje (NE Italy)

P. Turpaud, C. Calligaris, and L. Zini

Abstract

In the north-western area of the Classical Karst (NE Italy), the Mucille depression, after abundant precipitations, is subject to frequent floodings, which become problematic since 2001 as they more frequently affect housing and recreational areas, leading the population to believe that the swallow holes draining the area stopped functioning. The climate changes as well as the increased frequency of intense rainfall events led to evaluate the draining capacity of the swallow holes in order to provide fundamentals for the mitigation measures. The depression is fed by a spring area and drained by two swallow holes one of which is permanently active, while the other functions only during floods. About 24 h after the onset of heavy rains, the whole depressed area is flooded. About 8 days later, the water level begins to decrease, coming back to its initial height in about fifteen days. During floods, while springs and swallow holes discharges measurements are impossible, the extension of the flooded areas has been mapped. The obtained flooded surface together with high resolution DTM coverage allows to calculate the volume of surface water. Consequently, the hydrologic balance can be estimated during the whole event. This study provides meaningful evidences for the design of measures to mitigate the risk. It estimates the discharge of the swallow holes, confirming their efficiency. Nonetheless, it also emphasizes the need to improve their draining capacity, especially considering the unsuspected high outflow of the springs at the onset of the flood.

Keywords

Karst hydrogeology • Flood hazard management • DEM analysis • GIS • Groundwater monitoring

1 Introduction

In the last decades, invasive and destructive flood events are constantly increasing (Hirabayashi et al. 2013; Kvočka et al. 2016; Tabari 2020) and karst areas are no exception. Their response to floods and to the water outflowing is dependent on the intrinsic characteristic of the karstified hydrostructure (conduits and fractures). The study of a small but meaningful area (the Mucille karst depression) in the Friuli Venezia Giulia Region (NE Italy) provides insights concerning the flood dynamics in such environment.

After abundant precipitations, the Mucille karst depression is subject to frequent floodings which become problematic since 2001 as they, more frequently, affect housing and recreational areas, leading the population to believe that the swallow holes draining the area stopped functioning. This belief, together with the climate changes that will most probably cause an increase of the frequency of intense rainfall events, led to evaluate the draining capacity of the swallow holes and the aquifer dynamics both by direct discharge measurements and by water balance modeling. These assessments provide insights for flood risk reduction measures and data that can be helpful in evaluating the efficiency of the realized mitigation actions.

The Classical Karst hydrostructure extends for approximately 750 km^2 from the Soča/Isonzo River to the Adriatic Sea and up to the town of Postoina. The springs draining it, drain waters of three main contributions: the Isonzo groundwaters, the Reka and Raša rivers input through swallow holes and the effective infiltration. The groundwaters of the Isonzo Plain are partially drained along the contact between the karst and the alluvial plain (Timeus 1928;

