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CONTEMPORARY TRENDS IN THE BIAŁKA RIVER CHANNEL DEVELOPMENT IN THE WESTERN CARPATHIANS

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Abstract: Białka is a typical river that has its origins in the high mountains of the High Tatra and the Belanske Tatra Mountains. Transport of gravel from the Tatra Mountains down to the foot of the mountains over a long period of time, during the Pleistocene and the post-glacial era, led to the formation of a typical braided river channel. During the last 150 years the river channel was gradually narrowed and deepened. This process has clearly intensified since the end of the 1960s due to human intervention that changed the course of the river channel. Exploitation of the river channel by extraction of sediment also had an impact. From the geomorphological and ecological point of view, the changes occurring in the Białka River channel, which are still continuing, are not progressing in a positive direction.

Key words: mountain river channels, braided river, fluvial processes, the Western Carpathians.

INTRODUCTION

The differences among present-day river channels are a result of long-term processes that have been occurring within entire river catchments. Knowledge of the characteristics of entire river channel systems allows to recognize how the systems function (Chorley and Kennedy, 1971). Therefore, research of entire river channel systems is very important in order to get to know the current state they are in, and to forecast future trends in their development (Wasson *et al*., 1993; Chełmicki and Krzemień, 1999). Podhale is a region that in the Pleistocene was an area where material transported from the Tatra Mountains by proglacial and nival proglacial rivers was deposited. The transfer of water and clastic material was a complex process (Klimaszewski, 1972) because of the diverse landscape of the area. Alluvial fans were formed of the rock material carried by proglacial and nival proglacial rivers within the Sub-Tatra Trough at the foot of the Tatra Mountains. Subsequently, the material was moved through three narrow valleys of the Czarny Dunajec, Biały Dunajec and Białka rivers, down to the large Orava-Nowy Targ Basin (Fig. 1).

Over a long period of time, these rivers formed their channels to become typical braided river channels. River training changed the river channels later on. River training was driven by the economic development of the river valleys. After the Second World War, the river channels were exploited by way of channel load extraction. So far, the Biały Dunajec River channel was the most trained, followed by the Czarny Dunajec River channel that was also heavily trained (Krzemień, 2003; Korpak, 2007; Gorczyca and Krzemień, 2010). The Białka

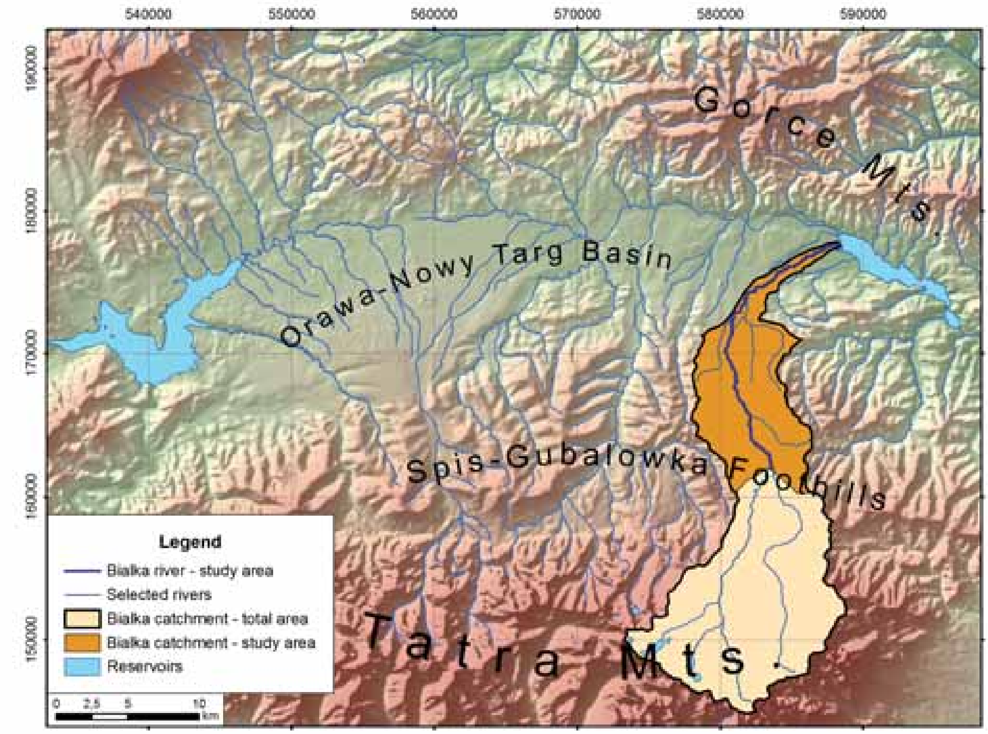

Figure 1. Location of the study area

River channel was the least affected by human intervention. As the last river channel of this type in the Polish Western Carpathians it should be protected from any kind of hydro-technical regulation. The same should apply to similar river channels in other countries (Chełmicki and Krzemień, 1999). The braided river channel of the Białka River is one of the exceptional phenomena in the Polish Carpathians. The authorities responsible for land use and the proper management of the area officially declared that further river training is not planned. In addition, any river channel sediment mining is prohibited by law. Regretfully, occasionally some river channel aggregate extraction still occurs in some places. The aim of this research conducted in the Białka River valley was to gain the knowledge of the layout and detailed structure of the river channel system, and to investigate and show a present-day trend in its development.

RESEARCH AREA

The Białka River catchment covers an area of 232 km^2. Over 60% of the catchment area lies in the High Tatra and the Belanske Tatra Mountains. This part of the catchment area is fan-shaped. It is primarily built of granitoids, limestones, dolomites, sandstones and shales.

