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Floods in mountain environments: A synthesis

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ABSTRACT

Floods are a crucial agent of geomorphic change in the channels and valley floors of mountains watercourses. At the same time, they can be highly damaging to property, infrastructure, and life. Because of their high energy, mountain watercourses are highly vulnerable to environmental changes affecting their catchments and channels. Many factors have modified and frequently still tend to modify the environmental conditions in mountain areas, with impacts on geomorphic processes and the frequency, magnitude, and timing of floods in mountain watercourses. The ongoing climate changes vary between regions but may affect floods in mountain areas in many ways. In many mountain regions of Europe, widespread afforestation took place over the twentieth century, considerably increasing the amounts of large wood delivered to the channels and the likelihood of jamming bridges. At the same time, deforestation continues in other mountain areas, accelerating runoff and amplifying the magnitude and frequency of floods in foreland areas. In many countries, in-channel gravel mining has been a common practice during recent decades; the resultant deficit of bed material in the affected channels may suddenly manifest during flood events, resulting in the failure of scoured bridges or catastrophic channel widening. During the past century many rivers in mountain and foreland areas incised deeply; the resultant loss of floodplain water storage has decreased attenuation of flood waves, hence increasing flood hazard to downstream river reaches. On the other hand, a large amount of recent river restoration activities worldwide may provide examples of beneficial changes to flood risk, attained as a result of increased channel storage or reestablished floodplain water storage. Relations between geomorphic processes and floods operate in both directions, which means that changes in flood probability or the character of floods (e.g., increased wood load) may significantly modify the morphology of mountain rivers, but morphological changes of rivers can also affect hydrological properties of floods and the associated risk for societies. This paper provides a review of research in the field of floods in mountain environments and puts the papers of this special issue dedicated to the same topic into context. It also provides insight into innovative studies, methods, or emerging aspects of the relations between environmental changes, geomorphic processes, and the occurrence of floods in mountain rivers.

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1. Introduction

Mountain environments cover roughly 25% of the land surface and are often referred to as 'natural water reservoirs' as a substantial amount of water surplus is usually transported from mountain areas to adjacent lowlands in some of the largest river systems on Earth (Viviroli et al., 2003). Mountain regions cover 52% of Asia, 36% of North America, 25% of Europe, 22% of South America, 17% of Australia, and 3% of Africa, as well as substantial areas of islands including Japan, New Guinea, and New Zealand (Bridges, 1990). Mountain rivers are defined here as having a mean elevation above sea level ≥1000 m (Viviroli et al., 2003). Despite the fact of being widespread, mountain rivers and river floods have not been studied in detail in the past and have only seen increased attention over the past decade (Wohl, 2010). Increased attention has been directed to maintenance or restoration of rivers and as critical areas of water supply in mountain environments, where human pressure typically is smaller than in the adjacent lowlands. In addition, steep and coarse-grained mountain rivers with poorly sorted beds and limited sediment supply are more poorly described by empirical equations for hydraulics and sediment dynamics, which renders them an ideal field for research and a challenge for river managers.

The hydrological response of mountain river catchments is driven by many factors including temperature, precipitation, soil, lithology, vegetation or slope, just to name a few. Floods in mountain rivers will be favoured by the typically steep channel gradients and can be generated by various types of rainfall, rain-on-snow, snowmelt, or the failure of either natural or artificial dams (Weingartner et al., 2003). As a result, floods in mountain rivers often differ from those in lowland environments because of the close coupling between the channel and adjacent hillslopes (Wohl, 2010).

This contribution does not aim at providing a complete review of literature on floods in mountain rivers and their histories, drivers, and changes but merely tries to summarize some of the key issues in the research field and to put the contributions of the special issue *Floods in Mountain Environments* into perspective. Most of the contributions of this chapter have in fact been presented during the International Geographical Union (IGU) Regional Conference in Kraków, Poland, between August 18 and 22, 2014 (www.geo.uj.edu.pl/konferencja/igu2014/).