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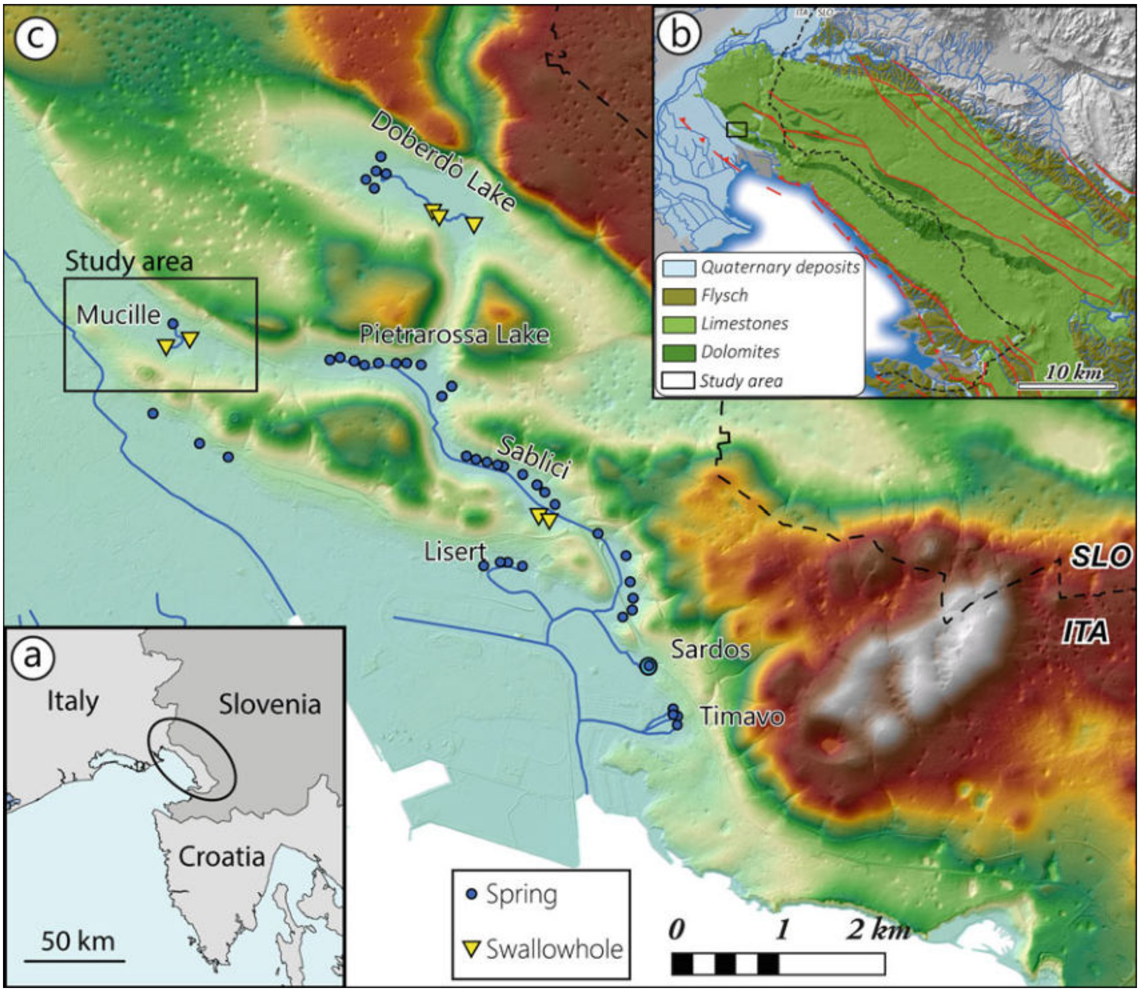

Fig. 1 The study area is located along the south-western edge of the Classical Karst. The latter spans across the Italian-Slovenian border **a**, **b**. Simplified geological map of the Classical Karst after Jurkovšek et al. (2016). The Mucille depression belongs to a network of polje featuring numerous springs that drain the aquifer (**c**)

Mosetti and D'Ambrosi 1963; Gemiti and Licciardello 1977; Cancian 1987; Doctor et al. 2000; Samez et al. 2005; Urbanc et al. 2012; Zini et al. 2015). This contribution is calculated at approximately 10 m^3/s (Zini et al. 2011, 2013; Calligaris et al. 2019). In the southeastern sector of the hydrostructure, in Slovenia, at the contact between flysch and carbonates, several swallow holes drain the Reka and Raša rivers. If the latter drains only small water quantities, Reka river input definitively influences the hypogean flows of the whole eastern sector of the Classical Karst as its discharge ranges between 0.18 m^3/s and over 300 m^3/s with an average of 8.26 m^3/s (Gabrovšek and Peric 2006).

Effective infiltration represents the main contribution to the aquifer recharge with an average value of 20.6 m^3/s (Civita et al. 1995). Rainfalls quickly infiltrate into the articulated paths of the karst structure thanks to an average high rainfall (between 1000 mm/year on the coast and 1800 mm/year in the innermost areas), a poor vegetation cover, the absence of thick soils and an intense and widespread karstification of the rock mass.

