Chapter 2
Channel Changes due to Extreme Rainfalls in the Polish Carpathians

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Abstract This chapter describes a role of extreme rainfall events in the development and transformation of channels in the Polish Carpathians. An analysis was based on the example of four selected events, which occurred in different parts of Polish Carpathians (Western Tatra, Bieszczady, and Beskid Niski Mountains) during the period 2003–2010. The findings underline that changes of the largest extent follow short and heavy rainfalls. Furthermore, their geomorphic impacts are the most significant in small watersheds. The research showed that the largest transformations of mountain rivers occur in the main channel, while the floodplain is only locally altered. The regularities identified in the study areas are relevant for mountain river channels in forested terrains, where a large supply of woody debris, for example, stems and branches, is ensured.

Keywords Extreme rainfall • Flash flood • Catastrophic events • Channel erosion • Sediment transport • Woody debris • Polish Carpathians

2.1 Introduction

Extreme weather events are undoubtedly the prime driving force behind landform change. They set in motion powerful processes that upset the equilibrium of natural systems such as river channels (Thornes and Brunsden 1978). The three basic types of these extreme events include short but very intense precipitation, heavy long-term precipitation, and rapid snowmelt. They tend to occur infrequently on the long

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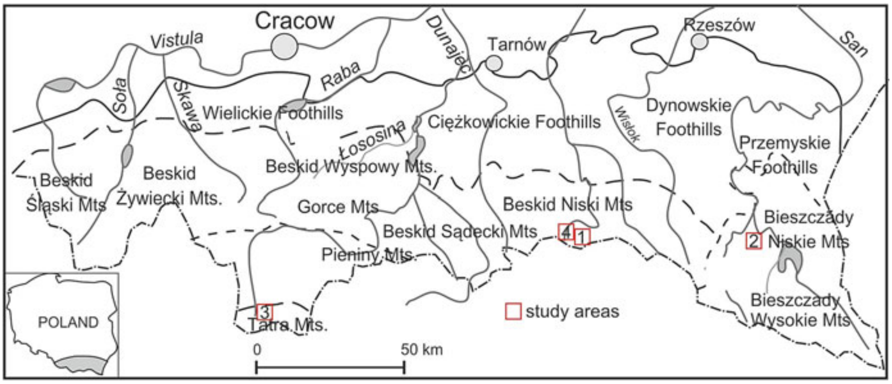

Fig. 2.1 Study areas: *1*, Wisznia basin; *2*, Hoczewka River basin; *3*, Western Tatras; *4*, Upper Wisłoka basin

term but are often clustered with short intervals between them (days, months, or years) (Starkel and Sarkar 2002). The intervals are too short for the system affected to recover after the previous event, and it arrives at a new equilibrium.

During the period 2003–2010, the slopes and valleys of the Carpathian Mountains underwent considerable transformations following intense precipitation and rapid thawing (Gorczyca 2004, 2008; Izmaiłow et al. 2006; Cebulak et al. 2008; Gorczyca and Krzemień 2008; Gorczyca and Wrońska-Wałach 2008; Starkel 2008, 2011; Święchowicz 2008; Kijowska 2011). The areas affected are located in the Beskid Niski, the Bieszczady, and the Western Tatra Mountains (Fig. 2.1).

2.2 Methods

The study involved two main types of fieldwork: (1) geomorphological *mapping* of stream and river *channels* and (2) detailed *land surveying*. Landforms developed during preceding events were identified, and the minimum/maximum grain size of the material transported was measured. Longitudinal and cross sections of selected valleys were also analyzed.

Channels were mapped using a special manual and a set of templates (Kamykowska et al. 1999). Survey maps of the channels and the sets of landforms identified in each of them were used to break down the channels into basic reaches, which were then described. Qualitative and quantitative features were identified, as well as erosion and accumulation – type forms, ruble, and training. Certain areas, for example, the Wisłoka River basin, were mapped both before and after the extreme events.

