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Geomorphologic effects of river engineering structures in Carpathian fluvial systems

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Abstract: Long stretches of Carpathian river channels have been engineered, which has had an impact on their morphology and functioning. Three different river engineering periods have been identified for Carpathian Mountain rivers – different in terms of the type of work performed and its intensity. The first period covers the third quarter of the 20th century, when a large number of structures (groynes, weirs, debris dams) were built causing significant changes to river channels. The aforesaid structures led to a significant reduction in the amount of alluvia present in river channels, as did large scale gravel removal projects and land use changes in the catchment. The second period (1977–1996) was characterized by a rather small number of river engineering projects. This was the result of a relative lack of major floods during this time period. Channel gradient reduction with use of drop structures was the primary "fix" at the time. It contributed to further reductions in the amount of alluvia present and led to channel deepening, although at a slower rate. The third period (post-1997) was characterized by renewed engineering efforts, which were primarily a response to the occurrence of major floods that helped destroy old hydraulic structures and alter river channels. New types of "natural" engineering structures began to emerge, which were designed to imitate natural channel forms such as rapids. The principal morphologic outcomes of river engineering efforts were the transformation of braided channels into single-thread channels as well as channel deepening and narrowing. River engineering efforts produced the largest changes in channel morphology between 1950 and 1976. Long stretches of river channels were incised as deep as solid rock. Today, the primary fluvial process transforming river channels in the Carpathian Mountains is downcutting.

Introduction

The morphology and dynamics of river channels depend on a variety of environmental factors such as climate, tectonics, and plant cover. As such factors change over time, so do river channels, which are subject to constant transformations. Under natural circumstances, channel evolution is slow. Nevertheless, the 20th century has witnessed an acceleration in the evolution of mountain river channels. The two major changes that have taken place were changes in flow patterns (braided to single-thread) and significant increases in channel depth.

Analysis of climate and hydrological data series has failed to show significant changes in river regimes in the Carpathian Mountains in the 20th century (Stachy & Nowak 1977, Soja 1996, 2002). Morphotectonic research in the Carpathians has indicated some lifting activity in some mountain ranges (Forma & Zuchiewicz 2001), however, the activity has not been strong enough to cause substantial changes or rapid changes in river channels. The aforesaid changes must be attributed to man who exerts a direct or indirect influence on river channel systems. River engineering is clearly the major culprit. Other key forms of human impact include channel gravel extraction and changes in land use. These different forms of human activity have not had a uniform impact on river channels over the last few decades. Consequently, the river channel response has been uneven. The purpose of the paper is to show the different types of human activity exerting an impact on Carpathian fluvial systems during selected time periods as well as to analyze their geomorphologic effects.

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Study area

The research was performed in the channels of small Carpathian rivers such as the Mszanka (Raba Basin), the Porębianka (Raba Basin), and the Biały Dunajec (Dunajec Basin), starting at the point where the Poroniec merges with the Biały Dunajec in the town of Poronin to the mouth of the Biały Dunajec in the town of Nowy Targ. River channels in the area are straight, sinuous, single-thread, narrow, and incised. The two drainage basins differ in terms of geologic structure – variable in the Biały Dunajec Basin and homogenous flysch-type in the Mszanka Basin – as well as relief energy (higher in the Biały Dunajec Basin). The two river channels are typical of high mountain rivers (the Biały Dunajec) and middle mountain rivers (the Mszanka and the Porębianka). What they have in common is the way they have been engineered and the fact that they were engineered at about the same time. Other similarities include the length of their engineered sections and the use of similar longitudinal hydraulic structures (groynes and bank reinforcements) and similar transversal hydraulic structures (weirs, debris dams, drop structures). A number of basic characteristics of the two river channels and their drainage basins are listed in Table 1.

Research methods

In order to understand the history, type, and scope of engineering efforts in the study area, archived river engineering data provided by the Kraków Regional Water Management Authority was analyzed. The data included technical fieldwork descriptions, channel maps (scale: 1:1000 and 1:2000), and channel profiles (longitudinal and cross sectional). Project data for subsequent stages of river engineering provide an excellent source of information on "channel evolution". Other types of data used to assess human impact on river channels and channel response included archived topographic maps and aerial photographs. Cartographic materials were also used to analyze changes in land use. The contemporary morphology of the channels was studied between 2001 and 2005 during a river channel mapping project using a topographic maps at a scale of 1:10 000 as the base maps and a river channel mapping protocol (Kamykowska et al. 1999).

Causes of changes in river channels between 1950 and 2010

River channel engineering

The 1950–2000 study period has been divided into three unique time periods – each being characterized by different types of river engineering efforts in the study area.

River channel engineering between 1950 and 1976

The vast majority of longitudinal structures such as groynes and larger transversal structures such as weirs and debris dams (2.8–5.6 m high) were constructed in the 1960s and 1970s. Drop structures were rarely built at the time (Table 2).