The study area, located at the contact between the south-western edge of the Classical Karst and the Isonzo Plain, is characterized by a series of polje NW–SE oriented which include, in addition to the Mucille plain, Doberdò and Pietrarossa lakes as well as the Sablici depression (Fig. 1).

The karst aquifer, which in the area can be found on average at elevations between 2 and 5 m a.s.l., is intercepted by these karst depressions giving rise to a complex system of springs characterized by extremely variable flows according to the rainfall regime. This hydrogeological context was heavily modified in the post-war period by the construction of a channel draining, toward the Adriatic Sea, Pietrarossa and Sablici lakes (Zini et al. 2022). The result is a lowering of their baseflow level of about 1 m. Mucille and Doberdò lakes were not directly involved by the reclamation activities and thus maintained their natural hydrography characterized by the presence of a spring area, a drainage channel and a series of sinkholes. Nonetheless, also Doberdò Lake evidenced a lowering of its baseflow level of about 1 m leading to longer drought periods. This lowering is not proven in the Mucille area due to the lack of data regarding the level monitoring but is can be expected.

The Mucille depression is laid on a gently SSW dipping cretaceous bedded limestone of the Povir formation (Jurkovšek et al. 2016).

It is fed by a spring area (S-02). During low-water conditions, the flow is channeled toward a swallow hole (Sw-01), while at high water table conditions, a second swallow hole (Sw-02) participates in draining the area (Fig. 2).

The minimum elevation within the Mucille depression of about 4.8/4.5 m a.s.l. is encountered along the channel connecting the spring area to the swallow holes. The rest of the area is almost flat with elevations ranging from 6.0 to 8.5 m a.s.l. The lower groups of houses can be found at 8.1 and 8.8 m a.s.l., respectively.

2 Methods

The hydrogeological characteristics of the area have been defined by field-survey and manual monitoring of water level, electrical conductivity and temperature. Alongside, water level in an adjacent piezometer (S20, Figs. 2 and 3) has been monitored continuously in between 2017 and 2019 using a CTD-Diver (Van Essen Instruments) multiparametric probe. Pressure was compensated using a Baro-Diver probe (Van Essen Instruments).

Hydrograph analysis of two flood events together with hydrologic balance and in situ discharge measurements helped to define a flood control strategy. Discharge measurements at various water level have been performed with an MF Pro (OTT HydroMet). While discharge measurements are possible in low-water conditions, during floods assessment of springs and swallow holes discharge is impossible due to channel overflow. Digital terrain model allows to calculate the surface water volume at incremental water table level (Fig. 4). Using phreatic levels registered in