2.3 Floods and Their Effects

2.3.1 The Wilsznia Basin

A catastrophic flood struck parts of the Wilsznia River basin in the Beskid Niski Mountains range on 18 July 2003. It was triggered by a *downpour* roughly restricted to the river basin itself. Records from a pluviograph at Krosno show that the bulk of the rain fell between 8:00 and 9:00 p.m. (Izmaiłow et al. 2006). Data from precipitation stations located in the area suggest that the largest total daily rainfall was recorded in the upper sections of the basin (88.0 mm at Wisłok Wielki and 98.7 mm at Orzechówka). According to interviews with the local population, the rainfall began around 7:00 p.m. and continued until 10:30 p.m. but was most intense between 8:00 and 9:00 p.m. According to some assessments, more than 100 mm of rain fell in the study area over the course of 1.5 h. An analysis of floodmarks on the rivers and stream suggests that the water levels on the Wilsznia River reached 4 m. The effects in the river valley were devastating. A bridge at Polany was destroyed, and the river current returning through a side channel knocked a car carrying five people off the road. All five perished in the water.

Stream channels in the Wilsznia basin are typical of the Beskid Niski Mountains, as they run through *alternating narrow and broad valley sections*, depending on the underlying geology. In the broader sections, streams converge, which can generate a high flood wave after intensive downpours. The channels, mostly meandering in character, run either askew or parallel to strata with only short reaches perpendicular to the geology. The channels have uneven longitudinal profiles. Bank height normally ranges from 0.5 to 1.5 m, but increases to 3–5 m, and at undercut banks exceptionally up to 20 m.

The mapping resulted in the identification of 17 discrete *reach*es broken down into five *types*. These included (1) straight rocky channels with a tendency to intensive downcutting, (2) rocky and alluvial meandering channels with a tendency to downcutting and local accumulation, (3) rocky and alluvial channels with a tendency to lateral erosion and intensive local accumulation, (4) alluvial channels with small slope and a tendency to intensive accumulation and local lateral erosion, and (5) alluvial channels with a tendency to intensive accumulation.

As a result of the event, the Wilsznia channel changed considerably, especially in reaches nos. 9–11 (Fig. 2.2). There are three reasons for this pattern: (1) the upper section of the basin was where the rainfall was heaviest, (2) this was also where three large streams came together, and (3) the largest amount of large woody debris (logs and branches) carried along these reaches caused channel clogging and avulsion in the valley bottom. Similar patterns emerged from studies of catastrophic floods along other Carpathian rivers and streams (Kaczka 1999; Wyżga et al. 2002–2003).

Despite the scale of change caused by the flood, the channel reach structure remained largely unchanged. Changes that did occur included the *number of landforms*, which decreased in the upper-course reaches and either decreased or slightly increased in the lower reaches (Fig. 2.2). Along most of the narrow reaches,