The remaining part of the catchment area is of an elongated shape (Figs. 1, 2). This part of the catchment is built of flysch formations with a small share of limestone and dolomite outcroppings, which are part of the Pieniny Klippen Belt.

The channels of the Białka River and its tributaries, within the part of the catchment located in the Tatra Mountains, down to the moraine ridges in the vicinity of Łysa Polana, are armored with moraine boulders. Therefore, they are relatively stable (Baumgart-Kotarba, 1983).

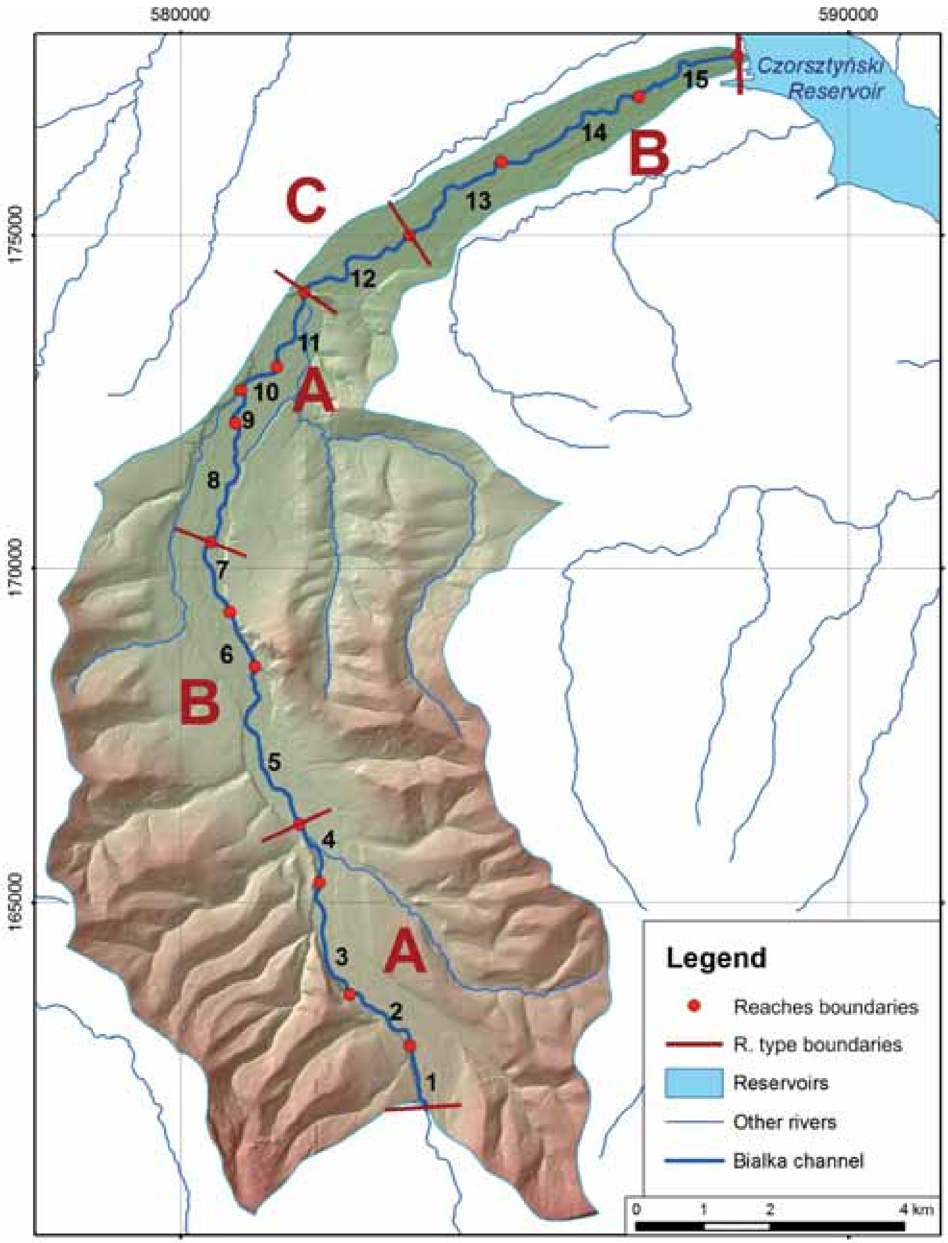

Figure 2. Location of the reaches of the Białka River channel and channel types

The river channels cut through the moraine ridges and there the rivers flow through gorges. However, the stretches of the river channels in the areas between moraine ridges are typical for braided rivers. The Białka River channel is rocky before it is joined by the Jaworowy Stream. The rocky part of the river channel includes a system of erosional channel forms, such as rock steps and pot-holes. The following sequence of erosional forms often occurs: a rocky or debris step, then a trough or a pot-hole cut in rocks or in debris, and mid-channel bars or side bars (Baumgart-Kotarba, 1983).

The part of the Białka River channel located within the Podhale region and in the lower-lying basins, which is the part that was researched, is a channel that was mostly cut in a gravel layer. There are numerous mid-channel and side bars in the river channel. This form of river channel was developed as a result of transport of rock debris that is resistant to abrasion from the Tatra Mountains over a long period of time.