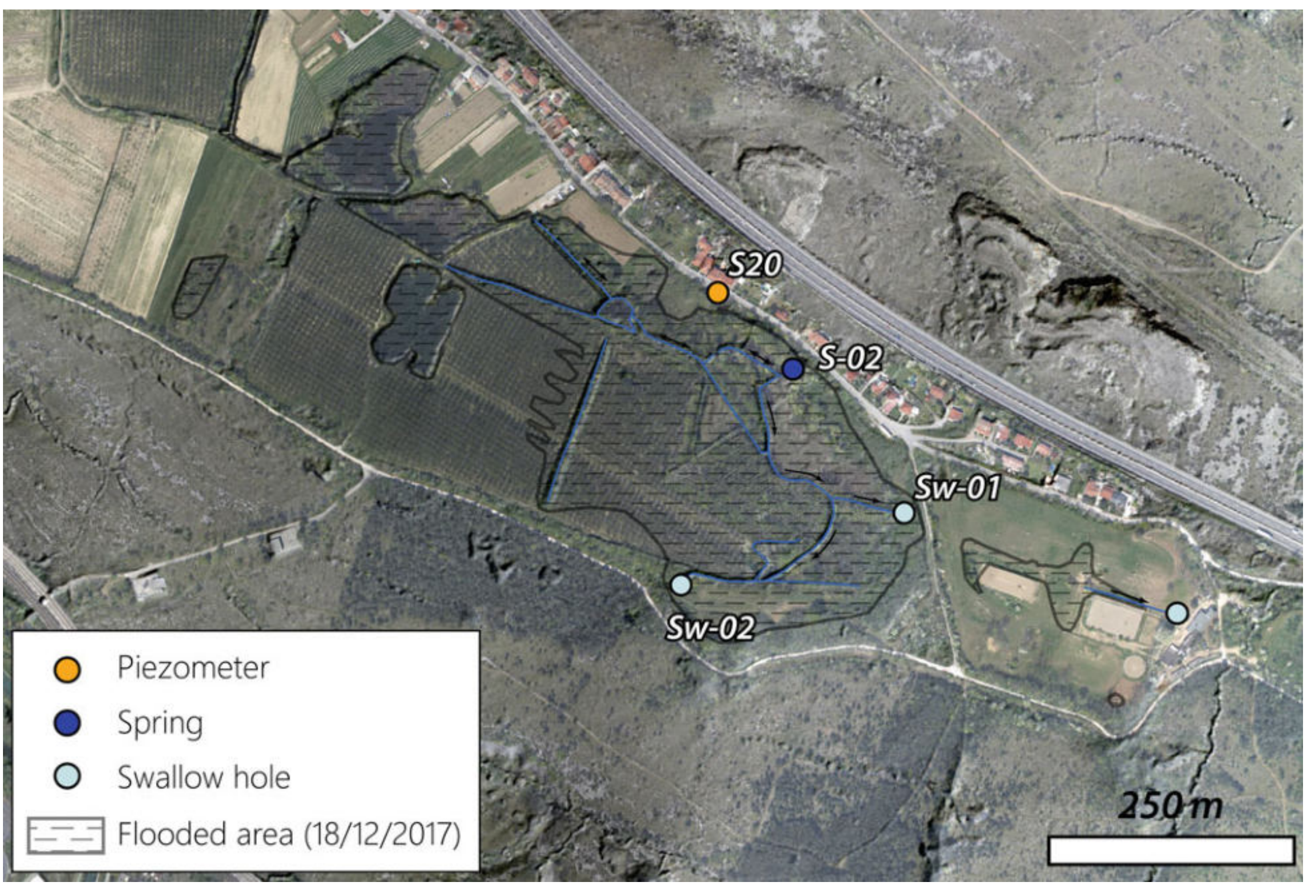

Fig. 2 Composite aerial photograph of the Mucille area. Spring area, swallow holes and monitoring piezometer are highlighted. The flooded surface on 18/12/2017 is mapped