The purpose of building longitudinal structures is to form a new single-thread channel in places threatened by lateral erosion. Selected river sections were shortened, straightened, and narrowed. For example, the section of the Porębianka River channel in Podobin was narrowed by an average of 68% (Fig. 1A). The intensification of discharge and increased gradients in altered channels cause increased erosion and decreased flow resistance. This also leads to a greater transport capability, which combined with a reduced supply of channel sediment, then leads to rapid incision (Bojarski et al. 2005). Lateral erosion is limited due to reinforced river banks. The process of downcutting was the most intensive shortly following river engineering works. The Biały Dunajec channel at

Table 1. Characteristics of the study area

River	Biały Dunajec	Mszanka	Porębianka
Gauging station	Szaflary	Mszana Dolna	–
Drainage area (km^2)	224	175	72
Channel length (km)	35	19.5	15.4
Channel slope (‰)	0.039	0.008	0.036
Channel width (m)	1–142	1–35	1–140
Q_2 (m^{3}s^{-1})	90	52	–
Q_{10}(m^{3}s^{-1})	306	190	–
Q_{20}(m^{3}s^{-1})	399	255	–
Q_{100} (m^{3}s^{-1})	622	640	–

Table 2. Progress in river engineering (BD – Biały Dunajec from the confluence with the Poroniec River to the mouth, M – Mszanka, P – Porębianka)

Type of river training	State in 1976 r.			State in 1996 r.			State in 2005 r.		
	BD	M	P	BD	M	P	BD	M	P
Number of debris dams or weirs	3	2	2	2	3	2	3	3	2
Number of drop structures	8	1	5	19	20	20	19	29	39
Length of the channel trained with groynes (percent of the entire river length)	19.5	4.0	18.9	18.4	4.0	21.0	8.7	4.0	2.1
Length of the channel trained with bank reinforcements (percent of the entire river length)	9.1	5.7	0	7.9	10.4	0.9	10.5	16.1	7.8
Length of the channel trained with drop structures (percent of the entire river length)	4.4	0	2.0	17.6	18.8	13.5	17.6	29.6	30.2

Szaflary became one to two meters deeper during the first six years (by 1977) following channel engineering. The maximum increase in depth was three meters by 2003 (Fig. 2). A lowering channel bed produced an increase in riverbank height. The space between groynes (quickly filled in with alluvia) became a terrace slowly filling with vegetation. This further reduced the amount of material being transferred to the river and reinforced its incision tendencies. Given the situation at hand, the only way a river can reestablish equilibrium is to reduce its gradient via deposition downstream and degradation upstream from the incised channel reach (Parker & Andres 1976). Consequences of channel incision included the exposition of groyne foundations and their gradual damage, further accelerated by large floods. River banks became unprotected from erosion at locations where groynes had become damaged. The river would gain a new means of adjusting its course to an altered regime via lateral migration. The Podobin groynes was most likely damaged during a flood in 1970. The average channel width increased by 150% shortly thereafter (Fig. 1B).

The purpose of debris dams is to limit the amount of channel bedload being deposited along downstream sections of river, which helps to protect adjacent land areas from flooding. Debris dams are installed along

