Geomorphology 272 (2016) 55–67

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Impact of a large flood on mountain river habitats, channel morphology, and valley infrastructure

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form 3 September 2015
Accepted 7 September 2015
Available online 12 September 2015

Keywords:
Mountain river
Physical habitat conditions
Channel morphology
Flood damages

ABSTRACT

The Biała River, Polish Carpathians, was considerably modified by channelization and channel incision in the twentieth century. To restore the Biała, establishing an erodible corridor was proposed in two river sections located in its mountain and foothill course. In these sections, longer, unmanaged channel reaches alternate with short, channelized reaches; and channel narrowing and incision increases in the downstream direction. In June 2010 an 80-year flood occurred on the river; and this study aims at determining its effects on physical habitat conditions for river biota, channel morphology, and valley-floor infrastructure. Surveys of 10 pairs of closely located, unmanaged and channelized cross sections, performed in 2009 and in the late summer 2010, allowed us to assess the flood-induced changes to physical habitat conditions. A comparison of channel planforms determined before (2009) and after (2012) the flood provided information on the degree of channel widening as well as changes in the width of particular elements of the river's active zone in eight stretches of the Biała. The impact of the flood on valley-floor infrastructure was confronted with the degree of river widening in unmanaged and channelized river reaches. Before the flood, unmanaged cross sections were typified by finer bed material and greater lateral variability in depth-averaged and near-bed flow velocity than channelized cross sections. The flood tended to equalize habitat conditions in both types of river cross sections, obliterating differences (in particular physical habitat parameters) between channelized and unmanaged channel reaches. River widening mostly reflected an increase in the area of channel bars, whereas the widening of low-flow channels was less pronounced. A comparison of channel planform from 2009 and 2012 indicated that intense channel incision typical of downstream sections limited river widening by the flood. Active channel width increased by half in the unmanaged cross sections and by one-third in the channelized cross sections. However, damage to the valley-floor infrastructure was practically limited to the channelized river reaches with reinforced channel banks. This indicates incompetent management of riparian areas rather than the degree of river widening as a principal reason for the economic losses during the flood.

1. Introduction

Literature on floods in mountain watercourses abounds in information concerning geomorphic effects of the floods and hazards associated with these events (Wohl, 2010, 2011, and papers cited therein). During the past century mountain streams and rivers in densely populated areas were considerably modified by human activities, such as extensive channel regulation, in-channel sediment mining, and the construction of dams and weirs (Bravard and Petts, 1996; Wohl, 2006; Comiti, 2012). Recognition of the adverse effects of these impacts on channel stability of the rivers and the condition of their ecosystems has stimulated a large amount of river restoration activities worldwide (e.g., Hillman and Brierley, 2005; Habersack and Piégay, 2008; Rinaldi et al., 2013). The identification of the geomorphic, ecological, and economic effects of floods on rivers undergoing restoration and their comparison with changes in the nearby reaches where human constraints are maintained are still lacking because of the recent nature of restoration activities.

As a result of large-scale anomalies in the oceanic–atmospheric interaction, such as the North Atlantic Oscillation, increased flooding may occur at the scale of catchments (Foulds et al., 2014) or large regions (Pociask-Karteczka, 2006). Such was the situation in 2010 when large floods occurred at various times during the warm half-year over vast areas of central Europe (Lóczy, 2013), including catchments in the Western Carpathians where they resulted in considerable flood damage and channel adjustments (Frandorfer and Lehotský, 2011; Gorczyca et al., 2013). In the Polish Carpathians, the Biała was among the rivers with the most extreme flood incidence in 2010. Interestingly, in the late 2000s an erodible corridor was

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http://dx.doi.org/10.1016/j.geomorph.2015.09.003
0169-555X/

established in mountain and foothill sections of this river. This restoration measure consists in allowing free channel development in a delimited portion of the valley floor to reestablish a natural course of fluvial processes (e.g., Piégay et al., 1996; Nieznański et al., 2008). This circumstance thus provided an opportunity to study the effects of the extreme flood of 2010 in the unmanaged reaches of the Biała and to compare them with those recorded in the adjacent channelized reaches.

The importance of flooding in maintaining the function and integrity of aquatic ecosystems has long been recognised (Wydoski and Wick, 2011). According to the Flood Pulse Concept (Junk et al., 1989), seasonal or regularly recurring flooding is considered a driving force in a river–floodplain system, allowing lateral exchange of water, nutrients, and organisms between river channel and the connected floodplain. Extreme flood events are generally considered to periodically pose a threat on aquatic ecosystems (Wydoski and Wick, 2011). However, the unpredictable nature of such events is a cause for very few studies comparing post-flood condition of riverine biocoenoses with that recorded shortly before the flood. A study on benthic invertebrates in the Alpine river Isar indicated no significant changes resulting from an extreme flood (Hering et al., 2004), but the reliability of this finding was reduced by the fact that the initial survey had been performed a few years before the flood. Studies on various river reaches (from mountain to lowland) indicated relatively minor effects of extreme floods on fish fauna, with the greatest decline in abundance recorded among young-of-the-year individuals (Bischoff and Wolter, 2001; Lojkasek et al., 2005; Jurajda et al., 2006) and the individuals of eurytopic (Bischoff and Wolter, 2001) or pelagic and benthic species (Jurajda et al., 2006). Washing down of fish individuals, especially juveniles, by floodwaters (Bischoff and Wolter, 2001; Lojkasek et al., 2005) and fish mortality caused by retreat from the floodplain of water with very low concentration of dissolved oxygen (Lusk et al., 2004) were indicated as the reasons for adverse changes among fish communities. While these effects are transient and reflect direct action of floodwaters on fishes, only the study by Bischoff and Wolter (2001) considered flood-related changes in physical habitat structure with more prolonged effects on fish fauna and found that some species benefited from increased habitat heterogeneity after the flood.

