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Morphodynamics of the River Łososina Channel after an extreme flood (Western Carpathian Mountains)

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In the Carpathian Mountains extreme events are infrequent, but have a powerful impact on the development of the local morphology. They trigger processes of a high morphological potential leading to a considerable transformation of natural systems, including channel or slope systems. Slope system responses tend to be delayed and limited to small portions of a slope. The channel typology was based on the reach boundary analysis method. Five channel types were identified in the Łososina channel: accumulation, lateral-erosion, downcutting, deposition and redeposition, transport. Additionally, six subtypes were defined: transport in reinforced channels, downcutting with minor lateral erosion and local accumulation; accumulation, lateral-erosion with the "backwater" effect, accumulation, transport, intensive downcutting.

The Łososina channel system has an erosion regime with local accumulation and lateral erosion. Downcutting landforms can be found along the entire channel length as confirmed by the existence of numerous rapids and kettle forms in the upper course and by the results of the minimum water level analysis in the lower course. Human activity, including that aiming to improve the safety of the local communities with river training measures, along with illegal prospecting of rubble, have significantly modified the natural channel processes.

Key words: morphodynamics, channel, channel topology, catastrophic flood

INTRODUCTION

In the Carpathian Mountains extreme events are infrequent but have a powerful impact on the development of local morphology. They trigger processes of a high morphological potential leading to aconsiderable transformation of natural systems, including channel or slope systems. Slope system responses tend to be delayed and limited to small portions of a slope. Channel systems, on the other hand, are perpetually adjusting to extreme discharges, and "a frequent crossing of threshold values changes the paths in landform evolution" (Starkel 1996). Each system has its specific structure, understanding of which provides clues as to its dynamic status.

The structure of mountain river channel systems has been the subject of many publications in Poland and internationally (Kaszowski, 1979; Klimek, 1979; Krzemień, 1991; 2003). Nonetheless, patterns of development and morphology in mountain fluvial systems are not sufficiently understood, and further research into this area must be considered highly desirable. Most river channel processes are slow and only accelerate at the time of floods. In July 1997, a flood in the Polish Carpathian Mountains modified the River Łososina's river channel itself and the hydrodynamic conditions in it. The morphodynamic effects of flood waves in a river channel are primarily manifested in the form of erosion and bedload transport. The flood of July 1997, which considerably transformed the middle and lower courses of the River Łososina channel, provided a useful opportunity to assess the effects of these processes and to understand the course of events. This study aims to comprehend the course and effect of the transformation of the Łososina channel during the extreme event of the 1997 catastrophic flood.

METHODS

The study of the River Łososina channel was carried out during the period 1997–2002. It started in 1997 with the mapping of the geomorphological outcomes of the catastrophic flooding along the middle and lower courses of the river and its side valleys (Gorczyca, 2004). Estimates were made of the quantities of rubble that had made its way from landslides along the river and its tributaries. In 2000–2001, the Łososina river channel was mapped. The 54-kilometre channel was divided into 38 reaches and mapped using a form designed for the purpose and a manual (Kamykowska et al., 1999). The mapping started at the confluence of two source streams at 800 m a.s.l. and ended at the mouth of Lake Czchowskie. The reaches were identified using the top-view channel pattern and described according to their channel features. The latter exercise involved a qualitative and quantitative assessment of the channel, including erosion and accumulation features, bedload, the degree of channel blocking and channel hydrology. Wolman's methodology (1954) was used to determine the mechanical and petrographic composition of rubble in the channel. Data were used from two hydro-meteo stations, at Jakubkowice and Piekiełko.

RESEARCH AREA

The Łososina basin, with an area of 407.1 km^2, is located in the Beskid Wyspowy mountain range of the Outer Western Carpathian Mountains (Fig. 1A). The basin typically features isolated domed peaks and ridges, the highest being Mts. Ćwilin (1071 m a.s.l.) and Mogielica (1171 m a.s.l.), rising high above the surrounding low foothills and mountain basins. Local drops extend to 500–600 m above valley beds.

The Outer (*flysch*) Carpathian Mountains were folded during the Tertiary Period. The river basin area consists of flysch formations of the Magura nappe, primarily from the Cretaceous and Palaeogenic ages (Cieszkowski 1992). Specifically, the area consists of sub-Magura layers (upper Eocene through Oligocene) and, to a lesser extent, of Magura sandstones of the glauconite facies and hieroglyphic layers (middle and upper Eocene) with Magura sandstones. In the centre of the study area rock layers follow a general E-W axis.

The Łososina springs from the northern slopes of Mt. Jasień at 850 m a.s.l. and ends in the artificial Lake Czchowskie on the River Dunajec. The river basin is largely deforested and managed, including a dense network of unpaved and field roads. Surface and mid-cover flow is fast and flood wave concentration time short (Starkel 1991).

The overall pattern of the River Łososina system is dendric and has a similar number of left- and right-bank tributaries. According to Strahler's classification (1952), the 56-kilometre channel of the River Łososina is of the sixth order.