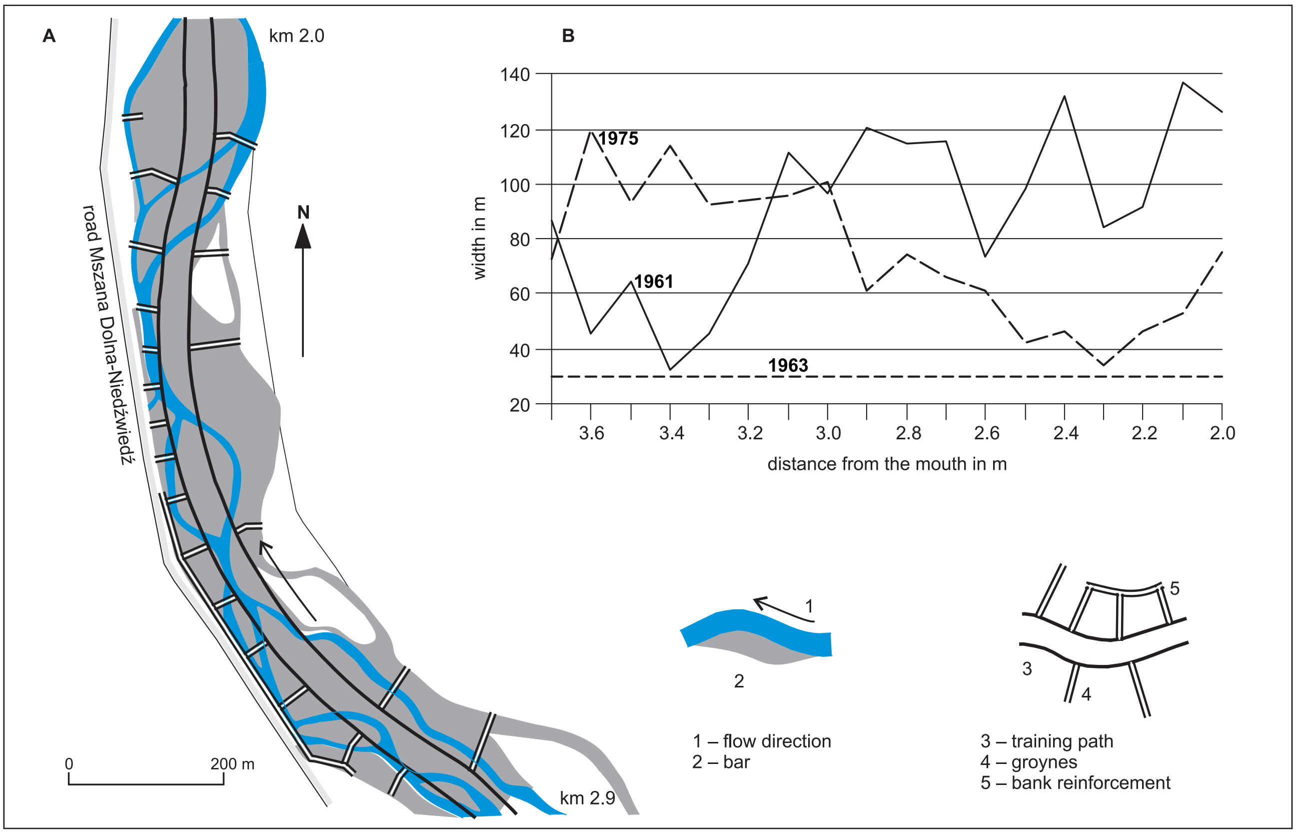

Fig. 1. The Porębianka River channel training with groynes in Podobin in 1962: A – change of the channel course, B – change of the channel width after training and after flood in 1970 (according to the technical design of regulation works No 4052 and the orthophotomap from 1975)

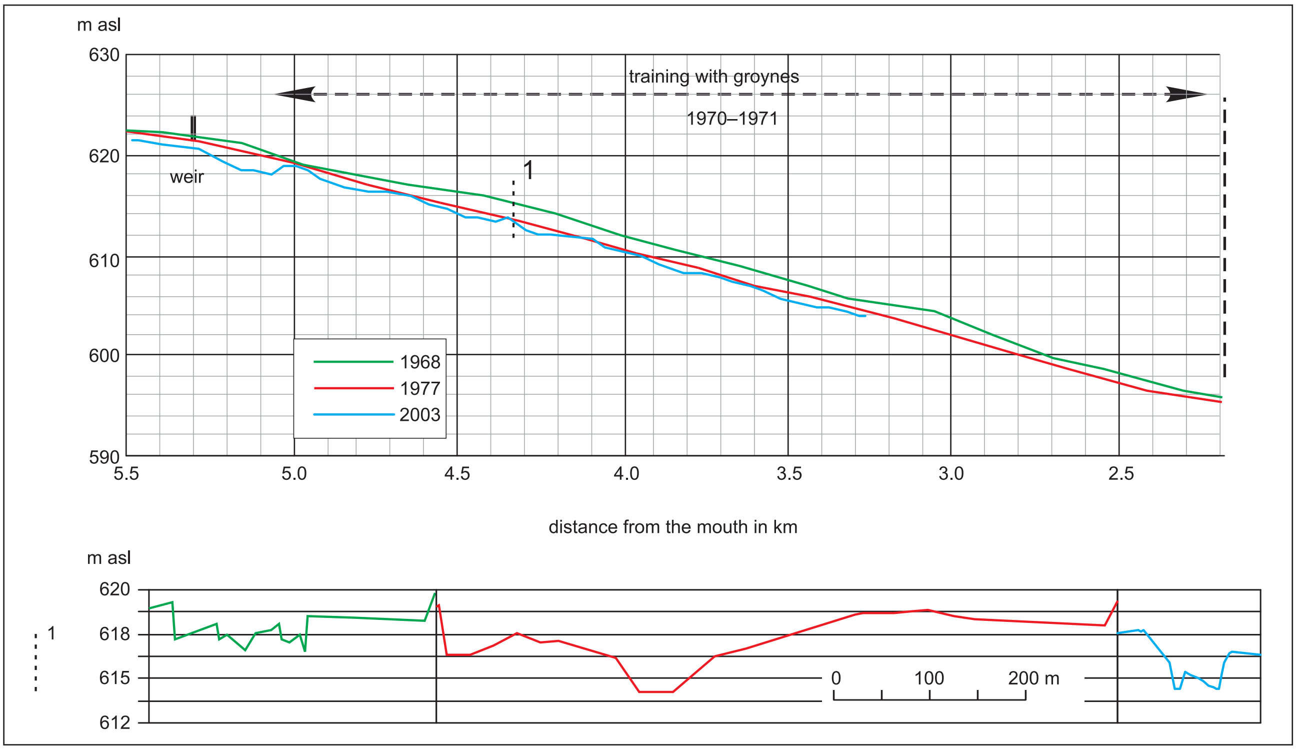

Fig. 2. The deepening tendency changes of of the Biały Dunajec River channel reach trained with groynes (according to the technical designs of regulation works No 3964, 101 and 2064)

the middle course of a river in alluvial sections characterized by intensive bedload transport and deposition. The primary purpose of weirs is to slow down water in order to capture it for a variety of uses. The secondary purpose of weirs is to limit channel bedload transport, which has a profound effect on channel morphology. From a geomorphologic point of view, weirs and debris dams play a similar role. As channel bedload becomes trapped upstream of the structure, the flow downstream of the dam becomes sediment-starved. As a result the channel upstream and downstream of the dam develops in other ways (Fig. 3A) and the continuity of a fluvial system is interrupted (Korpak 2008).