The present-day hydrological regime of the Białka River is determined by the hydrology of the highest mountain part of its catchment. Flood stages occur in the Białka River catchment in April and May. They are caused by a rapid snowmelt in the upper part of the catchment located in the Tatra Mountains. Another such period is in the summer months of June and July – flood stages are then a result of extreme precipitation (lasting 2–3 days) and prolonged precipitation. The greatest discharge rate occurred in 1934 and it was 433 m^3s^{-1} (Trybsz gauging station). The average discharge rate in the Białka River during the period from 1926 to 1964 was 5 m^3s^{-1} (Hennig et al., 1968; Baumgart-Kotarba, 1983) (Trybsz gauging station). The hydrological regime of the Białka River is typical of alpine, or high mountain rivers, just like the Czarny Dunajec and the Biały Dunajec rivers, which are also located in the Tatra Mountains (Dobija, 1981). According to Dobija (1981), the high mountain “Tatra effect” on the hydrological regime disappears rather quickly as the rivers flow through the Orava-Nowy Targ Basin, which falls outside of the research area.

RESEARCH METHODOLOGY

Research in the field was conducted in this area in August of 2009 and in September of 2010. A detailed questionnaire and instructions, created at the Geomorphology Department of the Institute of Geography and Spatial Management of the Jagiellonian University (Kamykowska *et al*., 1999), were used in order to study the river channel structure.

The Białka River channel system, downstream from the point where it is joined by the Jaworowy Stream, was divided into 15 homogeneous reaches (Fig. 2). The basic channel reaches of the river were identified on a topographic map at the scale of 1: 10,000 and on aerial photographs, based on the river channel layout across the terrain and existing channel forms. Given their descriptions, the reaches were subsequently judged to be homogeneous. The description of every river channel reach included qualitative and quantitative properties of the channel, of the existing channel forms, channel load, and of the hydro-technical infrastructure along the river channel. Additionally, the flood plain was also described. Fractional composition of the river channel material deposited on channel bars was determined by the method by Wolman (1954). A total length 22 km of the Białka River channel was mapped. After the properties of the river channel, channel forms and channel load had been determined and summarized, the river channel reaches and their types were finally identified by the method of reach endpoints (Kaszowski and Krzemień, 1999; Fig. 3).

Discharge rates at a filled river channel stage were determined (it was assumed that these are the Q50% discharge rates) for cross-sections that were at a distance of 1 km apart from one another. The determination was made based on data from the gauging stations at Łysa Polana and Trybsz as well as a numerical model of the terrain [or a Digital Elevation Model] by using the method of catchment increases (Ozga-Zielińska and Brzeziński, 1994). These data, in turn, allowed to calculate a unit stream power, which was subsequently averaged for each of the identified homogeneous river channel reaches (Fig. 4). The unit stream power is a parameter providing information on the amount of energy that is dispersed at a given discharge rate onto the banks and the bottom of a river channel per 1 metre of the chan-