During the period 1976–1990, records from two hydrometric stations along the Łososina, at Piekiełko (17.12 km) and Jakubkowice (33.2 km) (Fig. 1B), displayed similar water

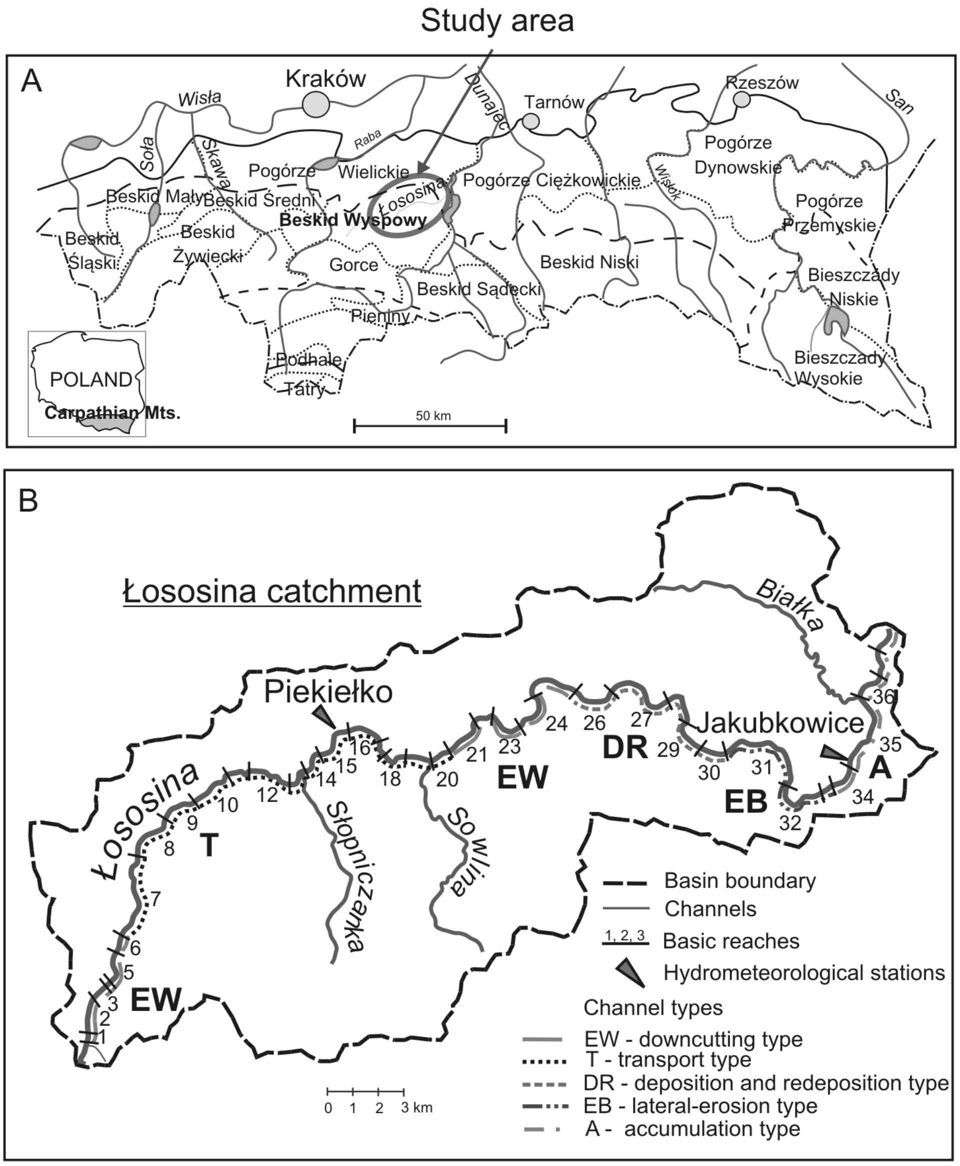
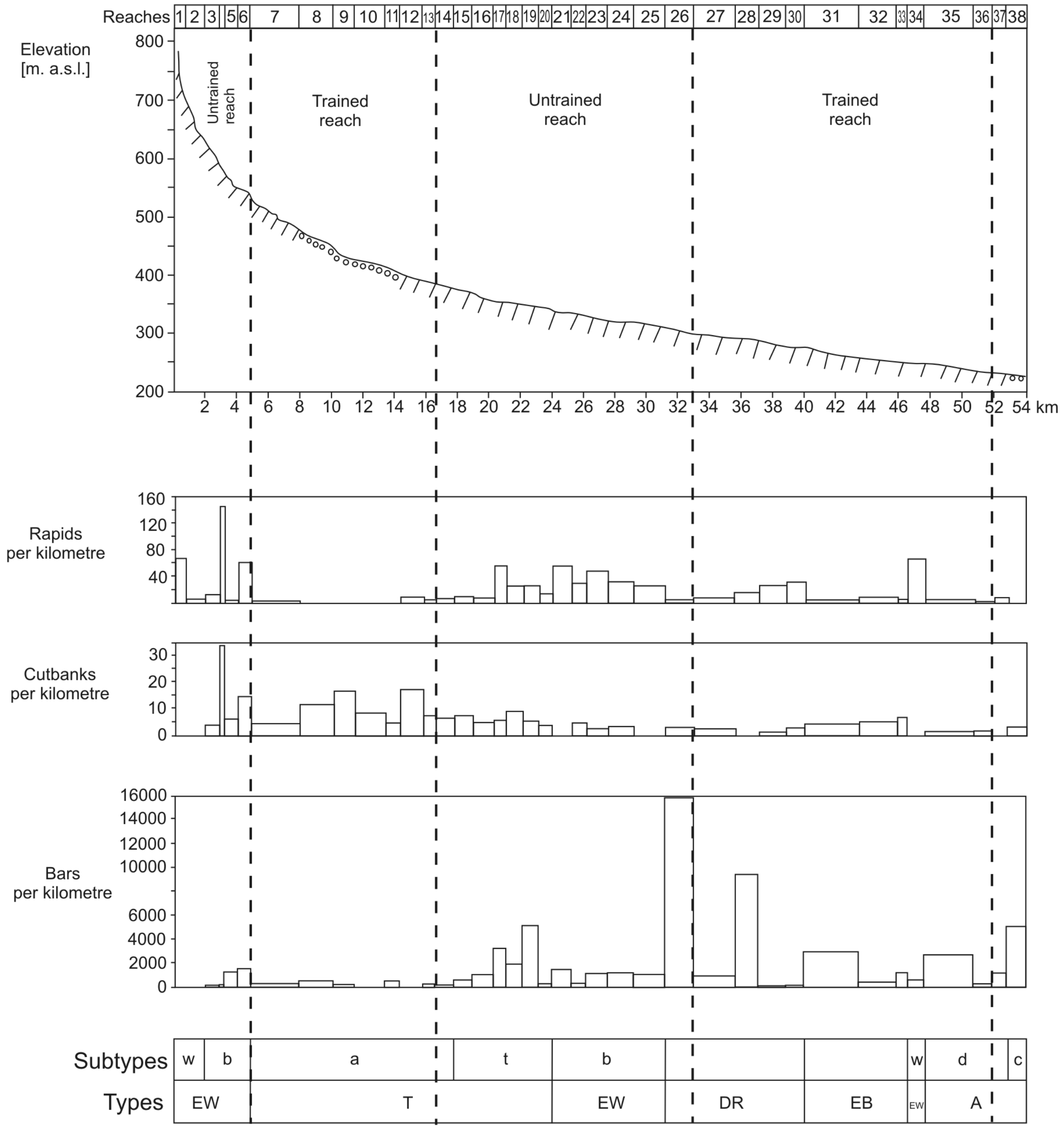