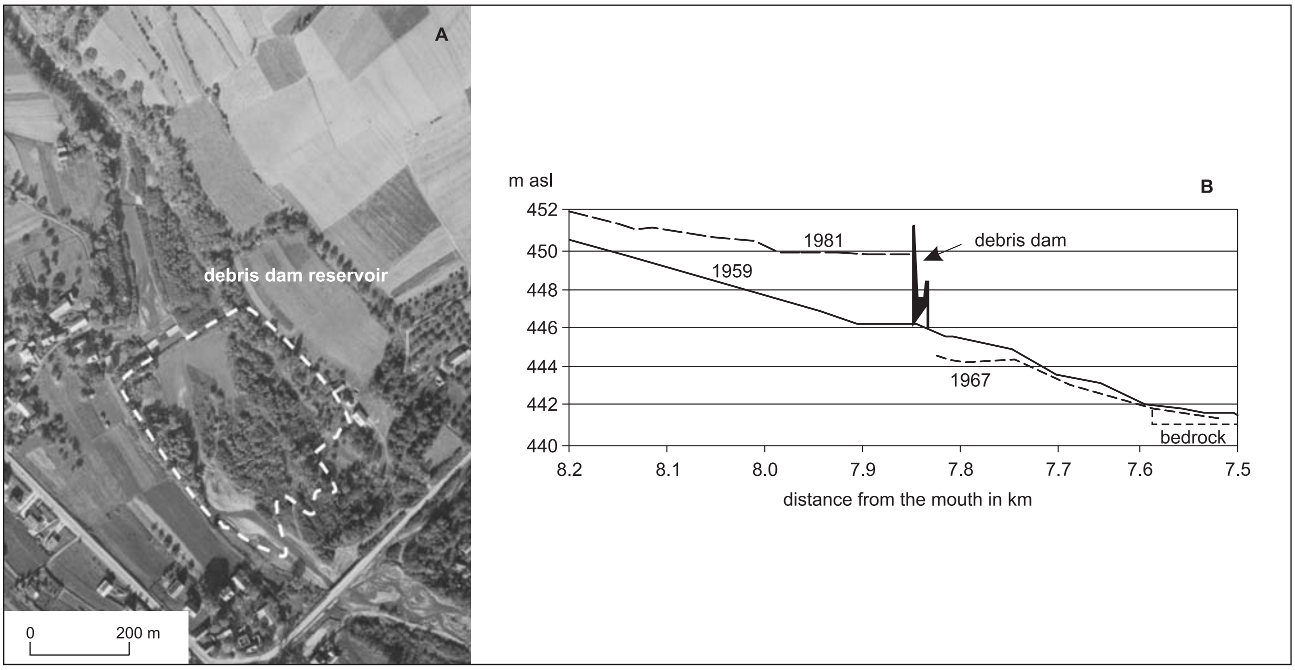

Fig. 3. Debris dam from 1961 in the Mszanka River channel in Mszana Górna II: A – different channel development upstream and downstream from debris dam in 1975, B – changes of channel bed level upstream and downstream from debris dam (according to the technical designs of regulation works No 2196, 1682 and 3375)

Changes upstream of debris dams in the study area affected reservoirs and reaches featuring reverse flow (several hundred meters, on average). Reservoirs are strongly affected by deposition. Reservoir floors slowly rise as do entire reaches of river bed in areas affected by reverse flow. The amount of deposited material becomes larger with decreasing distance to the debris dam. The floor of the Mszanka Reservoir at Mszana Górna II rose four meters between 1959 and 1981, while even at a distance of 300 m from the debris dam, a rise of 1.5 meters had been detected (Fig. 3B).

In most cases, changes taking place downstream from debris dams and weirs affected several hundred meters of channel length. The aforesaid reaches of channel changed from braided to single-thread sinuous (Fig. 3A). The main process responsible for forming these sections was downcutting, which was found to be at its peak shortly after the construction of a hydraulic structure. Six years after the Mszana Górna II debris dam was constructed, the river's channel gradient increased from 10.5‰ to 11.8‰. At the same time, the channel bed downstream from the structure became 1.5 m lower. At a distance of 200 m downstream from the structure, the channel's depth was only 0.5 m greater (Fig. 3B). The erosive power of the river had reached solid rock at this location, which did not stop the process of downcutting but only made it slower. The process of channel deepening was accompanied by the process of channel narrowing. At Mszana Górna II, the width of the river channel decreased from 34 m to 9 m over the course of six years – a decrease of 73.5%. The old river bed became filled with vegetation and transformed into a floodplain.

River engineering efforts between 1950 and 1976 resulted in significantly deeper channels and smaller amounts of material available for fluvial transport.

River channel engineering between 1977 and 1996

This time period was characterized by far fewer river engineering projects. One reason for this was the lack of larger floods between 1975 and 1996. Only the Mszanka River, which had not been subject to much engineering work, was "redone" along a substantial part of its length (Table 2). The way that channels were to be engineered changed during this period of time in response to channels becoming too deep. Virtually the only type of work done on channels at this time was gradient reduction with use of drop structures. The main purpose of this effort was to limit the incision of river channels (Table 2). Drop structures were usually applied to sections of river featuring intensive downcutting including areas downstream of debris dams and along sections with groynes. Channels undergoing gradient reduction were single-threaded, shorter, less sinuous, and much more narrow than natural channels (Fig. 4). In Nowy Targ, the width of the river channel was reduced about 40%, while in Mszana Górna and Mszana Dolna, it was 16% to 65%. Finally, a 50% reduction in channel width was achieved in Podobin. Channel width was kept uniform along the entire reach of river being engineered. In order to prevent the channel from incision, one meter high drop structures were constructed. River banks were reinforced, which served to prevent channel widening resulting from lateral erosion. Immediately following gradient reduction, channel bedload would start to deposit behind the drop structures. This would lead to a channel bedload deficit downstream, which would focus all of the river's flow energy towards channel bed incision. The process of channel incision downstream of drop structures was also the result of the way river engineering itself had been performed. Bulldozers were used to level the riverbed, thereby destroying the imbricated layer that protects against erosion. After a certain amount of time following gradient reduction, the space upstream of the drop structures would become filled with bedload. This was followed by the leveling of the step-type surface of the riverbed. Instead of re-depositing fluvial material, the river channel would transport it downstream. Gradient reduction with use of drop structures was always somehow incompatible with the variety of water levels and discharge rates of the rivers in the study area. At low water levels, the resulting engineered channel was too wide. The river would then deposit narrow bars along its banks, which would narrow down the river channel. At high water levels and high rates of discharge, the pathway would prove to be too narrow, and the river would erode its banks and the channel bed. Drop structures and riverbank reinforcements would become destroyed in the process. The channel bed would then evolve via the washing away of old banks and the deposition of new ones. Consequently, channel restoration efforts had to be undertaken following every major flood.