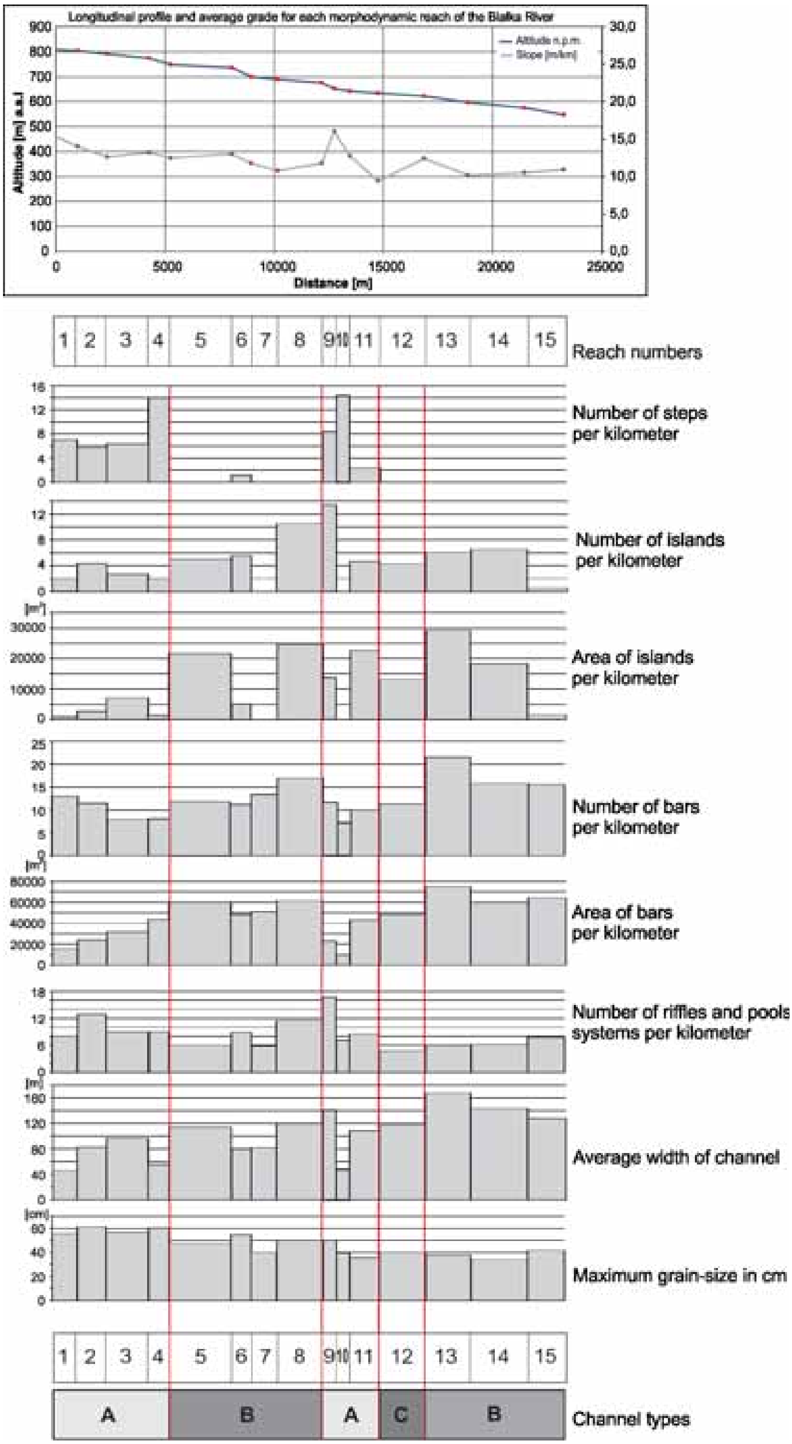

Figure 3. Characteristics of the Białka River channel and channel types

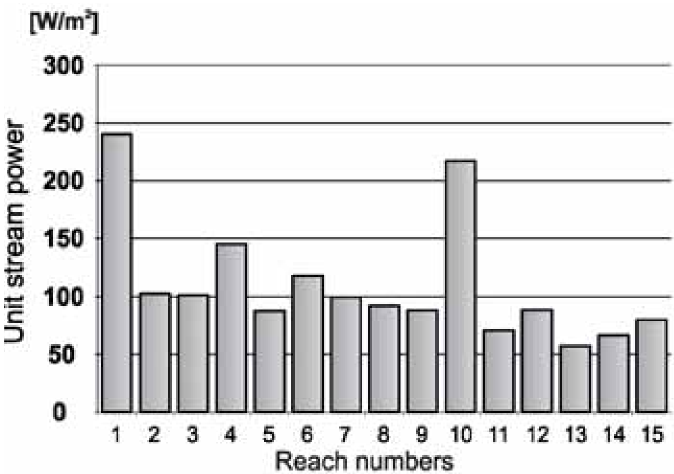

Figure 4. Unit stream power in the reaches of the Białka River channel

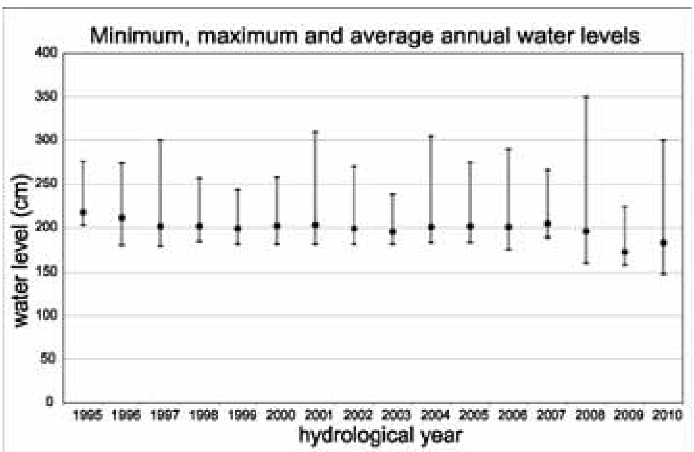

Figure 5. Minimum, average and maximum annual river stages in the years 1995–2010 at the cross-section of the Białka River channel associated with the gauging station at Trybsz

nel's width, and expressed in W/m^2 (Bagnold, 1966; Magilligan, 1992; Fonstad, 2003).

Data on the minimum annual river stages (the period 1995–2000) from the gauging station at Trybsz were used to determine the trend of a transformation of this river's channel at this cross-section over this period of time (Fig. 5).

Moreover, topographical maps from the 19th and the 20th centuries as well as aerial photographs and maps contained in the publications by Baumgart-Kotarba (1983) were used to determine the trend in river channel development.

CHARACTERISTICS OF THE BIAŁKA RIVER CHANNEL AND ITS CHANNEL LOAD

The Białka River channel, downstream from the point where it is joined by the Jaworowy Stream, is very "diverse" (Fig. 2). This pertains to its horizontal layout in the terrain, its longitudinal profile, its cross-section, and the number and size of channel landforms (Fig. 3).

The horizontal layout of the Białka River channel changes along the course of the river. The river channel is mostly winding from the 1st until its 4th reach, and its width is increasing along the course from 25 m to about 50 m. Starting with reach 5 until reach 8 the width significantly increases, from 80 m to 120 m. However, it briefly narrows down to 55 m in some places. They are usually local strengthened embankment zones, but it also happens in the great landslide zone, within reach 6, in the vicinity of Czarna Góra. Farther downstream, within reaches 9 though 11, the river channel changes its type from a braided river channel to a meandering one, subsequently switching back to the braided river channel type. Within these river reaches, the width of the river channel changes from about 120 m down to 35 m, then widening again to 120 m. Starting from the point where Białka River flows in a gorge cutting through the Pieniny Klippen Belt, within reach 12, the channel becomes a typical braided river channel. Its width reaches 230 m. Although wherever the river is meandering, it generally flows in a single channel.

The longitudinal profile of the Białka River channel within the study area is uneven, but rather its slope changes in a concave-convex-concave fashion (Fig. 3). Starting from the 8th river channel reach on, the slope uniformly decreases. Within the researched stretch of the Białka River, its channel is cut in alluvial sediment layers composed mostly of granitoid pebbles. Within the river channel reaches 1 through 4 and 9 through 11, the river cuts through the sediments down to the bedrock made of solid sandstone and shale of the Podhale Flysch, and in some places the river channel is cut in the solid bedrock (Figs. 6, 7). It ought to be mentioned that rock floors also sporadically occur in the 5th and the 6th river channel reaches. The highest rock steps and cascades occur in the 3rd reach, where they even reach 1.5 m in height.