Flood damage and flood losses are intrinsic to the occurrence of major floods (Merritts, 2011). Economic losses resulting from major flood events have increased during recent decades at various spatial scales, from local to global scale (Kundzewicz et al., 2013). In Poland material damage caused by the flood of 2010 equalled 1% of gross national product of the country (Kundzewicz et al., 2012), and a considerable proportion of the damage occurred in the valleys of Carpathian tributaries to the Vistula River (Biedroń et al., 2011) where floods typically have high energy and are thus highly erosive (Kundzewicz et al., 2014). Accelerated water runoff from catchments caused by urbanization and an increase in impervious surfaces (Hollis, 1975) and the loss of floodwater storage in floodplain areas resulting from river channelization and incision (Wyżga, 1997, 2001b) or flood embankment construction are frequently invoked to explain the high economic losses caused by major flood events. However, these factors do not apply to the sections of the Biała River considered in this study. During the last few decades the mountain part of the Biała catchment exhibited a marked increase in forest cover (Kozak et al., 2007) and no significant urbanization occurred there. The studied sections of the river are not embanked and channelized reaches constitute not more than 15% of their total length; channel incision apparent on a proportion of the sections length reduces floodwater storage in the floodplain areas (Czech et al., 2016-in this issue), but the resultant increase in the magnitude of flood flows must affect downstream river sections rather than the incised sections themselves. It is thus interesting to consider factors that determined the amount and spatial pattern of the economic losses caused by the extreme flood of 2010 in the studied sections of the Biała.

Using the example of the Biała, this study analyses hydromorphological, geomorphic, and economic effects of the extreme flood on a mountain river subjected to restoration. In particular, it aims to answer the following questions:

- How did the flood affect physical habitat conditions for riverine biota in the unmanaged, freely developing river reaches and the neighbouring channelized reaches?
- What was the effect of the alternation of the unmanaged and the channelized reaches and the differing degree of channel incision along the Biała on the spatial pattern of the changes in planform river geometry caused by the flood?
- What was the principal reason for the economic losses caused by the flood in the river valley?

2. Study area and the flood of June 2010

The gravel-bed Biała River drains a catchment with an area of 983 km^2 in the Polish Carpathians (Fig. 1). In its upper course, this 102-km-long river flows through the low mountains of Beskid Niski where it is fed with coarse and medium-sized sandstone material. As only shallow, slope aquifers occur in this part of the catchment, here the river is typified by very high flow variability; at the Grybów gauging station with a 50-year-long record period (Fig. 1B), the coefficient of runoff irregularity (ratio of the highest and the lowest flow on record) equals 7500. The high flow variability and the delivery of coarse bed material explain that in unmanaged channel reaches the river forms a wide, multithread channel. In the middle course within the Ciężkowice foothills, the Biała runs across alternating sandstone and shale complexes that supply the river with cobble to pebble material and large volumes of fines. Fed with such material, the Biała maintains a gravel bed, but tends to form a sinuous channel in its unmanaged reaches.

In the lower part of its mountain course and along the foothill course, the Biała incised by up to 2 m and its channel was considerably narrowed (up to a sixth of the original value) in the second half of the twentieth century. River training works (Wyżga, 2001a, 2008) and uncontrolled, widespread in-channel gravel mining (Rinaldi et al., 2005; Wyżga et al., 2010) were the main causes of these channel changes, although a reduction in catchment sediment supply (Lach and Wyżga, 2002) following a considerable increase in forest cover in the mountains in the second half of the century (Kozak et al., 2007) might have intensified the scale of the channel adjustments.

Several studies have demonstrated that channelization and incision of Polish Carpathian rivers bring about a range of adverse effects, such as a reduction in floodplain inundation at given flood discharges (Wyżga, 2001b; Czech et al., 2016-in this issue) and the resultant increase in flood hazard to downstream river reaches (Wyżga, 1997, 2008) or the degradation of physical habitat integrity (Wyżga et al., 2009) and the ecological state of the rivers (Wyżga et al., 2013). An erodible river corridor was thus delimited in the mountain and foothills sections of the Biała (14.5 and 5.9 km in length, respectively) (Fig. 1) in order to mitigate the adverse effects of the channel changes and improve hydromorphological quality of the river. Because the delimited streamway has to encompass the existing infrastructure, both sections of the corridor consist of alternating longer (1–3 km) unmanaged reaches and shorter (0.1–0.3 km) channelized reaches in the vicinity of bridges.

Annual precipitation in the catchment ranges from about 950 mm in its highest parts to 650–700 mm in the lowest parts (Niedźwiedź and Obrębska-Starklowa, 1991), and the respective values of the coefficient of runoff vary from 50% to <30% (Dynowska, 1991). At the Grybów gauging station located just downstream of the mountain river course, (catchment area of 210 km^2; Fig. 1B), mean annual discharge amounts to 2.9 $m^3\ s^{-1}$ and the average for the maximum annual discharges to 108 $m^3\ s^{-1}$. Frequent, moderate floods caused by snowmelt typically