The construction of drop structures did, in fact, reduce the river's channel incision rate. However, it not only did not solve the channel bedload deficit problem but tended to exacerbate it (Korpak 2007a).

River channel engineering after 1997

Intensive river engineering efforts began anew after 1997. The work was designed to fix the damage caused by several major floods taking place in 1997 1998, and 2001. Drop structures and river bank reinforcements were mostly build (Table 2). Engineers abandoned the use of groynes and debris dams, as they were very "invasive" in nature, and ultimately proved to be ineffective in mountain rivers over the long term. Traditional concrete drop structures continued to be used, although they do not aesthetically blend in with their surroundings and create unfavor-

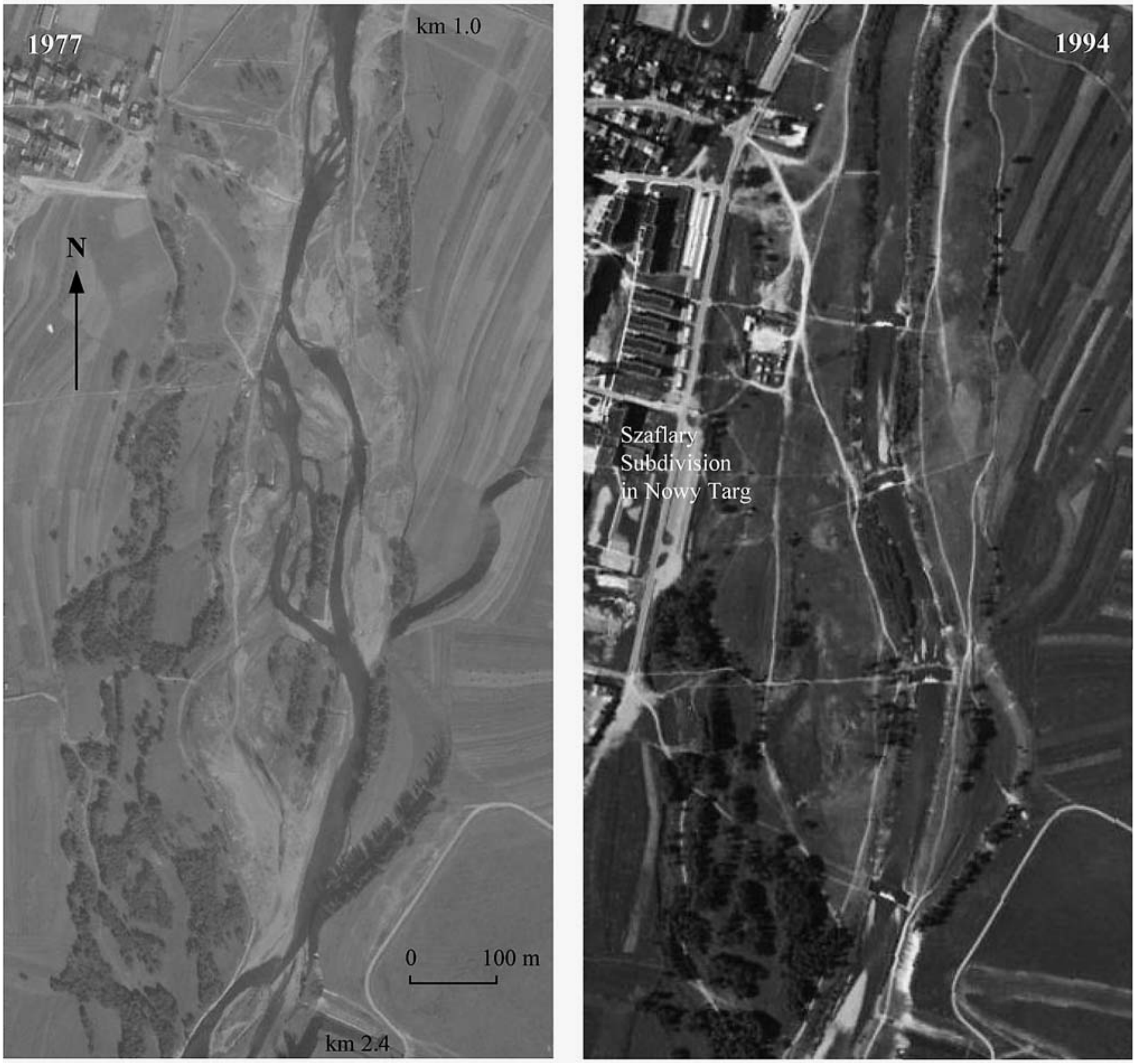

Fig. 4. The course of the Biały Dunajec River channel in Nowy Targ before and after the construction of drop structures

able conditions for migrating fish. Rapid hydraulic structures were introduced at this time. These structures imitate natural mountain river and stream rapids in terms of appearance and function. Rapid hydraulic structures function in an equivalent manner to concrete drop structures by reducing gradients without impeding fish migration. In addition, these types of structures help aerate water (Żbikowski & Żelazo 1993) and are constructed using natural materials that increase channel bed roughness. The reach of the Porębianka running through the town of Podobin is one location where rapid hydraulic structures have been constructed (Fig. 5). Each rapid structure consists of two rows of watertight walls made of steel. The space between the walls is filled with stones with a diameter of over 0.5 m (according to technical design No. 1889).