However, in the remaining reaches of the river channel, where there are rock outcroppings right in the river channel, namely in reaches 1, 2, 4, 6, 9, 10, and 11, rock steps reach a maximum of 0.7–1.0 m in height. Most of them are generally low and their height does not exceed 0.5 m.

The shape of a river channel cross-section is related to both the hydrodynamic conditions of a river as well as the properties of the rock layer that the river channel is cut in (Kaszowski, 1973). The shape of a cross-section of the Białka River channel most often reminds a trapezoid or a rectangle, more rarely it is elliptical. There are significant differences in the channel's width and depth from one reach of the river to another. This creates an environment of variable conditions for its modelling and for channel load transport.

The distribution of river bars and islands as well as cases of bank undercutting is generally related to the river channel type. River bars are most numerous in braided river channels, such as the reaches 8 and 13 of this river channel (Fig. 3). When it comes to the area occupied by river bars, the reaches 3–8 and 11–15 that are similar to each other stand out of the rest. Islands are most numerous in river channel reaches 8 through 9, 13 and 14, and their presence is typical for a well developed braided river channel type. The largest islands are found in the 5th reach and in the reaches 11 through 14. The cases of river bank undercutting are rather infrequent, and they are found primarily in the downstream course of the Białka River. The river channel there is typical for a braided river. The area of bank undercutting is rather significant, and it is noticeable at the beginning of the researched stretch of the river channel and also in the downstream part of the river – within the reaches 11 through 15.

The maximum grain size of channel load material does not show significant changes over the length of the river (Fig. 3). The size of the pebble fraction is rather large, from 55–62 cm at the beginning of the researched stretch of the river channel to 35–41 cm in the downstream part of the river. The size of the largest grain fraction of channel load is not very diversified and it ranges from 55 to 62 cm in the upper part of the researched river channel, from the 1st to the 4th river channel reach. The maximum size of the pebble fraction is 40–55 cm within the reaches 5 through 9. Then, there is a small change in diameter of the maximum grain size fraction, starting in reach 10. The grain size is in the range 35–41 cm.

In three of the river channel reaches, there is clearly a trend for the grain size of the pebble fraction to become smaller, but in the last reach the pebble grain size increases by 6 cm. The river energy distribution during large floods (Fig. 4) in undoubtedly related to the maximum grain size fraction of the channel load. The unit stream power is not uniform, but its high values may explain the river's activity within the researched river reaches. The highest unit stream power values occur in the river channel reaches 1 and 10, which are narrow and cut in a solid rock. Stretches of the river channel along its longitudinal profile may be identified, where the unit stream power is decreasing or increasing. The highest unit stream power values occur in reach 1. Then, the values of the same parameter are mostly increasing in the reaches 2 through 4. The parameters values are steadily decreasing in the reaches 6 through 9. There is a sudden increase in the unit stream power in the 10th river channel reach. In the reaches that follow, again there are increases in the parameter's value – in the reaches 11 through 12 and in the reaches 13 through 15.

There are rocky and alluvial parts of the channel along the Białka River's longitudinal profile and they occur interchangeably. Generally, the water current strength is rather significant regardless of the channel type, which causes the deepening of the researched river due to erosion.

THE RIVER CHANNEL STRUCTURE

After a detailed analysis of the properties of the river channel, channel forms and channel material, an attempt was made to establish how this river channel developed and what its channel types are. In order to accomplish this, the types of river channel reaches were determined by using the method of reach endpoint (or a boundary) analysis (Kaszowski and Krzemień, 1999). Based on the quantitative and qualitative properties and also the kind of a river channel substrate, a summary of types was prepared for the basic river channel reaches (Fig. 3). Then, the number of reach boundaries showing a particular trend for a given parameter was found. Next step was to evaluate the importance of these boundaries. The boundaries most frequently repeating were judged to be the channel type boundaries, and those less frequent to be the channel sub-type boundaries (Fig. 3). Four types of river channels were identified within the fluvial system of the Białka River channel. They were labeled from A to D. These types are characterized by the fact that each one possesses a defined leading function within the entire river channel system. The following types of river channel reaches are clearly distinguishable in the longitudinal profile of the Białka River channel.

Type A is a typical river channel, which is shaped by deep erosion. A river carves its channel mostly in fluvial sediments composed of large-grained rock material, or in the bedrock. Sometimes the river cuts through sediments down to the bedrock. This type of river channel is found in the reaches 1–4 and 9–11 (Figs. 6, 7). The channel within these reaches is usually deeply cut into the bottom of the valley, from 2.0 m to 2.5 m. There are steps on the river bottom, but they are low – not exceeding 0.5 m, only sometimes the height of the steps reaches 0.7 m to 1.5 m. Deep erosion is the dominant process in reaches 9 through 11. This fact was also stated by Baumgart-Kotarba (1983). A river channel of this type is characterized by a trapezoidal or a rectangular shape of a cross-section. The landscape of the alluvial plain also indicates an erosional channel type in the reaches 1 through 4 and 9 through 11. The alluvial plain landscape includes meander cut-offs, which are unused

Figure 6. Rock steps in the Białka River channel (reach 4)

Figure 7. Bedrock of the Białka River channel in its middle course (reach 10)

and cut-off river bends (Baumgart-Kotarba, 1983). The river channel in the 4th reach is in part changed by man. An embankment was built on the right bank and the river bottom was levelled in the downstream part of the reach 4 by a bulldozer. The 10th reach of the river channel was in part trained in the vicinity of a bridge by building bank reinforcements of sandstone blocks.