Fig. 1. *A* – study area against physical geography breakdown of the Carpathian Mountains (Kondracki, 1977); *B* – Łososina channel types (on the basis of Sołtys, 2001)

1 pav. Tyrimų arealas: *A* – Lososinos baseino padėtis Vakarų Karpatuose (Kondracki, 1977); *B* – Lososinos upės morfodinaminės atkarpos (remiantis Sołtys, 2001)



Subtypes: a - transport type in reinforced channels, b - downcutting type with some lateral erosion and local accumulation, c - accumulation type with lateral-erosion and a 'backwater' effect from Lake Czchowskie, d - accumulation type, t - transport type, w - intensive downcutting type

Types: EW - downcutting type, T - transport type, DR - deposition-redeposition, EB lateral-erosion type, A - accumulation type

After A. Sołtys, 2001

Fig. 2. Typological summary of the Łososina channel
2 pav. Lososinos upės vagos struktūriniai rodikliai

level patterns. The average water levels were close together, i. e. 125 cm at Jakubkowice and 115 cm at Piekiełko, and the water-level annual maxima were recorded in the warm half of the year at both stations. The average 1976–1990 maximum annual water levels calculated for Jakubkowice and Piekiełko were 218 cm and 169 cm, respectively. In 1913–1951, Jakubkowice recorded the minimum water levels to diminish at a rate of 2.48 cm per annum. At the same time, the river channel depth grew by 131 cm (Fig. 3). During the following period – 1952–1967 – minimum water levels increased by 1.3 cm pa and the channel bottom rose by 35 cm overall. The period 1968–1975 was marked by an intensive downcutting, resulting in an 82 cm deepening of the channel. This trend continued subsequently, increasing the channel depth by another 20 cm in 1976–1999 to reach an overall deepening of 202 cm during the period 1913–1999 (Fig. 3). The average discharge during that period was 2.58 m^3/s at

