



Sensitivity of a mountain basin flash flood to initial wetness condition and rainfall variability[†]

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SUMMARY

The sensitivities of runoff generation to rainfall variability and initial wetness conditions were examined for a major flash flood event that occurred during August 29, 2003 on the upper Tagliamento river basin in the eastern Italian Alps. The Triangulated Irregular Network (TIN)-based Real-time Integrated Basin Simulator (tRIBS) distributed hydrologic model was used to simulate the hydrologic response over a range of sub-basins. The model was calibrated for the single flash flood event based on the observed hydrograph at the outlet of the basin examined (Fella basin) and was validated based on the available observed hydrographs at interior points of the basin. A series of hydrologic simulations were performed for different initial soil moisture conditions and rainfall forcing resolutions in order to evaluate the sensitivity of runoff generation to those variables. Evaluation of the results suggests that both initial wetness and rainfall resolution affect significantly the simulated peak flow and runoff volume during the flash flood event. Sensitivity to initial wetness exhibits a scale dependence with the sensitivity increasing with basin scale. The bias introduced to the basin-averaged rainfall due to aggregation had a significant effect on runoff generation for all basin scales, while the effect of variability smoothing was important only for the larger scale basins. Finally, the sensitivity of the flood hydrograph to rainfall aggregation was shown to be more important for drier initial wetness states.

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1. Introduction

Flash flooding is a worldwide hazard responsible for significant damages and loss of life. The tremendous societal and economical impact of this hazard necessitates the development of effective hydrologic monitoring systems in order to advance warnings and mitigate the risk. The current state of flash flood warning systems is based on the use of models that simulate the hydrologic processes at the watershed scale (Norbiato et al., 2008). Two important variables that control runoff generation and serve as input to models are the initial soil moisture and rainfall distributions. Soil moisture is also a hydrologic state variable that describes the saturation conditions of the land surface, while rainfall is strictly a forcing variable defining the volume of water that falls on the land surface. They are both highly

variable in space and time and it is mainly due to this variability and interaction at the surface that the transformation of rainfall to runoff is a highly nonlinear process. Consequently, accurate knowledge of both variables is required to successfully predict the hydrologic response of a given basin.

Unfortunately, most real world hydrologic modeling applications lack accurate and adequate observations of rainfall and initial soil moisture distributions. Rainfall input is usually based on either sparse gauge observations or estimates from remote sensing (e.g., weather radar, satellite platforms), while soil moisture input is provided in most cases using indirect observations as a proxy (e.g., streamflow, depth to water table). In both cases, there are estimation errors due to limitations in the retrieval algorithms and measurement errors, as well as representation errors due to coverage limitations or the coarse resolution and sampling issues of the sensors. Overall, the result is that hydrologic models are typically forced with rainfall and initial soil moisture fields that are associated with high uncertainties, which have a subsequent effect on flood predictions. Assessing and understanding the sensitivity of hydrologic models to these important variables is necessary for the design of hydrologic forecasting strategies and decision-making procedures.

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Evaluating the sensitivity of runoff response to rainfall variability and initial soil moisture is an issue that has been well recognized by the research community. Sensitivity of streamflow generation to rainfall variability was initially addressed nearly four decades ago (Dawdy and Bergmann, 1969) and since then, numerous studies have been published on this subject (Beven and Hornberger, 1982; Ogden and Julien, 1993; Koren et al., 1999; Woods and Sivapalan, 1999; Bell and Moore, 2000; Segond et al., 2007; Vivoni et al., 2006; Nicótina et al., 2008; Sangati and Borga, 2009; Saulnier and Le Lay, 2009). Despite the extensive literature on this subject, results do not converge to a unified conclusion and sometimes are even contradictory, as Segond et al. (2007) points out, which highlights the complexity of the problem. Sensitivity of runoff generation to antecedent wetness conditions is also a well-established subject that has been investigated by several authors (Hino et al., 1988; Loague, 1992; Karnieli et al., 1993; Cerdá, 1997; Ceballos and Schnabel, 1998; Fitzjohn et al., 1998; Castillo et al., 2003; Vivoni et al., 2007). Despite the fact that the sensitivity of streamflow to rainfall is linked with antecedent wetness conditions (Singh, 1997), most studies have focused on the sensitivity effect of each variable and only few have analyzed the combined effect of rainfall and antecedent wetness to runoff generation (Shah et al., 1996; Zehe et al., 2005; Vivoni et al., 2007; Noto et al., 2008).