Type B includes gravel river channels, such as reaches 5–8 and 13–15. Such a channel is formed by a river that cuts into a wide valley floor that is composed of gravel with a top layer of alluvial formations. This is a braided river channel, but sometimes it is meandering. It is primarily shaped by the processes of deposition and re-deposition and by lateral erosion. Deep erosion occurs in some parts of the river, which is confirmed by existing rock steps and rock floors as well as abandoned side channels. Baumgart-Kotarba (1983) also mentions these processes as dominating factors in the development of the river channel. Fluvial processes may act without any significant limitations in this type of river channel. The width of the river channel reaches 200 m in the reaches 5–8.

A wide alluvial plain of a braided river, with numerous channel bars, islands and troughs, indicates that the river channel has been migrating substantially. The Białka River channel is a well-developed channel of a braided river system in reaches 13 through 15 (Fig. 8). The Białka River channel is wide – about 160 m in width, and its lateral migration zone here extends up to 350 m. This type of river channel includes trained river channel reaches, where the banks have been reinforced with sandstone blocks – such as reaches 5, 7 and 15. River engineering has been performed in reaches 13 through 15 since the 1960s. The work included reinforcing the banks and straightening the river channel (Baumgart-Kotarba, 1983).

Type C is represented by one reach only, and it is the 12th reach. This river channel is cut in alluvial deposits. This is a river channel type of increased longitudinal gradient and relatively small number of islands and channel bars. This reach of the river channel

Figure 8. Braided river channel of the Białka River within the 15th reach

has been changed substantially by human activity in recent times. The river bottom was levelled by a bulldozer. The banks have been reinforced by building embankments made of sandstone blocks and granitoid pebbles. Aggregate mining still occurs in some places within this river channel reach.

Generally, the river channel structure reflects the main stages in the landscape development of this area, what has been pointed out by Baumgart-Kotarba and Kotarba (1979) and also Baumgart-Kotarba (1983). The longitudinal profile of this river channel is diverse, especially in the upper and middle course of the river. The "maturing" of the river channel by its backward smoothing is thus taking place in several reaches simultaneously.

PRESENT-DAY DYNAMICS OF THE BIAŁKA RIVER CHANNEL

A typical property of the river channel along the researched section of the Białka River is the diversity of longitudinal gradients, of the width of the river channel with the associated flood plain, and of the extent of lateral river channel migration. The river channel material that is deposited on channel bars of different sizes, along the longitudinal profile of the Białka River channel, contains pebbles composed of granitoid, quartzite and also sandstone and shale of the Podhale Flysch.

River channel material from the reaches 1–4 is carried downstream and deposited in the lower-lying river channel reaches. The extensive channel bars in the 5th reach are a proof of that. The high energy possessed by the river in reaches 1 through 4 is decreased when it flows through the wide channel reach with an extensive bank undercutting. The energy of the river is very high again when it flows through the rocky channel of reach 10, but large grain size material here is scarce (Figs. 4, 7). One may think that available material that could be transported had been mostly carried away farther downstream to river channel reaches lying below. In the alluvial part of the river channel, after the river passes the gorge that cuts through the Pieniny Klippen Belt, the river flows via one engineered river channel and the lateral migration of the river channel within the flood plain occurs. The width of the flood plain, which includes the channel, is about 350 m (Fig. 8). Generally, deep erosion is a dominant process in the rocky parts of the channel, and re-deposition is a dominant process in the alluvial parts of the researched river channel.

During fieldwork, special attention was paid to the shape of channel bars made of sediment and to the material that was clearly imbricated in the Białka River channel. The material is a very good indicator of the river's transport capability, because if it is imbricated, then it must have been transported during recent high flows. It was concluded based on measurements performed that during flood stages the Białka River may transport material of significant grain sizes, from 60 cm in the upstream river reaches to 35–40 cm in the downstream river reaches. The energy level of the river is high, even very high. The main present-day problem regarding the river is the very increase in its energy level. This happens because of river bank engineering, aggregate mining, cutting through islands using bulldozers, and also levelling the bottom and banks of the river. These actions lead to an increase in the river's energy level.

The changes that are being made to the course of the river occur mostly in the vicinity of Czarna Góra, Białka Środkowa and Nowa Biała. There are two issues related to the area in the vicinity of the villages. On one hand, a lateral migration of the Białka River channel is occurring thus creating a threat to nearby buildings. On the other hand, if for a certain period of time floods do not occur or for the time being the embankments are strong enough to prevent it, then the construction of new homes in the area increases. This leads to pressure by the local population for more river training.

The Białka River channel is still a good example of a braided river channel, and it is the only river channel of this type in Poland. The entire length of this river channel should be protected as a natural area. The information signs posted along river reaches 13 through 15 are an indication that this way of thinking has taken root. Meanwhile, the deep erosion process in the Białka River channel is progressing at a high rate. This is due to river training and sediment extraction. Comparing the results of this research with those published by Baumgart-Kotarba and Kotarba (1979) and also Baumgart-Kotarba (1983), the river channel changes are not beneficial from a geomorphological and ecological point of view, and they are progressing very fast. A protection program is needed, similar to the one introduced to protect the braided river channel of the Feshie River in Scotland (Werritty and Brazier, 1991). In the meantime, human intervention into the Białka River keeps taking place. "Small", project-based training works are implemented on an "emergency basis" in order to ensure protection from floods, to protect health, life, and property of people in the local towns and villages of Jurgów, Bukowina Tatrzańska, Czarna Góra, Krempachy, Nowa Biała, Frydman and Dębno.