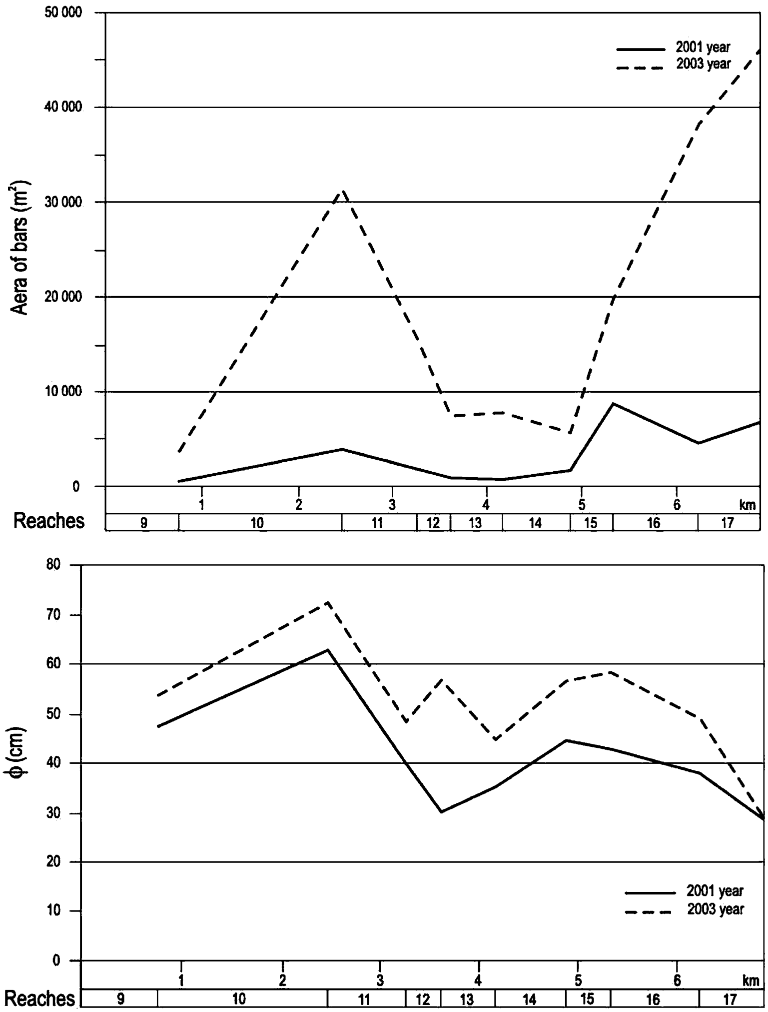

Fig. 2.2 Surface area of channel bars in the Wilsznia channel: (**a**) before and after the flood; (**b**) maximum grain size in the channel long profile (after Izmaiłow et al. 2006)

the number of landforms dropped, but their surface area increased. Indeed, there was a considerable increase in the surface area of mid-channel bars and erosional undercuts along the entire stream channel (Fig. 2.2). The large number of new *rock steps* (knickpoints) suggests an overall increase in downcutting, especially in the middle and lower courses of the stream. The appearance of new rock steps suggests that the alluvial cover is relatively thin even in braiding reaches, as is typical of Carpathian streams and rivers in general (Krzemień 1976, 2003; Wyżga 1992).

During the study period, the maximum *grain size* of sediment in the Wilsznia channel was found to have increased along its entire length (Fig. 2.2). This was due to higher stream power during the catastrophic flood, when large rocks were carved out of the channel bottom. Now these boulders are either scattered along the channel or form larger clusters, where imbricated specimens can be up to 1 m in size.

The most extensive incision was observed downstream from sites where rubble and woody debris blocked the streams, causing a sudden rise in stream power. Downcutting and lateral erosion were also generated by the accumulation of organic matter and bedload or found at sites of channel avulsion.

Following the extreme event, downcutting and lateral erosion continued along the bedrock reaches of the Wilsznia channel. Increased channel migration was found along the alluvial reaches with instances of avulsion due to channel blocking with large woody debris.

2.3.2 The Hoczewka River Basin

On 26 July 2005 an extreme rainfall event occurred in the Hoczewka River basin and around the Solina Reservoir. A single *thunderstorm* with an intensity of 0.9 mm min^{-1} produced 130.6 mm of rain within 2 h, as measured at the Baligród-Mchawa station. The downpour triggered gravitational processes on slopes and contributed to the formation of torrential flows within mountain stream channels as well as a high flood wave. An analysis of the evidence left by the high water has revealed that the culminations of flood waves were the highest on the streams of Cisowiec (ca 4 m) and Mchawka (ca 3.5 m). An analysis of channel geometry, the size of riverbed features, and maximum grain size of the sediment deposited in them suggests that the water levels were rising rapidly and the event was rather violent.

In the Cisowiec valley, erosion was not limited to the channel, but extended over to the valley floor. In terms of key processes, the Cisowiec channel can be divided into two reaches: the clearly *erosional upper reach* and the mixed erosional-depositional reach below (Fig. 2.3). In the former, *downcutting* alternated with lateral erosion, producing sizable erosion chutes, steps, potholes, side channels, scoured bedrock floors, and undercuts of various sizes. Channel resistance to erosion depended to a large extent on the *underlying geology* and especially on the relationship between channel direction, the tilt of rock strata, and on the cohesion of mineral material. In reaches aligned with the rock beds, large erosion chutes developed. The alluvia were swept clean and the channel bottom consisted of uneven bedrock with isolated boulders greater than 0.5 m in size. Wherever the channel crossed sediment beds, erosion produced steps with evorsion potholes below (0.8 m deep). The channel incised 1.5–2 m, as evidenced by the hanging position of a tributary confluence at ca 2.5 m.

Along the *lower reach* of Cisowiec stream, *erosion alternated with deposition*. Erosion was not confined to the channel itself, but reached existing dirt roads running parallel with the channel. Characteristic of the Cisowiec valley is the *channel walls* consisting of rough material on terraces. This might suggest a very dynamic transport resembling debris flow at some locations.