All the aforementioned studies have been based on various hydrologic contexts regarding storm characteristics (movement, duration, intensity), catchment properties (topography, vegetation, soil), wetness conditions and climatic regimes. The interaction between those factors possibly explains the variety of results found in the literature. While no generalizations can be made on the issue, each study has contributed towards the understanding of those complex interactions. In line with this concept, the study presented in this paper attempts to investigate and explain the sensitivity of flash flood generation to rainfall variability and initial wetness in a specific topographic setting. The study is focused on a major flash flood event that occurred on the upper Tagliamento river basin, in the eastern Italian Alps, which is characterized by complex terrain, high soil moisture capacity and a flashy flow regime (Borga et al., 2007). The influence of rainfall representation

on modeling the flash flood response is important due to the high spatiotemporal variability that characterizes the storms that induce these events (Creutin and Borga, 2003). Regarding the effect of initial soil moisture conditions, it is generally recognized that the role of antecedent wetness should decrease with increasing return interval (Wood et al., 1990). An open question is where 'large' begins. Indeed, some studies have reported significant impact of antecedent wetness conditions even for extreme floods (Borga et al., 2007; Marchi et al., 2010). Furthermore, Castillo et al. (2003) have shown that runoff sensitivity to soil moisture conditions is closely related to the dominant runoff generation mechanisms. For example, arid basins having infiltration-excess as the dominant runoff mechanism are expected to show much lower sensitivity than basins where subsurface mechanisms dominate.

The research objectives addressed in this paper include assessing: (i) the sensitivity of runoff generation to rainfall and initial wetness as a function of basin scale and (ii) the interdependencies of those sensitivities. This investigation has both practical and scientific merit because it allows us to identify the significance of each variable in flash flood modeling applications and to understand the complex interactions between rainfall and antecedent wetness. Section 2 describes the study area and data used and provides a short description of the flash flood case examined based on the available observations. The outline of the distributed hydrologic model as well as the setup, calibration and validation procedure is provided in Section 3. The sensitivity results to initial soil moisture conditions and rainfall variability are presented in Sections 4–6 and the main conclusions of this study are summarized in Section 7.

2. Study area and data

The basin considered in this study is the Fella basin located within the Friuli-Venezia Giulia region, northeastern Italy (Fig. 1). Fella basin is a major left-hand tributary of the Tagliamento River with an area of approximately 623 km², a mean altitude of 1140 m above sea level and an average annual precipitation of 1920 mm (Borga et al., 2007). Important sub-basins also analyzed in this

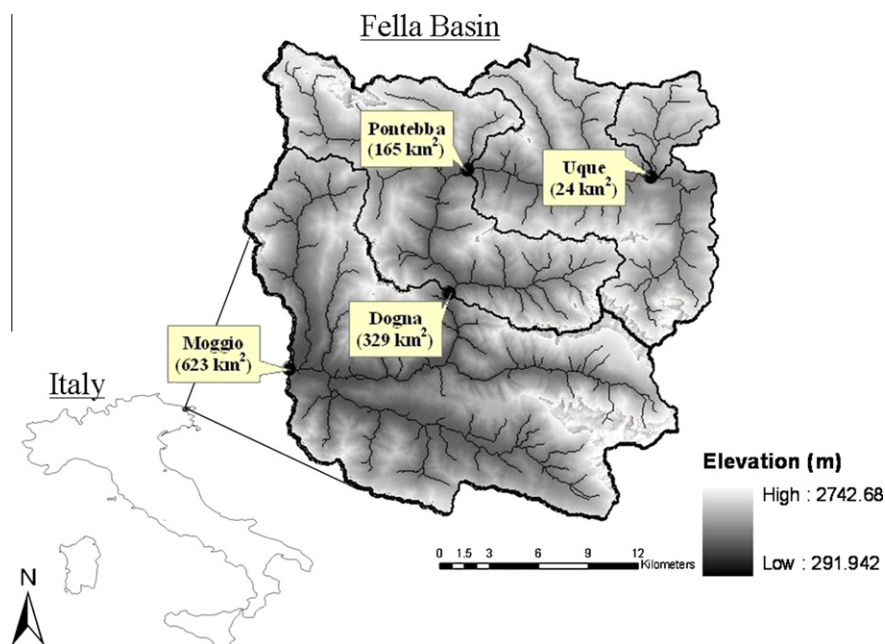


Fig. 1. Location map of the Fella river basin. The topographic representation is based on 20-m digital elevation model. Black dots mark the outlets of the basins examined in this study.

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