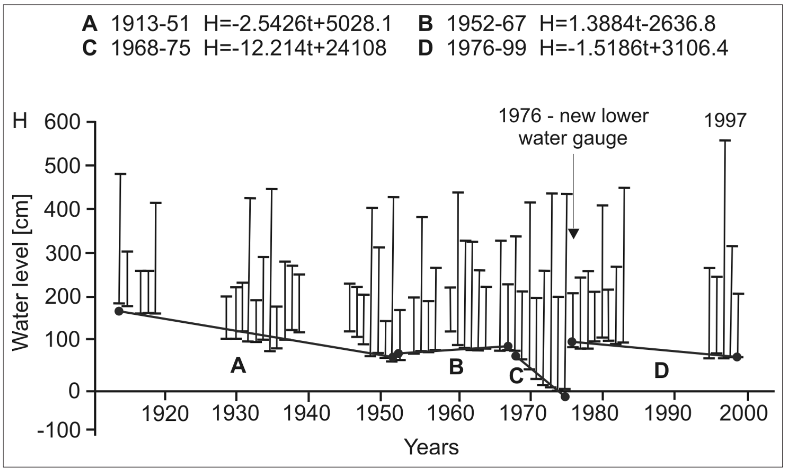


Fig. 3. Minimum and maximum water levels on the river Łososina during the period 1913–2000 at Jakubkowice (Fig. 1B)
3 pav. Lososinos upės minimalių ir maksimalių vandens lygių kaita Jakubkovicų vandens matavimo poste 1913–2000 m. (1 pav., *B*)

Piekiełko and 4.88 m^3/s at Jakubkowice. Just as with the maximum water levels, both stations recorded their maximum discharges during the warm half of the year, culminating in July, and the average fifteen-year (1976–1999) annual maximum water discharges were calculated at 63.3 m^3/s at Jakubkowice and 26.40 m^3/s at Piekiełko.

The River Łososina and its tributaries flood mostly during summer (especially in July) as a result of rain storms. Flood waves build up rapidly somewhere between a dozen and several dozen hours. Prior to 1997, the largest flood events of the research period occurred in 1934 (450 cm water level at Jakubkowice) and 1970–1973 (425 cm water level at Jakubkowice). The July flood of 1997 was classified as a "catastrophical scale" event with 5 percent probability of the actual culmination discharge. An intensive rainfall in the River Łososina basin fuelled a 205 cm high floodwave which exceeded the alert level at Jakubkowice (Grela et al. 1999). On 9 July 1997, the Piekiełko station recorded a culmination wave of 430 cm and Jakubkowice recorded 585 cm.

CHANNEL STRUCTURE AND TYPES

The Łososina channel runs along the E–W axis and has a winding course undercutting both the northern and the southern slopes. Its floodplain widens downstream to reach a maximum of 500 m in the lower course of the river.

There are clear distinctions between the upper, middle and lower courses visible in the longitudinal section of the channel. The initial gradient is very high, at 44 to 138‰, after which it drops to just over 10‰ in the middle course and c. 4‰ in the lower course. The average valley gradient is 10‰.

There are isolated rapids and rapid systems along nearly the entire length of the Łososina. Their distribution, however, is not uniform with the greatest concentration in the upper and middle courses (Fig. 2) and there are virtually no occurrences along trained reaches and in the mouth reach. Principally cut in sandstone and rarely in shale, the rapids typically measure between 0.5 m and a maximum of one metre in height. Transverse rapids are most numerous, but there are also some diagonal and longitudinal ones. Both discordant and accordant rapids are found along the entire channel length.

Very few bedrock rapids are located in rapid zones and cut in horizontal sandstone layers.

Kettles are found primarily in the upper course of the river and more rarely in its middle course. Cut in solid sandstone bedrock, they reach between 0.5 and 1 metre in depth.

Rubble bars can be found along almost the entire course of the Łososina channel, except for the source reach which is entirely cut out in solid bedrock. Most of the bars are of the lateral type. Median bars are less frequent and typically occur along trained reaches. Most of the bars are small and do not exceed 1000 m^2/km of the channel. The largest bars form in the middle and lower courses (Fig. 2). They range from 3000 to 9000 m^2/km, with a maximum of 16 000 m^2/km (Sołtys, 2001).

Cutbanks can be found along nearly the entire length of the channel. They are most frequent in the upper course, but their small size is not offset by large numbers and they have a much smaller combined area than those in the lower course of the river. In the middle and lower courses, less numerous cutbanks are much larger (Fig. 2), measuring up to 100 m in length and 6 m in height. They are located on both sides of the channel, mostly along concave banks.

Sandstone and shale rocks form a rubble composition in the Łososina channel, but sandstone dominates at 74 to 99%. The most typical granularity breakdown includes gravel, at 2 to 25 mm covering 44% of the channel length; pebble, ranging from 25 to 60 mm, covering 39% of the channel length; and boulder, ranging from 60 to 200 mm and covering 17% of the channel length. Overall, the lower the gradient, the smaller the most frequent granularity. The largest granularities are found in the middle course of the Łososina, at 30–50 cm. The largest rocks can be as big as 80 cm in diameter. The maximum granularity sizes depend on the local conditions where the rock material is supplied from cutbanks and from the channel.