2. Channel incision processes in mountain streams

In the last century a tendency to channel incision appeared so common worldwide that causes, controls, course, and effects of the phenomenon became a focus of international scientific debate (Darby and Simon, 1999); and incised rivers are now considered to represent typical *Anthropocene* landscapes (Florsheim et al., 2013). While bed degradation of alluvial rivers induced by tectonic uplift or climate change has mostly initiated the formation of new valley floors at lower positions, contemporary incised rivers are the effect of human-induced rapid rates of bed degradation usually coupled with constraints on lateral river migration. Opposite evolutionary tendencies of European mountain rivers in the eighteenth–nineteenth centuries and in the twentieth century (Kondolf et al., 2002; Rinaldi et al., 2013) indicate that floods are only a mechanism entraining and transporting bed material in incising rivers, whereas river incision itself has been caused by the lack of equilibrium between a river's transport capacity and the amount of sediment available for fluvial transport (Simon and Rinaldi, 2006). Sometimes incision can be ascribed to a single type of disturbance or environmental change such as channel regulation (Simon, 1989), catchment reforestation (Liébault and Piégay, 2001), or cessation of in-channel deposition of mine tailings (James, 1991). However, more frequent are situations when the tendency has resulted from a complex interplay of factors that either restricted availability of bed material for fluvial transport or increased transport capacity of the river (e.g., Bravard et al., 1997; Surian and Rinaldi, 2003; Wyżga, 2008).

Channel incision decreases local frequencies of overbank flows and—as a result of increased channel conveyance—affects downstream flow patterns. By comparing peak discharges of flood flows recorded upstream and downstream of incising reaches of two rivers in the Polish Carpathians, Wyżga (1997) demonstrated high temporal consistency of changes in vertical channel position of the analysed rivers and of the increase in flood peaks recorded downstream. This increase in flood hazard to downstream river reaches was attributed to increased concentration of flood flows in the deepened channel that reduced floodplain storage of floodwater and increased relative smoothness (ratio of water depth to the height of protrusion of bed-material particles to the flow) of channel flows, hence accelerating the passage of flood waves (Wyżga, 1996). Costa and de Almeida Prado Bacellar (2007) found that gullying of catchments in southeastern Brazil results in decreased base flow and increased occurrence of high but short-lasting storm flows and explained the change in flow pattern by increased rates of regolith drainage after rainfall events.

Wyżga et al. (2016–in this issue) consider impacts of channel incision on the hydraulics of flood flows using examples from Polish Carpathian rivers. They first indicate that in the literature, channel deepening is frequently ascribed to channel incision; but it may also result from river metamorphosis changing a wide and shallow channel to a narrow and deep one. In contrast to channel incision, this process does not lead to increased channel capacity; consequently, a lowering of water stage associated with a given discharge rather than a lowering of river bed should be used as a diagnostic feature of channel incision. The authors next discuss suitability of a lowering of minimum annual stage at gauging stations as a metric used to assess the hydraulic importance of channel incision and to compare it along a given river or within a particular region. In Polish Carpathian rivers, absolute amounts of incision are greater in the middle and lower courses. However, the relative increase in channel conveyance resulting from incision is greatest in their upper courses, where the initial channel capacity was relatively low. As the loss of floodplain storage of floodwater caused by channel incision tends to be largest in upper river courses, this is where special efforts should be made to arrest, limit, or prevent river incision. Finally, the authors demonstrate that hydraulic effects of channel incision depend on lateral stability of an incising river. Where the incising rivers remained laterally stable, incision has mostly reduced water stages associated with low flood discharges and considerably decreased flow velocities over the floodplains. In contrast, the formation of incised meander belts caused by lateral migration of incising rivers has substantially lowered stages for all flood discharges and increased flow velocities over the newly formed, low-lying floodplains.

3. Riparian forest development and increased wood delivery to watercourses

Mountain and piedmont areas in Europe experienced remarkable expansion of riparian forest cover over the last century (e.g., Kondolf et al., 2007; Wyżga et al., 2012). One of the effects of riparian forest development was the intensification of large wood recruitment and increased flood hazard resulting from wood transport and deposition during flood events. This is reflected in increased frequency of clogging by wood in critical river sections such as those with bridges (e.g., Ruiz-Villanueva et al., 2013; Lucía et al., 2015). Effective prevention of flood hazard related to large wood in mountain watercourses may require structures that trap wood from floodwaters (Comiti et al., 2012), but better recognizing wood dynamics during floods is crucial. Research of wood dynamics in mountain watercourses is thus an important element of projects aimed to improve the recognition of flood hazard and risk in mountain areas (Kundzewicz et al., 2014).

Use of innovative techniques of the monitoring of large wood recruitment, transport, and deposition during flood events improved insight into the wood dynamics in watercourses. MacVicar et al. (2009) indicated a possibility of recording the transfer of large wood pieces