The work there is focused on moving gravel material in order to build dams for water mill streams, and on removing channel bars and gravel piles in order to force the water current into the middle part of the river channel, which includes cutting through islands. Moving of gravel material is planned in order to raise the elevation of the banks. Removal of wooden debris that was brought into the river channel by flood waters is also planned. The named activities were allowed by the Regional Water Management Office in Kraków. A decision on these matters was made in June of 2010. It is further stated in the decision that the use of heavy machinery is required for the tasks, and that gravel material will be moved, but not taken out of the Białka river channel. It was found during an on-site inspection that river channel material is still extracted for the needs of local population. The Regional Director for Environmental Protection in Kraków feels that the planned work will not cause a "significant negative impact on species and their habitats that are protected within the Białka River Gorge at Krempachy [”Przełom Białki pod Krempachami”] Nature Reserve and the Białka River Valley ["Dolina Białki"] Natural Area, which is included in the Nature 2000 protection program."

These decisions do not do any harm over a short period of time, within one year, but in the long run they will be harmful. Relatively small interventions into the river channel, in the opinion of the Regional Water Management Office, will allow cutting through the Białka River alluvial formations, and the braided river channel will be transformed into a single channel rocky river channel. Examples of this exist in the Podhale region (Krzemień, 2003; Korpak, 2007) and in the Beskidy Range (Zawiejska and Krzemień, 2004; Korpak *et al*., 2008). Moreover, material of organic origin, deposited in the river channel during floods, should not be removed because of considerations regarding sedimentology and ecology (Wyżga and Zawiejska, 2005).

As emphasized by Baumgart-Kotarba (1983), transformations of the Białka River channel consist mostly of the following changes: lateral migrations, channel bar deposition, and the local deepening of the river channel to 1–1.5 m in depth. The braided river channel type of the Białka River is related to the washing out of material of the thick layers of glaciofluvial deposits found in upper terraces.

As stated by Baumgart-Kotarba and Kotarba (1979) and also Baumgart-Kotarba (1983), the rate of lowering of the Białka River channel is increasing. This is attested to by the increasing area of rock exposures in the form of steps, troughs, and rock floors, the disuse of meander cut-offs and side channels. Other symptoms of the river channel lowering are: the increasing length of the river channel with rock exposures, the lowering of minimum annual river stages as measured at the gauging stations (Fig. 5), the increased length of straightened river channel reaches. The process of deepening of the Białka River channel is still rapidly occurring at the gauging station at Trybsz, where the river channel is rocky (Fig. 5). The river channel became lowered by 51 cm in the years 1995–2010. This means that the average annual depth increase was 3.4 cm per year. This value is almost the same as in the 55-year long period of time (1925–1980) when the channel was mostly cut in an alluvial substrate. The pace of the processes of this type in the Białka River channel is not different from those occurring in channels of other rivers in the Podhale region (Krzemień, 2003; Korpak, 2007).

The large number of erosional channel forms, especially concentrated in river channel reaches 1 through 4 and 9 through 11, should be ascribed to the great strength of the water current (Fig. 4). Clear signs of the occurrence of deep erosion processes were observed when many new rocky channel forms were created after the flood of 2008.

Further actions of deep erosion may lead to the degradation of the braided river system in the future. It is of special importance to pay attention to engineering work involving bridge repairs, strengthening embankments, and digging of channel shortcuts in the central part of the braided river channel. Giving the river a zone for lateral migration would be a long-term protection measure against potential problems related to the increasing pace of deep erosion. On the other hand, leaving the river as it is, which should be judged as a good condition, ought to be one of the priorities for spatial planning. This river channel is especially valuable and it should be protected as a treasure of nature.

Present-day shaping of the researched river channel varies over the course of the longitudinal profile. The shaping involves carrying away of fine material and building-up of the river channel armor (Fahnestock, 1963; Krzemień, 1992). This process clearly intensifies as the river flows downstream. The narrowing of the river channel and the artificial embankments intensify the trend to deepen the river channel and to carry away gravel material down to the Czorsztyn Water Reservoir.

CONCLUSIONS

The present-day Białka River channel has been, so far, the least transformed river channel out of the river channels crossing the Podhale region, when it comes to the share of anthropogenic factors taking part in the change. This river channel is still a good example of the braided river channel development among the rivers originating from the Tatra Mountains. The remaining channels, of the Biały Dunajec and the Czarny Dunajec rivers, have been trained to a large degree. If the Białka River channel is not protected, it will become a single channel river channel that is mostly cut in a solid rock. This way, one of the most valuable river channels in Poland will suffer, just like many river channels of this type in the Carpathians. The existing trend to cut deeper into the Białka River channel along its course will intensify due to changing land use in the river's catchment. These types of changes in land use can be clearly seen in other Carpathian catchments.

Any form of aggregate mining in the Białka River channel system ought to be absolutely disallowed. It is necessary due to harmful changes to its channel. It is necessary to protect the unique, semi-natural reaches of the river channel, still not destroyed by excessive human intervention. The kinds of programs for river channel protection have been introduced earlier in other areas in Europe, for example in the mountains of Scotland. The research of the Białka River channel and its findings may be taken as a warning against excessive human intervention in a fluvial system. Such intervention destroys natural river channels without the possibility of retracting to the original state. In addition, the planned goal is not achieved, which was to limit the channel load transport and the lateral migration of the channel. The intervention in the Białka River channel and its surroundings, so far, has caused a clear increase in the pace of deep erosion. This, in turn, causes many harmful changes in the natural environment, such as an increase in groundwater drainage.

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REFERENCES

Bagnold, R.A. (1966), An approach to the sediment transport problem from general physics, *US Geological Survey Professional Paper*, 422-J, Washington, DC.

Baumgart-Kotarba, M. and Kotarba, A. (1979), Wpływ rzeźby dna doliny i litologii utworów czwartorzędowych na wykształcenie koryta Białej Wody w Tatrach [Influence of the landscape of a valley bottom and the lithology of Quaternary formations on the development of the Biała Woda River channel in the Tatra Mountains], *Folia Geographica, series Geographica-Physica*, 12: 49–66.