During the 1980s, after numerous floods, the upper course of the Łososina channel was trained. Concrete was used for step structures, pools and dams. Various engineered structures, including bank reinforcement and bridges, are found along much of the channel length. The source reach and the middle course of the river remain the only untrained parts (Figs. 1, 2). The lower course was trained with step structures and bank-reinforcing gabions. A road runs along much of the channel length, requiring concrete bank reinforcement where the valley narrows.

Human interference in the Łososina river valley is not restricted to the channel itself, a common practice here is to extract rubble from the channel bed. Bars as signs of this activity can be found along the entire length of the river.

The channel typology was based on the reach boundary analysis method (Kaszowski, Krzemień, 1999). Five channel types were identified in the Łososina channel: A – accumulation type, EB – lateral-erosion type, EW – downcutting type, DR – deposition and redeposition type, T – transport type (Figs. 1, 2). Additionally, six subtypes were defined: a – transport type in reinforced channels, b – downcutting type with minor lateral erosion and local accumulation, c – accumulation, lateral-erosion type and with the 'backwater' effect from Lake Czchowskie, d – accumulation type, t – transport type, w – intensive downcutting type (Sołtys 2001).

Type A (accumulation type) spans reaches 35–38 in the lower course and mouth reach of the river Łososina. It is typified by a high proportion of large bars; reach 35 – 2700 m^2/km and the mouth reach more than 5000 m^2/km. The mouth reach (38) is under a considerable influence of Lake Czchowskie, with very fine silty deposits at the channel bottom.

Type EB (lateral-erosion type) spans reaches 31–33, with few but very large cutbanks ranging from 900 to 2000 m^2/km.

Type EW (downcutting type) spans reaches 1–6, 21–25 and reach 34. In the upper course the reaches are cut entirely in solid rock. There are very numerous rapids along all of these reaches, bars and cutbanks being rather rare.

Type DR (deposition and redeposition type) spans reaches 26–30. Material is deposited in the form of large bars and moved again during subsequent floods.

Type T (transport type) spans reaches 7–20, most of which are trained (reaches 7–14). The numerous cutbanks found here are small and bars are few. None of the reaches features a dominant process.

Erosional reaches are separated by either accumulation type, deposition-redeposition type, or transport type reaches. Erosion affects both the upper and the lower courses of the river whose channel structure has been considerably modified by human activity. The largest number of reaches are of the transport type (more than 35% of the river length); most of them have been trained (Fig. 2).

CHANNEL DYNAMICS

Development trends of a channel system may be ascertained by changes in the location and size of morphological features within the channel. This can be done using maps and aerial photos made at different times. In the case of the River Łososina, three sets of maps were used: from the 1930s (before the training), 1980s (after) and present (Sołtys, 2001). Prior to the training, the Łososina had numerous braiding reaches. The training efforts involved directing the river into a single channel, its banks were reinforced in many places with concrete or crushed rock held down with wire mesh. The upper course saw the most extensive engineering measures, with numerous concrete step structures and pools. Currently, this course of the river is observed to follow a return trend back to the initial state, as was the case prior to the training. Indeed, both up- and downstream of each concrete step-and-pool structure median bars have developed. Additionally, fresh cutbanks can also be found downstream, renewed during each flood. However, along the middle course where the banks are reinforced with concrete or gabions (reaches 19–21, 24 and 27–29), no return trend has been observed. In these reaches the transport process prevails with a low intensity of other processes.

A long-term minimum water level analysis provides clues as to whether the channel bottom is rising or deepening (Fig. 3). A comparison of these parameters at the two hydrometric transects clearly shows that the channel is deepening in the lower course of the river (Jakubkowice). During the period 1968–1975, at Jakubkowice the channel bottom was deepening at the rate of c. 11 cm/year and during the period 1976–1999 c. 1.5 cm/year. A reverse trend was observed in the late 1990s when the channel bottom at Piekiełko was rising by 2.8 cm per year (Sołtys, 2001).

The river channel processes tend to be very slow and only accelerate at the time of floods. This is what happened in July 1997 when rains of an intensity unseen over the previous 24 years fell in southern Poland, causing catastrophic flooding. The Beskid Wyspowy range was among the worst-affected areas of the Flysch Carpathian Mountains. A low pressure system stagnating over the northern Carpathian foreland and the related inflow of a wet northern air mass combined to produce long-duration rains that fuelled the catastrophic flood on the Polish side of the Carpathian Mts. (Niedźwiedź, Czekierda, 1998). After four days of prolonged rainfall yielding 10–30 mm of water per day between 4 and 7 July 1997, on 8th July the Beskid Wyspowy range was hit by a rainstorm that produced 85 mm (at Limanowa). The Łososina and its tributaries swelled and the floodwave peaked in the evening of 8th July, flooding the main valley and side valleys. Due to the steep gradients the water flowed fast and the streams quickly returned to normal levels. On the following day, 9th July, a thunderstorm cell that had formed earlier that day over the central part of the Łososina basin yielded 150 mm of rain in two hours. Water rushed violently along valleys, roads, erosional cuts and even in sheet flow down the slopes. The V-shaped valleys were significantly deepened, down to two metres in places, and numerous steps and eversion kettles developed along their longitudinal profiles. Nearly all rubble and landslide material was swept away from the valleys and deposited at their mouths in deep and vast torrential fans. The swollen waters of the Łososina and its tributaries provided a stimulus activating erosion processes in the channels and landslide processes on the slopes and at the edges of elevated terraces. Major changes were observed in the channel.