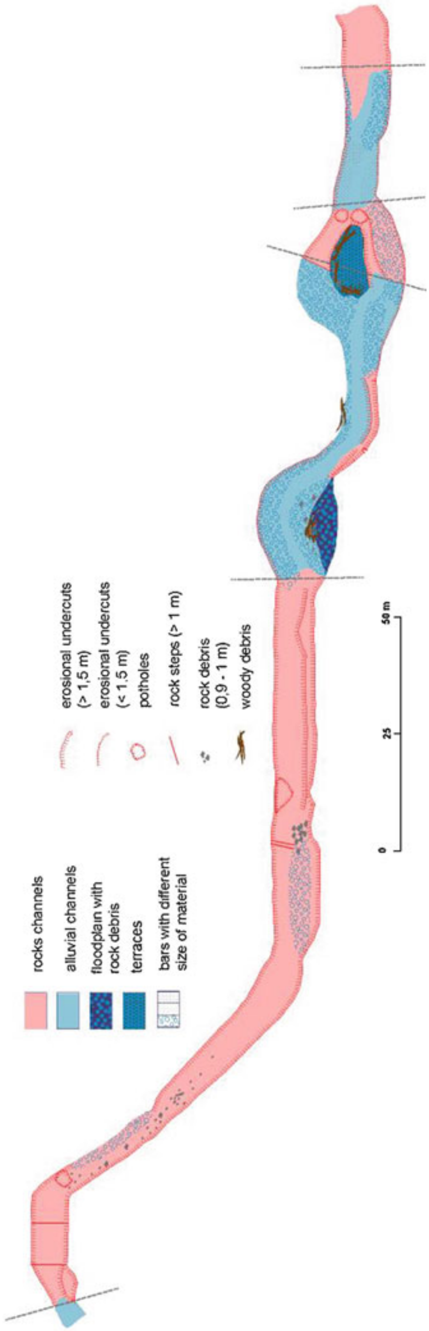

Fig. 2.3 Morphodynamic reaches in the middle course of Cisowiec stream in the Bieszczady (modified after Gorczyca and Wrońska-Wałach 2008)

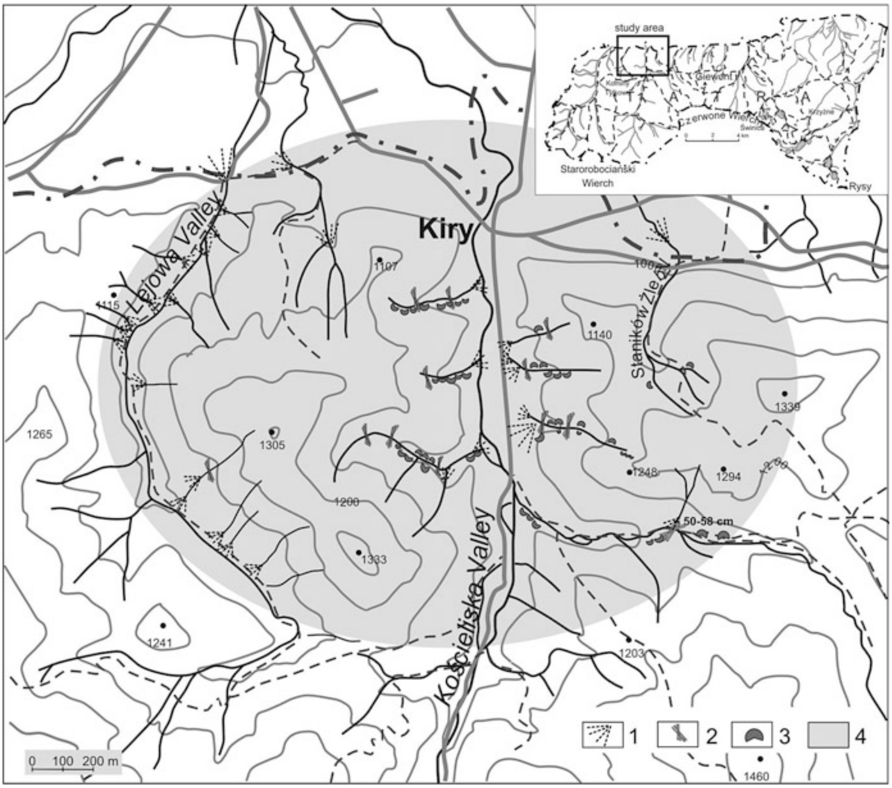

Fig. 2.4 Geomorphological effects of catastrophic rainfall on 5 June 2007 in the Western Tatra Mountains (After Gorczyca and Krzemień 2008); 1 – torrential fan, 2 – woody-debris-dam, 3 – landslide, 4 – area of geomorphological impact of catastrophic rainfall