Fig. 5. The rapid hydraulic structure in the Porębianka River in Podobin

Gravel extraction from the river bed

The extraction of gravel from the river bed leads to a disequilibrium between debris supply and a river's ability to transport debris. In most cases, the rate of gravel extraction is much higher than the natural rate of replacement driven by fluvial transport from upstream locations and a river's overall drainage basin (Kondolf 1997). The channel sediment deficits force rivers to focus their erosive power on channel incision (Galarowski & Klimek 1991, Kondolf 1997, Radecki-Pawlik 2002).

Gravel extraction was at its peak in the Podhale region in the 1950s (Kukulak 1994). The same was true of the Gorce Mountain region in the 1960s (Osuch 1968). Gravel extraction was pursued on an industrial scale until the late 1970s, with the primary end users being the residential and commercial construction industry and the road construction industry. Crystalline rock material from the Tatra Mountains was considered particularly valuable. The construction industry viewed the Białka Tatrzańska granite quarries as a "natural warehouse of debris and granite… which could be used to produce as much as one million tons of rock" (Ring 1956). Large gravel extraction operations were also set up in the Czarny Dunajec and the Biały Dunajec rivers (Kukulak 1994).

The era of industrial scale gravel extraction eventually came to an end. This type of activity did continue but it was now geared mainly towards local construction needs. Today, the extraction of river channel debris is against the law, however, there are still signs of small scale activity across the study area. Most bars along the Biały Dunajec, the Mszanka, and the Poręcbianka show signs of extraction in the form of depressions, excess amounts of fine-grained gravel, and a shortage of imbricated layer. River channel material has been observed in the foundations of most local homes – both old and new. Other signs of extraction activity included the presence of bulldozers and horse-drawn carriages in river channels. Special structures such as small bridges and platforms dot the area, enabling locals to easily transport river channel material for construction purposes. Piles of pebbles ready for shipping have also been observed along some stretches of river.

Changes in land use

Most Carpathian rivers possessed wide braided channels at the beginning of the 20th century. This was also true of most of their smaller tributaries up until the 1950s. This was not a natural state but one largely determined by human impact. Forests have been cleared in the Carpathian Mountains for hundreds of years in order to create open space for agriculture. Plowed slopes – unprotected by natural vegetation – supplied fine-grained material to river channels. Most rivers were not capable of transporting this much sediment and this resulted in the accumulation of fluvial material.

Land use in the Carpathian Mountains slowly began to change in the 1950s. Animal husbandry became an important industry. Farmland was turned into meadows in order to feed animals (Guzik 2004; Fig. 6). Forests also became more commonplace. Local agriculture shifted away from cereals and potatoes and focused on fodder crops (Górz 1994). The 1960s and early 1970s saw the emergence of forests at locations where sheep grazing had been outlawed. As the amount of forest and meadow cover increased, so did the ability of drainage basins to retain water. Reductions in the amount of farmland produced reductions in the amount of weathering material being flushed into river channels. Other practices that reduced the quantity of sediment entering river channels were the abandonment of unused field roads (encroaching vegetation), abandonment of plowing fields straight down hill slopes, and slope terracing (Lach 1984).

The shift in land use, initiated in the 1950s across the Carpathian Mountain region, continues to affect the area today. In fact, it has tended to accelerate after the political system transformation in 1989. The new economic situation in Poland has made agriculture in the Carpathian Mountains unprofitable. The shift from arable land to meadows continued to change the Carpathian landscape. For example, in the mountain Township of Biały Dunajec, meadows have made gains at the expense of arable land between 1988 and 1996, increasing from 39.4% to 84.8% of all cultivated land. In the Township of Nowy Targ, meadows have increased from 42.2% to 72.1% over the same period of time (Górz 2003). Mountain meadows in the Gorce Range have seen a progression from grassland to woodland. A total of 21.5% of meadows became fully covered with forest between 1954 and 1997, while 36.5% were at different stages of reforestation (Wężyk & Pyrkosz 1999). In 1997, about 27% of the Mszanka River Basin was covered by grasses, shrubs, and woodland (Korpak

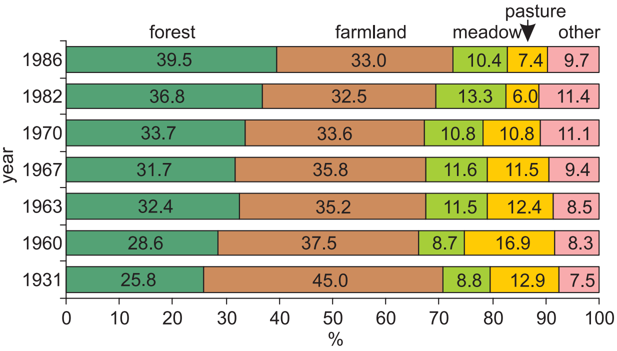

Fig. 6. Land use change in the Podhale region between 1931 and 1986 (according to Górz (1994))

2007b). The study area has also experienced a marked increase in residential construction at the expense of arable land. The new housing units tend to be located close to river channels. An example of this is the Szaflary Subdivision in the City of Nowy Targ (Fig. 4). All of the aforesaid changes have contributed to a decrease in the amount of weathering material being delivered to river channels.