Numerous cutbanks evolved and there were some cases of avulsion of the main and tributary channels (Fig. 4). A mass of angular-edged material was supplied into the channels from various types of landslumps and cutbanks (Fig. 5). In the middle and lower sections of the Łososina basin the mapping exercise yielded 505 landslide forms, primarily minor landslumps (Gorczyca 2004). Between Tymbark and the river mouth 101 landslide forms emerged, mostly small landslumps, but also some larger landslides. An effort was made to assess the quantity of material supplied to the channel system from these features. From the mapped surface area of the landslide features and their depth, the figure was estimated at c. 820,000 m^3. This, however,

Fig. 4. New avulsive channel of the Starowiejski stream cut down to c. 2 metres in solid ground during the 1997 flood

4 pav. Per 1997 m. potvynį susidariusi nauja Staroviejsko upelio vagos atkarpa, 2 metrus įsirėžusi į konsoliduotas nuogulas

Fig. 5. A zone with clearly marked accumulation across the Łososina channel width after the 1997 flood

5 pav. Akumuliacinės vaginės formos, susidariusios šalia Lososinos upės vagos po 1997 m. potvynio

may be overstated due to an inherent lack of accuracy in the measurement method, but also because some of the displaced material might have stopped short of the channels themselves either in the landslide cavity itself or further down the slope in a typically partly extant spout. The figure quoted excludes any material started in the channel zone and supplied from larger side valleys and roads. The Łososina channel received material not just directly from its slopes, but also from the side valleys. That amount is difficult to estimate, and much of it was accumulated in cones and fans at their confluences. The fans tended to be very deep, up to two metres, and located within the wide main valley floor, thus stopping the material from reaching the channel proper. Estimates were made of the quantities of material carried away from two of the tributaries: the Rozpite stream, with a wooded basin (2.4 km^2), high local drops and a steep channel gradient, and the Kamionka stream basin (8.2 km^2), largely deforested, densely developed and farmed. On the slopes of the Rozpite stream, 22 landslide features emerged with a combined volume of c. 54,000 m^3. Most of that material was swept from the valley and reached the Łososina channel. On the Kamionka stream slopes, 43 landslide features developed with a combined volume of 72,000 m^3. Much of that was retained within the valley floor and in its accumulation fan. After the flood, the Kamionka channel had both erosion and deposition reaches where most of the waste material started by the landslide and erosion was accumulated (Fig. 6). The accumulation fan, up to two metres deep, never reached the Łososina channel, but was very quickly removed in a flood recovery campaign.

After the 1997 flood, the volume of rubble material and a number and size of the channel bars increased considerably. Immediately after the event, the Łososina featured several multi-branched reaches not unlike a braided river, but it was quickly brought back to a single channel using bulldozers. There is no doubt that the volume of the rubble material deposited in the channel would have been greater had it not been for the common, though essentially illegal, practice of material

Fig. 6. The Kamionka stream channel after the 1997 flood
6 pav. Kamionkos upelio vaga po 1997 m. potvynio

prospecting, mainly for construction purposes. Some of the accumulation fans and rocky bars were also used to rebuild and repair gravel and unpaved roads severely damaged during the extreme rainfall event.

River training and other engineering structures in the Łososina river suffered considerable damage. Many bridges and bank reinforcement structures were destroyed by the floodwave. Lateral erosion threatened a regional road running alongside the river in many places, which required new bank concrete reinforcements.

To protect Lake Czchowskie from the supply of rubble with the inflowing water, the channel gradient was reduced. The project was then evaluated for its impact on the intensity of bedload transport (Bednarczyk et al., 2003). It seems that the dragged load was reduced in trained reaches, especially along the lower reach near the confluence at Lake Czchowskie. According to Bednarczyk et al. (2003), these results confirm the usefulness of the training project on the Łososina river. The granularity of the rubble was reduced, but it is important to remember the prospecting traditionally practised by the local communities. Indeed, the most desirable material size is 6 cm in diameter or more, which can largely be held accountable for the diminishing of the average rubble granularity. In future, that effect may contribute to a distortion of natural channel processes during floods and lead to a considerable domination of downcutting over other processes.