Baumgart-Kotarba, B. (1983), Kształtowanie koryt i teras rzecznych w warunkach zróżnicowanych ruchów tektonicznych (na przykładzie wschodniego Podhala) [River channel and fluvial terrace development under the conditions of diverse tectonic movements (on the example of the eastern Podhale region)], *Prace Geograficzne* 145, Instytut Geografii i Przestrzennego Zagospodarowania (IGiPZ) PAN: 7–133.

Chełmicki, W. and Krzemień, K. (1999), Channel typology for the river Feshie in the Cairngorm Mts, Scotland, in Krzemień, K. (ed.), *River channels. Pattern, structure and dynamics*. *Prace Geograficzne Instytutu Geografii UJ*, 104: 57–68.

Chorley, R.J. and Kennedy, B.A. (1971), *Physical geography. A systems approach*, London, Prentice Hall, 1–370.

Dobija, A. (1981), Sezonowa zmienność odpływu w zlewni górnej Wisły (po Zawichost) [Seasonal variability of runoff in the catchment of the upstream part of the Wisła (Vistula) River (down to Zawichost)], *Zeszyty Naukowe UJ, Prace Geograficzne*, 53: 51– 112.

Fahnestock, R.K. (1963), Morphology and hydrology of a glacial stream – White River, Mount Rainier, Washington, *USGS Professional Paper*, 422-A: 1–70.

Fonstad, M.A. (2003), Spatial variation in the power of mountain streams in the Sangre de Cristo Mountains, New Mexico, *Geomorphology*, 55, 75–96.

Gorczyca, E. and Krzemień, K. (2010), *Chanel Structure Changes in Carpathian Rivers*, in Radecki-Pawlik, A. and Hernik, J. (eds.), *Cultural Landscapes of River Valleys*, Wydawnictwo Uniwersytetu Rolniczego w Krakowie, 185–198.

Hennig, J., Pietrzyk, J., Solik, R. and Zelech, M. (1968), *Dane wyjściowe systematycznej regulacji rzeki Białki Tatrzańskiej z dopływami* [Output data on the systematic river regulation of the Białka Tatrzańska River with its tributaries], Hydroprojekt- Kraków Oddział II, unpublished report.

Kamykowska, M., Kaszowski, L. and Krzemień, K. (1999), River channel mapping instruction. Key to the river channel description, in Krzemień, K. (ed.), River channels, Pattern, structure and dynamics, *Prace Geograficzne Instytutu Geografii UJ*, 104: 9–25.

Kaszowski, L. (1973), Morphological activity of the mountain streams (with Biały Potok in the Tatra Mts. as example), *Zeszyty Naukowe UJ, Prace Geograficzne*, 31: 1–101.

Kaszowski, L. and Krzemień, K. (1999), *Classification systems of mountain river channels*, in Krzemień, K. (ed.), *River channels, Pattern, structure and dynamics*, *Prace Geograficzne Instytutu Geografii UJ*, 104: 27– 40.

Klimaszewski, M. (1972), *Karpaty Wewnętrzne* [The Inner Carpathians], in: *Geomorfologia Polski*, T. 1, *Polska Południowa*, [Geomorphology of Poland, Vol. 1, Southern Poland], Wydawnictwo Naukowe PWN, Warszawa, 25–52.

Korpak, J. (2007), The influence of river training on mountain channel changes (Polish Carpathian Mountains), *Geomorphology*, 92: 166–181.

Korpak, J., Krzemień, K. and Radecki-Pawlik, A. (2008), Wpływ czynników antropogenicznych na zmiany koryt cieków karpackich [Influence of anthropogenic factors on changes in the Carpathian stream channels], *Infrastruktura i Ekologia Terenów Wiejskich* [Infrastructure and Ecology of the Countryside], 4, a monograph series, Komisja Technicznej Infrastruktury Wsi, PAN: 1–88.

Krzemień, K. (1992), The high mountain fluvial system. The Western Tatra perspective, *Geographia Polonica*, 60: 51–65.

Krzemień, K. (2003), The Czarny Dunajec River, Poland, as an example of human-induced development tendencies in a mountain river channel, *Landform Analysis*, 4: 57–64.

Magilligan, F.J. (1992), Thresholds and the spatial variability of flood power during extreme floods, *Geomorphology*, 5: 373–390.

Ozga-Zielińska, M. and Brzeziński, J. (1994), *Hydrologia stosowana* [Applied hydrology], Wydawnictwo Naukowe PWN, Warszawa.

Wasson, J.G., Bethemont, J., Degorce, J.N., Dupuis, B. and Joliveau, T. (1993), *Approche ecosystémique du bassin de la Loire*. *Eléments pour l'élaboration des orientations fondamentales de gestion*, Lyon, Saint-Etienne, 1–102.

Werritty, A. and Brazier, V. (1991), *The geomorphology, conservation and management of the River Feshie SSSI, Report for the Nature Conservancy Council,* Department of Geography and Geology University of St. Andrews, 1–69.

Wyżga, B.J. and Zawiejska, J. (2005), Wood storage in a wide mountain river: case study of the Czarny Dunajec, Polish Carpathians, *Earth Surface Processes and Landforms*, 30: 1457–1494.

Zawiejska, J. and Krzemień, K. (2004), Man-induced changes in the structure and dynamics of the Upper Dunajec River channel, *Geografický Časopis*, 56 (2): 111–124.

Wolman, M.G. (1954), A method of sampling coarse river – channel material, *American Geophysical Union Transactions*, 35, 6: 951–956.

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