Changes in river channel systems resulting from human impact

Changes in river channel systems have included altered channel courses, widths, depths, channel bed material, types of fluvial forms, number of fluvial forms, and dominant fluvial processes. The greatest changes in channel systems in the study area took place between 1950 and 1976. A large number of river engineering projects were completed. The structures that were built tended to be very "invasive" and generally disrupted channel profile equilibria. At the same time, channel debris extraction reached its peak across the study area. The changes in land use initiated at the time helped to bring about a significant increase in the water retention ability of Carpathian drainage basins. The primary result of the aforesaid forms of human impact was a decrease in the amount of bedload available for fluvial transport. The equilibrium between the amount of bedload available and bedload transport capacity became disrupted. This led to increased channel incision. The river channels in the study area were the most stable between 1977 and 1996. There were a number of reasons for this: 1) lack of major floods 2) long stretches of engineered river channels, 3) good condition of hydraulic structures. Several major floods occurred after 1996, which destroyed quite a few hydraulic structures and led to an automatic "return to nature" at some locations. The floods prompted a response in the form of new river engineering projects.

Most side arm channels ceased to function by 1976. Less sinuous single-thread channels became the standard across the study area (Fig. 7).

River channels became much more narrow and homogeneous, especially their middle and lower sections. Research in the Mszanka River channel has shown that its rate of narrowing was the greatest between 1959 and 1975 (2.5 m/yr). The aforesaid rate decreased five-fold in the years that followed. The smallest and most stable channel width was observed during the 1990s but prior to 1997 (Table 3). A series of floods occurred in 1997 and in the years that followed. This led to the widening of channels at some locations, especially places where riverbank reinforcements had been damaged, prompting lateral erosion (Table 3).

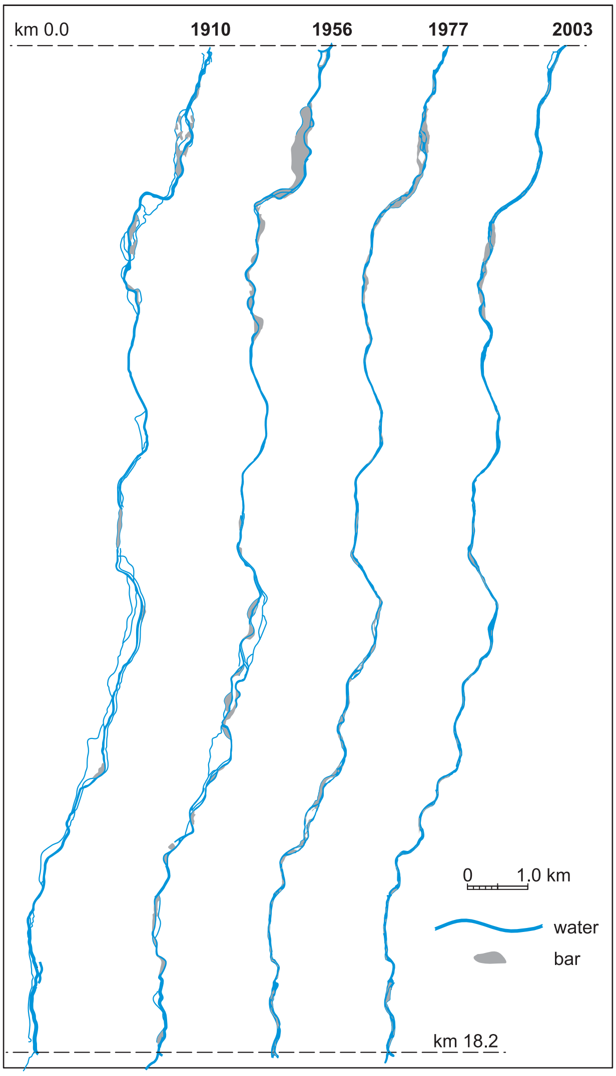

Fig. 7. The change of the Biały Dunajec River channel course between 1910 and 2003 (1910, 1956 – according to the topographic maps at a scale of 1:75 000 and 1:25 000, 1977, 2003 – according to the orthophotomaps at a scale of 10 000)

River channels became much deeper. An analysis of minimum annual water stages in the Biały Dunajec and Mszanka has shown that both rivers began to experience channel incision processes starting around 1960 – more or less the same time as the start of large scale river engineering projects (Fig. 8). Channel cross section data has shown that such pro-

Table 3. The changes in width of the Biały Dunajec channel (based on the measurements using aerial photos)

Year	Width of the Biały Dunajec channel (m) along the reach 18.4–0.0		
	average	maximum	minimum
1977	51.8	234	15
1994	35.1	76	14
2003	45.8	142	18