The Łososina channel was also evaluated for the morphological effect of the floods. A 400 metre reach in the middle course of the river was selected for the fieldwork with a number of transects (Tekielak et al., 2006). It was found that during the period 2004–2005, the Łososina channel had widened by 0.7 m, its bottom had deepened by 20 cm and the volume of material eroded away was estimated at 250 m^3. These results would suggest that the rubble transport process was very intensive, thus suggesting instability of the channel bottom.

As a result of the 1997 flood, the greatest material damage was suffered by the Laskowa municipality located in the central area of the basin. The rushing streams and landslides considerably damaged the Limanowa–Nowy Sącz regional road as well as approximately 35 km of municipal and 120 km of local roads. Dozens of houses and farm buildings, numerous schools, warehouses, and waste-water treatment plants were flooded and considerably damaged. In the aftermath of the 1997 flood, the material losses of the Laskowa municipality were estimated at 34 million zloty (more than 9 mill. €).

CONCLUSIONS

The study of the river Łososina channel found a high level of erosion activity, considerable rubble transport intensity and, during extreme flood events, also a common activation of landsliding on the slopes. An understanding of the Łososina channel dynamics is necessary for the appropriate development of the valley floor. Insights into these mechanisms may well help protect the local infrastructure and avoid the vast damage suffered in 1997.

The Łososina channel system has an erosion regime with local accumulation and lateral erosion. Downcutting landforms can be found along the entire channel length, as confirmed by the existence of numerous rapids and kettle forms in the upper course and by the results of the minimum water level analysis in the lower course. This makes the Łososina channel, with its dominance of erosion over all other processes, a typical Carpathian river.

Most river channel processes tend to be very slow and only accelerate at the time of floods. This is what happened in July 1997 when the swollen waters of the Łososina and its tributaries provided an important stimulus activating landslide processes on the slopes. Large volumes of angular-edged material were supplied into the channels from various types of landslumps and cutbanks.

Human activity, including that aiming to improve the safety of the local communities with river training measures, along with illegal prospecting of rubble, have significantly modified natural channel processes.

Many of the river's reaches are currently observed to have entered trends leading to the reinstatement of its natural braided pat-tern. Concrete step structures, pools and bank reinforcements ensure an equilibrium at low and medium water levels. During floods, however, the river energy is high enough for lateral erosion to affect the engineering infrastructure in the area. Prospecting leads to a reduction of the granularity of the channel material that can be displaced during floods, thus contributing to a distortion of natural channel processes and a clear domination of downcutting over all other processes.

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References

1. Bednarczyk T., Radecki-Pawlik A., Słowik-Opoka E. (2003). Wpływ regulacji technicznej rzeki Łososiny na zmianę warunków transportu rumowiska wleczonego dostarczonego do zbiornika Czchów. *Acta Scientiarium Polonorum – Formatko Citrumiectus. 2*: 13–24.
2. Cieszkowski M. (1992). Płaszczowina magurska i jej podłoże na północ od Kotliny Sądeckiej. *Przegląd Geologiczny. 7*: 410–416.
3. Gorczyca E. (2004). *Przekształcanie stoków fliszowych przez procesy masowe podczas katastrofalnych opadów (dorzecze Łososiny)*. Kraków: Wydawnictwo UJ.
4. Grela J., Słota H., Zieliński J. (1999). *Dorzecze Wisły.* Monografia powodzi lipiec 1997. Kraków: Wyd. IMGW.
5. Kamykowska M., Kaszowski L., Krzemień K. (1999). River Chanel mapping instruction. Key to the river bed description. *Zeszyty Naukowe UJ, Prace Geograficzne. 104.*
6. Kaszowski L. (1979). *Dynamiczna typologia koryt rzecznych na obszarze Karpat i ich przedgórza. 21 (1).*Sprawozdanie z Posiedzeń Komisji Nauk PAN, Oddział w Krakowie. Kraków.
7. Kaszowski L., Krzemień K. (1999). Classification system of mountain river channels. *Zeszyty Naukowe UJ, Prace Geograficzne. 104.* 27–40.
8 Klimek K. (1979). Geomorfologiczne zróżnicowanie koryt karpackich dopływów Wisły. *Folia Geographica. Seria Geographica-Phisica. 12.* Kraków.
9. Kondracki J. (1977). *Regiony fizycznogeograficzne Polski.* Wyd. UW.
10. Krzemień K. (1991). *Dynamika wysokogórskiego systemu fluwialnego na przykładzie Tatr Zachodnich.* Rozprawy habilitacyjne UJ. 215.
11. Krzemień K. (2003). The Czarny Dunajec River, Poland, as an example of human-induced development tendencies in a mountain river channel. *Landform Analysis. 4.*
12. Niedźwiedź T., Czekierda D. (1998). Cyrkulacyjne uwarunkowania katastrofalnej powodzi w lipcu 1997 roku. *Powódź w dorzeczu górnej Wisły*. Red. L. Starkel, J. Grela, Kraków: Wyd. PAN. 53–66.
13. Sołtys A. (2001). *Struktura i dynamika koryta Łososiny (Beskid Wyspowy).* Archiwum Zakładu Geomorfologii IGiGP UJ. Kraków.
14. Starkel L. (1991). Rzeźba terenu. *Dorzecze górnej Wisły*. Cz. I. Red. I. Dynowska, M. Maciejewski. Warszawa-Kraków: PWN. 42–54.
15. Starkel L. (1996). Geomorphic role of extreme rainfalls in the Polish Carpathians. *Studia Geomorphologica Carpatho-Balcanica. 30:* 21–28.
16. Strahler A. (1952). Dynamic basis of geomorphology. *Bull. Geol. Soc. Am. 63.*
17. Tekielak T., Michalik A., Bąk Ł. (2006). Morphological effects of freshets in section of the Łososina river channel. *Infrastruktura i ekologia terenów wiejskich. 4 (2).* Kraków: Wyd. PAN. 193–202.
18. Wolman M. G. (1954). Method of sampling coarse riverbed material *Am. Geohys. Union Trans.* 35.35.6