Large woody debris and stream training were considerable factors during the flood. Perhaps the greatest role, however, was played by the flood wave and destruction of two *fishponds* on one of the tributaries of the Cisowiec. An estimated 3,800 m^3 of water from the ponds would have greatly increased the flood wave, which was indeed found to have reached a level of 3.5–4 m downstream of the ponds. Bridges and road culverts along the stream narrowed down the flow path and were soon clogged with organic debris. The swelling stream rushed over roads, destroying them, while adjacent channel reaches were also considerably transformed.

2.3.3 Mountain Watersheds in the Western Tatras

An extreme rainfall event in June of 2007 affected the montane zone of the Western Tatra Mountains, including the Kościeliska, Lejowa, and Stanikow Żleb Valleys (Fig. 2.4). This middle mountain area is mainly built up of limestones, dolomites, and marls of Triassic, Jurassic, and Cretaceous age and *Eugenia* limestone, shales, and conglomerates (Bac-Moszaszwili et al. 1979). The event caused major changes primarily in young river valleys, ravines, and V-shaped valleys with narrow floors and uneven longitudinal profiles. The valleys tend to widen on outcrops of softer rocks and narrow down across more resistant limestone and dolomite zones (Klimaszewski 1988). During the Pleistocene and Holocene, periodic water flows transported debris and created *torrential fans* in the main river valleys.

The catastrophic downpour occurred on 5 June 2007, when daily precipitation was 104.2 mm. Much of that amount fell during a thunderstorm that produced 74.1 mm of rain between 2:00 and 5:00 p.m., but its peak intensity of 1 mm min^{-1} lasted for only 1 h (14:30–15:30), totalling 61 mm.

During fieldwork we discovered considerable changes on montane-zone valley floors and accumulation fans. A general *pattern of erosion* emerged in all of the 30.44 km of valleys mapped. In their longitudinal profiles, there were four main types of reaches: the uppermost reaches (*A*) were the least affected (Fig. 2.5), only by the transport of boulders up to 20 cm in size. Channels downstream (*B*) were incised and bed load transported with some deposition of organic and mineral material. There was also a set sequence of *bottom features*: rock and debris steps, erosion chute, and a long stretch of incised bedrock floor. The downstream reaches (*C*) were similar to the *B* reaches, but the valley slopes also showed traces of mass movements (Fig. 2.5). Saturated with water, the thin waste mantle could not hold trees, which were uprooted and fell into the channel. The trunks clogged the streams and caused debris to accumulate, while there were some local accumulation upstream steps in the long section. At the valley mouths, torrential fans, made up primarily of rock boulders with some large woody debris, were either accumulated or cut through (*D*) (Fig. 2.5). An analysis of excavations in the cuts shows their complex structure with alternating layers of fine loam depositions and sandrock beds of 15–30 cm size. This points to two kinds of fan accumulation: medium-power events contributed the deposition of loamy material, while extreme events deposited the coarse fraction.

The size of *bed load transported* within the channels during the event reached 80 cm within the channels and ca 50 cm across the fans. This is much above the sizes identified after the most intense rainfall to date, on 1 July 1973 (Kaszowski and Kotarba 1985).

Perhaps this type of extreme event is more frequent in the history of middle mountains than has been thought before. The considerable rate of changes identified in the montane zone of the Tatras confirms earlier suggestions that local downpours played a significant part in local geomorphic evolution (Jakubowski 1974; Starkel 1996; Gorczyca 2004).

2.3.4 The Upper Wisłoka Basin

In May and June 2010, two floods occurred in the upper Wisłoka River basin as a consequence of continuous rainfall. On 17 May 2010, a flow of 96 $m^3 s^{-1}$ was recorded at the Krempna-Kotań gaging station. It was preceded by 79.6 mm rainfall