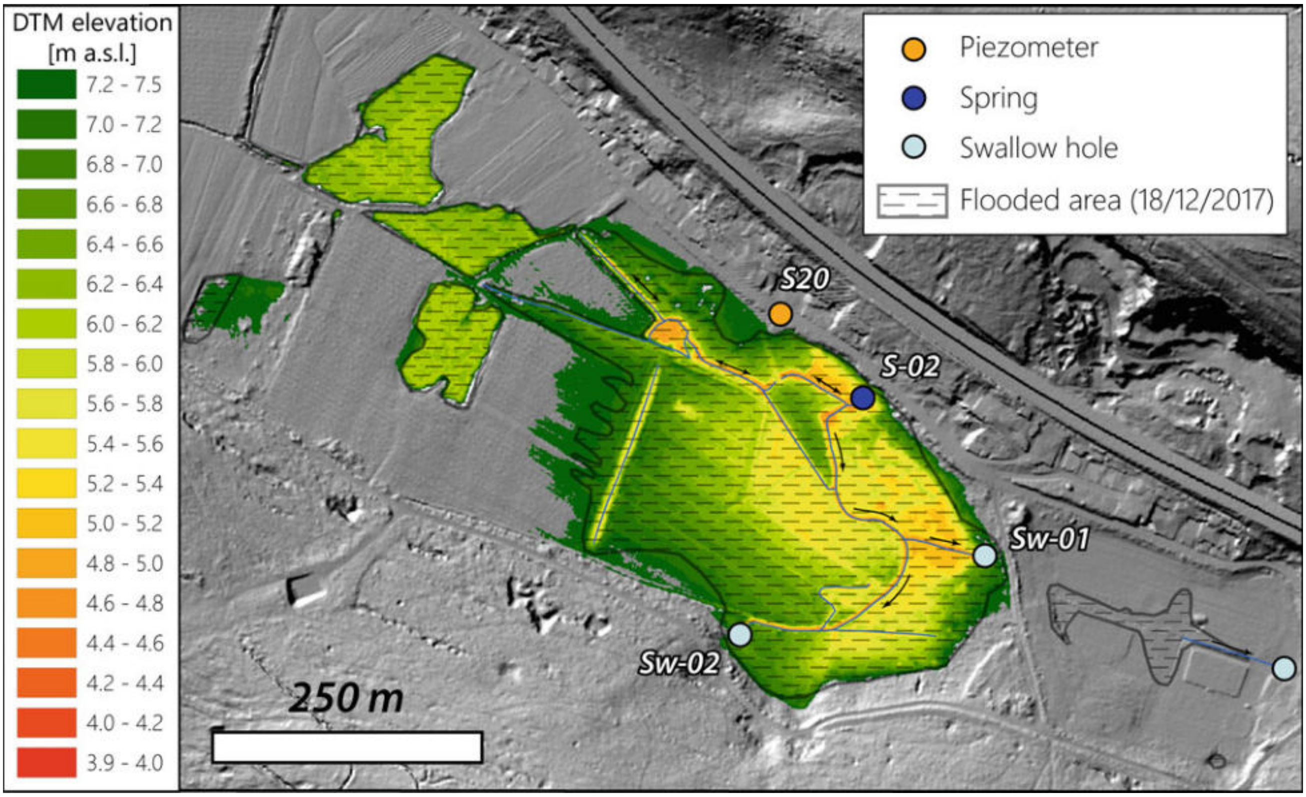

Fig. 3 DTM of the Mucille depression. The flooded area at the peak of event 1 (18/12/2017) coincides with the 7.5 m a.s.l. elevation. The surface water volumes calculated with DTM allow the modeling of the water table elevation as function of the surface water volume

an adjacent piezometer (S20), this volume can be computed over time. Consequently, the hydrologic balance (inflow minus outflow) has been estimated during two flood events.

3 Results

The water balance and draining capacity of the swallow holes were analyzed for two different flood events. The results of in situ discharge measurements acquired during the second one and at various stages during other floods (not presented here) are also discussed.

Event 1

The flood was caused by two rainfall events: a first one between 25th November and 1st December (76 mm) and a second one between 8 and 16th December (153 mm) 2017 (Fig. 5). The flood recorded a maximum water table at 7.5 m a.s.l. The fast water rise required a mean balance of 880 l/s (inflow minus outflow) for one day (to be compared with the low-water conditions springs discharge of about 50 l/s). The following day it decreased to 280 l/s. The next 5 days, the water balance oscillated between 0 and about 200 l/s. From the eighth day on, while water level began to lower, the

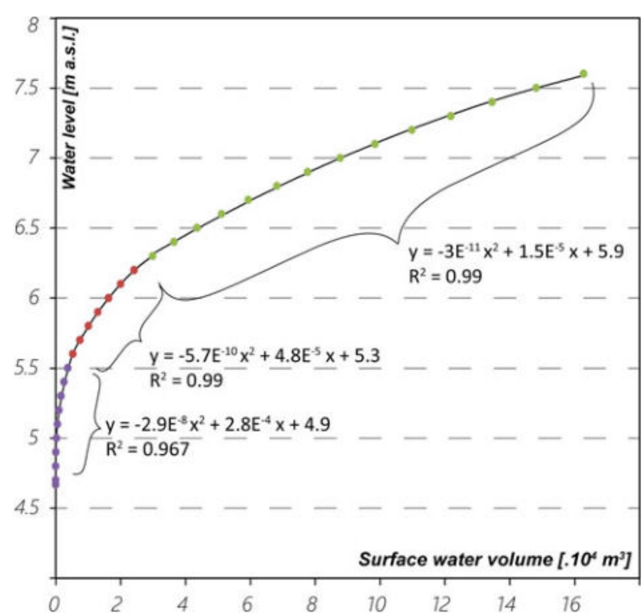

Fig. 4 Relationship between water level and surface volume obtained by DTM elaboration. Successively this model was used for water balance calculation

balance became negative for 8 days with values around −200 l/s. As springs were still active, what obtained demonstrates the high drainage capacity of the swallow