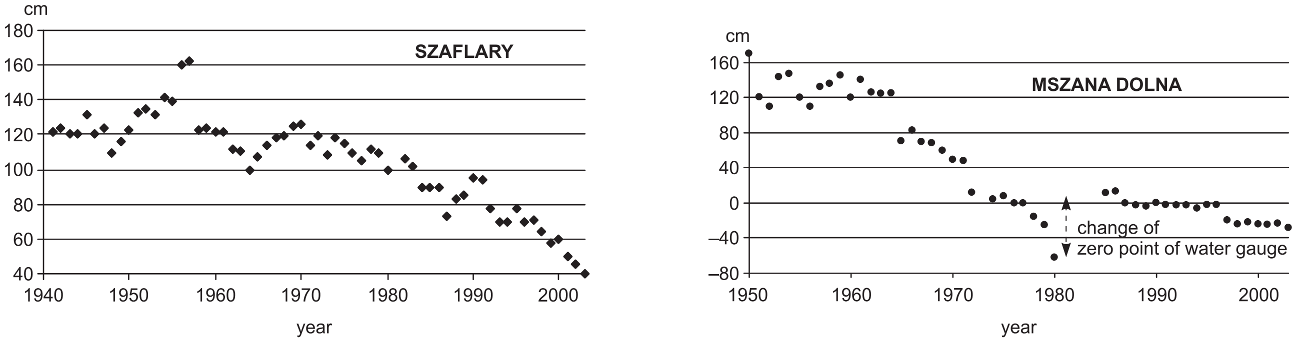

Fig. 8. Lowering of the minimum annual water stages of the Biały Dunajec River at the Szaflary gauging station and the Mszanka River at the Mszana Dolna gauging station as an indicator of incision rates. (Data from Institute of Meteorology and Water Management)

Table 4. Change of number of fluvial forms and braiding ratio during almost 30 years ("–" – lack of data; data from 1975 after Krzemień (1984))

Fluvial forms	Biały Dunajec		Mszanka		Porębianka	
	1977	2003	1975	2004	1975	2004
Number of rocky steps per 1 km	–	–	2.6	7.1	4.3	7.2
Number of cutbanks per 1 km	–	–	1.6	3.2	4.1	5.0
Number of bars per 1 km	7.6	6.0	9.6	2.7	20.4	12.5
Braiding ratio	3.7	3.0	6.5	0.8	14.3	5.5

cesses took place at the greatest rate in the Mszanka River between 1964 and 1972 (14 cm/yr) and in the Biały Dunajec River between 1958 and 1964 (10 cm/yr). The channel incision rate slowed down to 2.2 cm/yr and 2.3 cm/yr, respectively, in the years that followed. This resulted in a decrease in the channel gravel extraction rate and the abandonment of engineering solutions such as groynes and large transverse structures. Gradient reduction with use of drop structures became the preferred solution along significant stretches of river.

Intense downcutting led to the incision of the alluvial cover and the exposure of the bedrock along significant stretches of river. In 1975, bedrock channel reaches constituted 39.5% of the length of the Mszanka River channel and 47.4% of the Porębianka River channel (Krzemień 1984). In each case, the remaining channel length was alluvial. In 2004, bedrock channel reaches constituted 67.1% of the length of the Mszanka River channel and 63.8% of the Porębianka River channel (Korpak 2007a). Today, bedrock channel reaches can be encountered not only in upstream sections of river but also in middle sections as well as downstream sections – primarily downstream of debris dams, weirs, and high drop structures.

The decrease in the amount of channel debris led to a change in predominant channel form from deposition-type to erosion-type (Table 4).

Today, downcutting is the dominant process foming river channels in the study area. Deposition process are of negligible importance. Debris is normally stopped in reservoirs behind debris dams as well as behind weirs and drop structures. Lateral erosion only plays a meaningful role at some locations featuring alluvial banks with no reinforcements.

Conclusions

The greatest changes in the fluvial systems of interest took place in the third quarter of the 20th century. River channels became much deeper and much more narrow. This was the result of multiple anthropogenic factors acting on these systems. These included engineering efforts, debris extraction, and changes in land use. The ultimate result of these three types of activity was a reduction in the quantity of bedload available for fluvial transport. Intensive human activity in the basin was the consequence of an anthropocentric approach to nature, which was not viewed as valuable in itself but rather as a tool to be used by man in order to maximize his benefit. River channels were treated as a collection of independent segments, which could be altered without consequences for the fluvial system as a whole. This type of thinking led to the creation of artificial channel reaches transformed primarily by engineers rather than by natural forces present at a given point along the river profile.

While the approach to nature did not change very much in the fourth quarter of the 20th century, fluvial systems were subjected to far fewer modifications than in the years before. There were a number of reasons for this – the most important being the lack of major floods. In the absence of major flooding, economic damage was virtually nonexistent, and the few efforts to further engineer fluvial systems were undertaken. The few projects that were started were geared towards stream gradient reduction.

A series of major floods at the turn of the 21st century prompted new river engineering efforts designed to control fluvial systems and fix the damage produced by the floods. At about the same time, Poland entered the European Union and its official stance on human intervention in the natural environment had to change. The EU Water Framework Directive (WFD) requires member states to improve river water quality. Carpathian rivers that had been subject to engineering efforts are in a particularly poor ecological state. According to the WFD, river channel engineering is permitted only as a last resort and must attempt to preserve a state that is relatively close to the state of a natural river. In addition to engineering projects that meet the aforesaid requirements, other projects are still being pursued. These "other" projects are still damaging river channels in southern Poland. Fortunately, it is becoming more and more common for Polish engineers and society in general to consider river systems as an integrated entity. A growing number of individuals are increasingly looking at the array of relationships that affect different elements of the natural environment. This type of approach ventures beyond traditional engineering and takes into account the views of both engineers and environmental scientists.

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