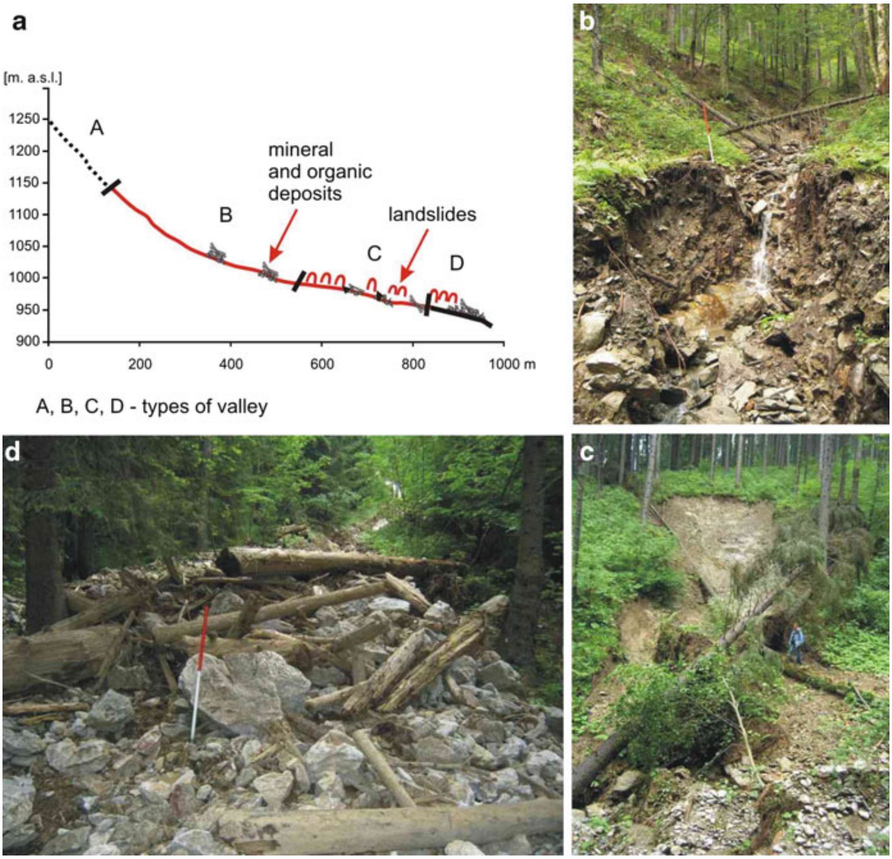

Fig. 2.5 Landform patterns in morphodynamic reaches of the valleys studied in the Western Tatra Mountains; (**a**) longitudinal profile of valley, (**b**) type B of valley, (**c**) type C of valley, (**d**) type D of valley

between 10 and 17 May (with a peak of 35.2 mm on 16 May), recorded at the Wyszowatka station. A second flood on 4 June 2010 had a flow of 85 $m^3\ s^{-1}$, preceded by a 126.6 mm rainfall between 30 May and 4 June (41.3 mm on 3 June). Between 2 May and 4 June, a cumulative rainfall of 303.3 mm was recorded.

The gravel-bed channel of the Wisłoka River runs through the Beskid Niski, a middle mountain range. Also here channel geometry is controlled by the underlying geology, which resulted in a particular *morphological pattern* of parallel ridges and valleys with water gaps across the ridges at almost right angles. This pattern, also found in the Wisłoka river, involves narrow gap segments with intensive erosion and a straight bedrock channel as well as broader segments (embayments) with intensive accumulation and a meandering alluvial channel.