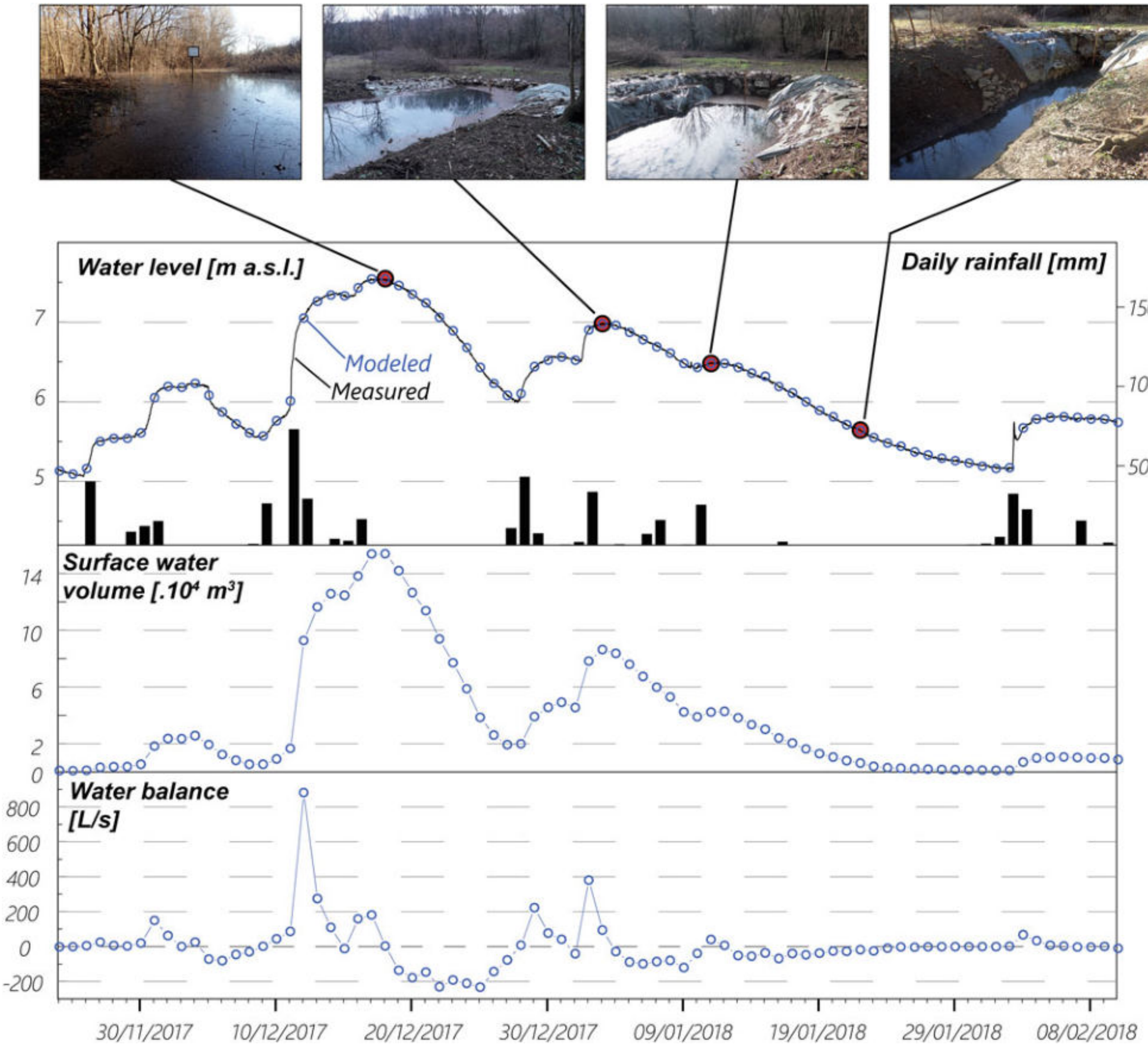

Fig. 5 Water level measured in the S20 piezometer and daily rainfall data from Gorizia Italy (provided by ARPA-OSMER) during event 1. Photographs illustrate the situation in the Sw-02 at different levels. The water level allows the calculation of the surface water volume (middle graphic) and consequently the daily mean water balance (lower graphic)

holes at high-water conditions when direct discharge measurements are impossible.

Event 2

The flood was caused by two precipitation pulses which took place on 28th February (15 mm) and between 1st and 4th of February (88 mm) 2018 (Fig. 6). This event illustrated a more common and less intense rise of the water table with a maximum of about 6.5 m a.s.l. The excess input of about 300 l/s for one day became negative after 5 days. It remained negative (at ca. −50 l/s) for the next 7 days. The last 7 days of the modeled period were characterized by a slightly negative balance (between −7 and −2 l/s).

After the peak of event 2, in situ discharge measurements have been performed to assess directly the swallow holes drainage capacity. Before becoming inactive due to water lowering, Sw-02 absorbs about 80 l/s. Sw-01 absorbs ca. 70–80 l/s before the return to low flow condition.

Discharge Rating Curves

Further in situ discharge measurements have been performed at different stages. The discharge rating curves of both