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EKSTREMALAUS POTVYNIO PASEKMĖS LOSOSINOS UPĖS (VAKARŲ KARPATAI) MORFODINAMIKAI

Santrauka

Karpatų kalnuose ekstremalūs upių potvyniai nėra dažni, tačiau jų poveikis vagų morfologijai labai didelis. Staigūs potvyniai ypač stipriai transformuoja upių vagas ir šlaitus. Tyrimo tikslas buvo atskleisti vagos, krantų ir šlaitų pokyčius po katastrofinio 1997 m. Lososinos upės potvynio.

Lososinos upėje buvo išskirta po penkis vagos tipus ir potipius: tipai – akumuliacijos, šoninės erozijos, gilinamosios erozijos, akumuliacijos ir perklostymo bei transportavimo; transportavimo potipis dirbtinai sukurtose vagų atkarpose, gilinamosios erozijos potipis su nestipriu krantų ardymu ir vietine akumuliacija, akumuliacinis potipis su priešsrovine šonine erozija, akumuliacinis potipis, transportavimo potipis ir intensyvios gilinamosios erozijos potipis.

Tyrimais nustatyta, kad Lososinos upės vagoje vyksta labai intensyvi erozija, kurios metu vagos dugnu gabenami gausūs rupūs nešmenys. Be to, per potvynius intensyviai formuojasi nuošliaužos upės krantuose ir slėnio šlaituose. Upės vagos kaita leido įvertinti ir slėnio pokyčius. Vaginių procesų mechanizmo pažinimas padėjo numatyti upės slėnyje sukurtos infrastruktūros apsaugos priemones ir išvengti tokių niokojimų, kokie buvo per 1997 m. katastrofinį potvynį.

Visoje Lososinos upės vagoje vyksta gilinamoji erozija, o akumuliacijos ir krantų erozijos atkarpos paplitusios tik kai kur. Gilinamosios erozijos formos tęsiasi išilgai visos upės vagos. Upės aukštupyje gausios rėvos kaitaliojasi su erozinėmis duobėmis, tuo tarpu žemupyje vagos dugnas lygesnis, tačiau per visą plotį veikiamas gilinamosios erozijos. Erozijos požiūriu Lososina yra tipiška Karpatų kalnų upė.

Vaginiai procesai Lososinoje vyksta gana lėtai, ypač nuosėkio metu, tačiau per potvynius jie suintensyvėja. Taip atsitiko 1997 m. liepą, kada patvinusi Lososina ir jos intakai sudarė palankias sąlygas formuotis gausioms nuošliaužoms slėnio šlaituose. Nuošliaužos ir griūvantys krantai į upės vagą sunešė labai daug aštriabriaunių nuolaužų.

Natūraliems vaginiams procesams didelę įtaką darė ir daro žmogaus ūkinė veikla. Ypač stipriai minėtus procesus veikia krantų stiprinimas, krantinių statyba ar neapgalvotas uolienų pylimas upės pakrantėse. Visa tai daroma norint apsaugoti pakrantės gyvenvietes nuo potvynių, tačiau nenatūralūs vaginiai procesai gali sukelti neigiamą efektą.

Šiuo metu daugelyje kalnų upių stebimas buvusių vagų morfodinaminių atkarpų atsikūrimas, t. y. natūralaus vingiuotumo formavimasis. Dirbtiniai slenksčiai, krantų stiprinimas ar tvenkinių statyba leidžia stabilizuoti vaginius procesus, tačiau šios priemonės yra efektyvios tik esant žemam ar vidutiniam vandens lygiui upėse. Tekantis vanduo potvynių metu turi pakankamai energijos krantų ardymui ir sukurtos infrastruktūros naikinimui, nes išplaunami susmulkinti nešmenys. To pasekmė – pradeda vyrauti gilinamoji erozija, užgoždama kitus vaginius procesus.