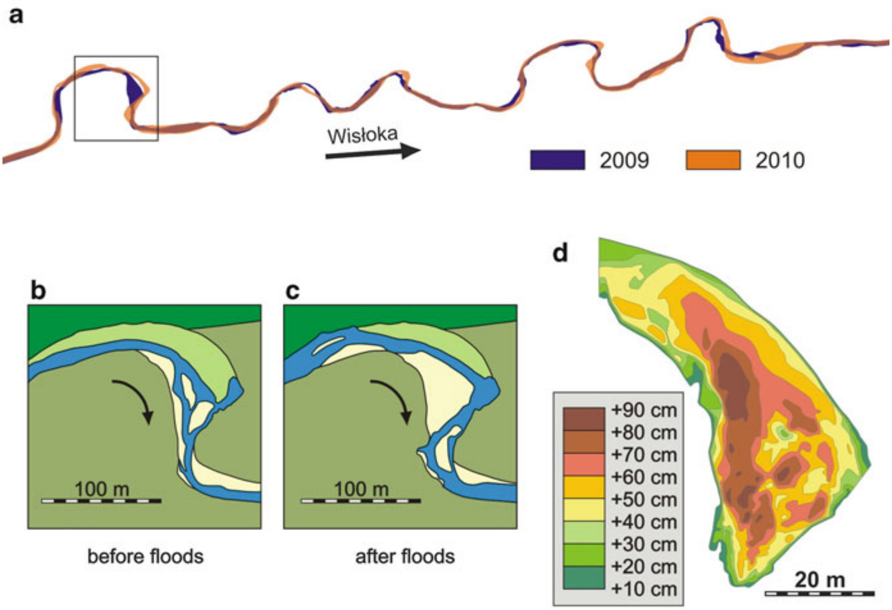

Fig. 2.6 Changes in the studied section of the Wisłoka River channel following floods in May and June 2010: (**a**) Wisłoka channel changes between Nieznajowa and Rozstajne, (**b**, **c**) changes of the undercut reach in Nieznajowa, (**d**) differential surface in the area of developed point bar

During the two floods, the largest scale of change was found in the *broader sections* of the valley. A two-kilometer reach of the river between two adjacent gap sections was selected for a more detailed analysis (Fig. 2.6). The segment involves a 200–400 m wide valley floor, out of which the channel and the lower terrace make up 200 m. Located within the Magura National Park, the meandering channel with braiding migrates freely, without human intervention, over the floodplain.

Analyzing *channel changes* on orthophoto maps from 2009 to 2010, we found that, as a result of the floods, the channel became broader and showed more developed meanders (Fig. 2.6a). Land surveys performed both prior to and following the events showed progressing lateral erosion of both the flood and dry terraces at the site of the undercut reach studied. Maximum channel shift was ca 20 m (Fig. 2.6b, c). This was accompanied by deposition, particularly on the inside of the bend, point bar accumulation providing new land available for the expansion of vegetation. A general overhaul of the pool and riffle pattern attests to a considerable modification of the channel.

The second land survey helped assess the change in bed load volume in the channel. The map shows a segment of the channel at Nieznajowa where a bar has expanded. Isolines connect points of equal vertical debris accumulation (Fig. 2.6d).

The irregularities in the distal section of the bar are a result of a high rate of change in this part of the channel. The deposition of large woody debris induces local scour and fill. Hanging channel reaches are found within the bar that developed during the descending of the flood wave in supercritical flow conditions. These features are shown as measured during the first and second surveys, and the differential surface reflects the complexity of factors driving the development of this channel system.

In general, during the two springtime floods, *bank undercutting* shaped the Wisłoka channel, particularly across its flood terrace, which resulted in a well-developed meandering channel pattern. Across the flood terrace, the flood destroyed some of the surfaces occupied primarily by pioneer vegetation, making way for large amounts of debris transported. Areas consolidated by older vegetation resisted any major change.

2.4 Conclusions

In a selected study area of the Carpathian Mountains, rainfall with catastrophic consequences is rare. An analysis of the catchments studied shows that disastrous rainfall occurs every 20–30 years on average. The pattern applies to both valley floors and on slopes. The extreme cases studied here suggest that the greatest degree of change follows *short but intensive storms* with a very limited spatial extension. Their geomorphic action is only significant in small watersheds with little impact on larger basins. An exception is when there is a clustering of events in a certain area leading to the triggering of geomorphic processes of extreme intensity.

Due to the considerable channel incision of the Carpathian rivers, a transformation of a mountain river channel system tends to be limited to a deep *chute cutting* into the terraced valley floor. Along bedrock reaches, catastrophic floods lead to local downcutting and lateral erosion. Fresh sediment is brought into the channel, which is clearly seen in the maximum fraction of bed load measured. Along alluvial reaches, there is a significant increase in *channel migration*. Cases of *avulsion* may follow the blocking of the channel with large woody debris or damaged built structures. In 2010 mountain streams were the most affected along their main channels, especially around sites clogged with logs. In general, the floodplain is affected locally by debris accumulation or erosional dissection, which typically happens when the main channel is blocked and the current is deflected onto the floodplain. The patterns identified at the study sites apply mainly to mountain river channels in areas with a high proportion of woodland, which ensures an ample supply of large woody debris.

The study of deposits indicates that *extreme events* occurred repeatedly during the Holocene, as evidenced by the alternating layers of fine and coarse sediments. For this reason, it is likely that such extreme events are *not at all exceptional* in the geomorphic evolution of mountains and their forelands.

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