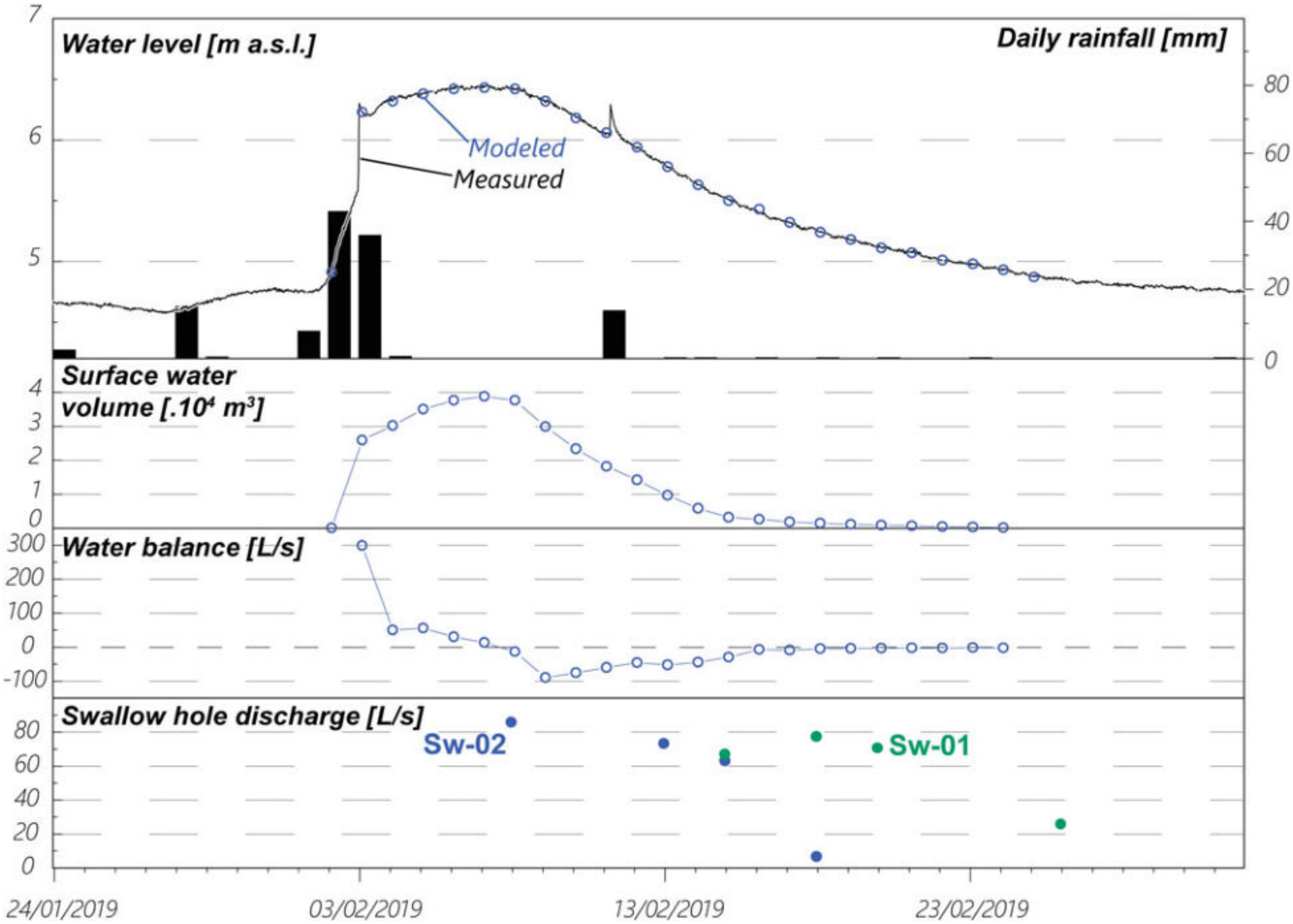

Fig. 6 Water level measured in the S20 piezometer and daily rainfall data from Gorizia Italy (provided by ARPA-OSMER) during event 2. The water level allows the calculation of the surface water volume and consequently the daily mean water balance. Discharge values (in situ measurements) of both swallow holes are plotted in the lower graphic

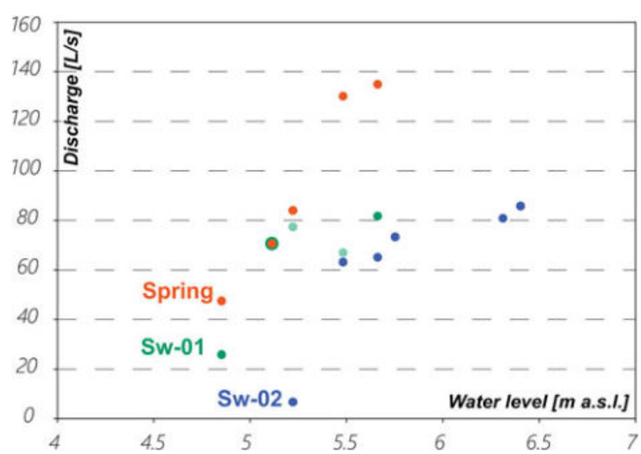

Fig. 7 Discharge rating curves of the two swallow holes and of the spring area

swallow holes and spring area are plotted in Fig. 7. Data confirm the swallow hole draining capacity of at least 80 l/s each, up to a water level of 6.5 m a.s.l.

4 Conclusions

This study provides insights concerning the flood dynamics in karst environment through direct and indirect assessments.

In detail, the direct discharge measurements confirm the functioning of the swallow holes even at relatively high water levels (6.5 m a.s.l.). Hydraulic balance model allows to indirectly assess their draining capacity during floods when in situ measurements are impossible to be done (up to about 7.5 m a.s.l.).

The 880 l/s difference between input and output at the incipient of large floods was not expected. It implies that the maximum discharge at the spring should be about 1 m^3/s. Consequently, the conventional pumping to lower water level would be insufficient to mitigate damages.

The proposed solution involves first of all the regular maintenance and cleaning of both swallow holes. On the other hand, a drainage by channel would be prohibitive due to costs. Housing and recreational areas could be protected with the construction of an embankment and the mechanical enlargement of the southern swallow hole (active only during floods) in order to improve its drainage capacity. The comparison of the discharge rating curves and of the water balance before and after the intervention will permit to assess the efficiency of the intervention.

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