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Regulation of mountain streams versus ecological balance as illustrated by the example of the upper Vistula basin (part I)
Regulacja potoków górskich a równowaga ekologiczna na przykładzie dorzecza górnej Wisły (cz. I)

Key words: Carpathian water-courses, hydraulic stuctures, hydrobionts, renaturization
Słowa kluczowe: cieki karpackie, zabudowa hydrotechniczna, hydrobionty, renaturyzacja

Characterization of mountain watercourses and living conditions of hydrobionts

Watercourses are surface waters, which, under the influence of gravity, flow in a concentrated form in a natural or artificial channel and have a specific territory of water supply. They appear in different forms, depending on their geographical location and hydromorphological conditions. Mountains and highlands are dominated by streams. A stream is usually described as a small, natural water-course which issues out of an efficient source and is characterized by a rapid current, narrow channel as well as a gravelly or sandy (more seldom muddy) bottom and turbulent flow of water that determine the lack of oxygenic and termal stratification (Starmach et al., 1976; Kasprzak, 2003). The river bed is the place where dead organic matter, mainly of allochthonous origin, accumulates (Mikulski, 1974; Kajak, 1998). The term "stream" is usually applied to mountain water-courses which are characterized by a gradient higher than a few feet per mile and chich are the same as the rhitron zones. They are inhabited by groups of psychrophilic, aerobic and rheophilic (adapted for living in flowing water) organisms. On stony and gravelly ground periphyton assembles may form, whereas in the environment characterized by a slower flow macrophytes may also appear.

Bajkiewicz-Grabowska and Mikulski (2008) have defined the following zones in a mountain stream:

– the catchment area (so-called pothole) – the upper section without a fully shaped channel, in which the mountain stream is formed.
– the middle section (so-called “neck”) – the proper part of the stream with a fully formed and deepened channel as well as a floodplain in the lower course.
– the detrital fan – forms in the place where the stream issues onto the valley of the water-course into which it flows; a fold in the stream valley causes accumulation of loose rock material in the form of a cone whose apex points upstream.

Both the stream and the basin undergo various hydromorphological processes. Denudation processes in the basin area cause products of soil and rock erosion as well as organic fragments to get into the stream with the surface runoff (Starmach et al., 1976). As they are transported by water along the course of the stream, they are called debris and can be carried by draggingor suspension.Another source of debris, apart from denudation processes in the basin, is channel erosion. It develops when the river transports less debris than is allowed by the energy of flowing water. In such case the energy is directed into deepening and widening of the channel. This leads to lateral, bottom and vertical erosion (Klimaszewski, 1978). Lateral erosion, in which the banks are washed away and widened, usually takes place in the middle section of the river. While the current attacks the banks alternately, it creates bends (or possibly meanders) and characteristic riffle-pool sequences. In mountain streams, the distance between riffles is usually from 2 to 4 greater than the width of the channel. Riffles are formed by coarser material, which is not as well sorted as in pools, and they are characterized by a quite high gradient. Pools, on the other hand, are deeper, have better-sorted material and lower velocities of flow (Radecki-Pawlik, 2006). As a result of bottom erosion, which involves washing away of alluvial material deposited in the channel, evorsion hollows and potholes may appear among other things. However, vertical erosion causes the stream to cut into the rock building the channel. The intensity of channel erosion depends on many factors. These are, among other things: the gradient and pattern of the channel, velocity of the water flow, intensity of water turbulence, types of alluvial material and rocks within the channel as well as the amount and type of transported debris (Starmach et al., 1976; Radecki-Pawlik, 2006; Bajkiewicz-Grabowska and Mikulski, 2008).

One of the components of debris is wood, i.e. pieces of wood of various sizes which are carried by suspension or dragged in water. The presence of wooden debris, especially large pieces of it (trunks, logs, rootstock, bushes, wood heaps, i.e. collections of wood and fine organic and mineral material) is conducive to morphological diversity of the stream channel. This, in turn, not only influences fluvial processes, the diffusion of water energy (e.g. when the water level rises), the shape of the channel (e.g. development of pools) and formation of a stepped profile in mountain streams, but also facilitates the deposition of alluvial material, reduces channel erosion and counteracts the intensive processes connected with vertical and bottom erosion (Wyżga et al., 2002; Wyżga, 2007). Heaps of rubble forming in mountain streams can intensify the lateral erosion by redirecting the current. The presence of wood rubble in a mountain stream not only leads to changes in hydromorphological parameters, but also provides refugia to water fauna, which creates biodiversity in the stream (Haden et al., 1999).Wood provides a place where invertebrates can settle and feed. Besides, heaps of rubble are places where organic material (e.g. needles and leaves), which is an important element of the food chain, accumulates (Cummins, 1974; Vannote et al., 1980). As a result, the streams in whose channels wood rubble deposits, are characterized by a greater amount and biomass of invertebrates and ichthyofauna (Harmon et al., 1986).

Methods of water-course river training works

The ecological state of rivers depends on various natural and anthropogenic factors, including regulation procedures and erection of hydraulic structures. These factors also apply to water-courses in mountainous regions. Water-courses are regulated for various purposes. The main objectives are: adaptation of the water-course to navigation and urbanization as well as to the exploitation of water intakes and water drops, protection from flooding and erosion, power engineering, agricultural cultivation of valley bottoms. Another process is the exploitation of river alluvia (Starmach et al., 1976; Rinaldi et al., 2005; Żelazo, 2009; Radecki-Pawlik, 2011, 2012).

There are various methods of water-course regulation, and the regulation itself can proceed in multiple ways. One of the assumptions behind the technical system of creating a regular river channel, including its protection from erosion, is the regulation along the length of the whole course or along selected sections (e.g. in the proximity of water structures or bridges, urban areas). Regulation can be achieved with the use of cross-wise and parallel dams. Among thehydraulic structures which protect against flooding there are: storage reservoirswith low-head dams, flood control reservoirs (so called polders), relief canals and embankments (Bednarczyk and Duszyński, 2008). Lateral erosion can be prevented by, among other things, the use of concrete bank reinforcements and retaining walls, whereas bottom and vertical erosion can be stopped by river bars and drop hydraulic structures of varying sizes as well as anti-debris dams (Mamak, 1958; Skatula, 1964; Radecki-Pawlik, 2012). Low-head damsare different from other hydraulic structures as they lead to the development of two zones of water flow – the one characterized by high velocities and accelerated movement and the one with retarded flow and a high intensity of disturbances (Naprawa, 2012). Small cross-wise hydraulicstructures include mainly river bars, drop hydraulic structures, anti-debris dams and weirs. Particular types of small cross-wise hydraulic structures and rules of their construction have been described by, among others, Wołoszyn et al. (1994), Mokwa and Pietraszko (2009) as well as Radecki-Pawlik (2012).

The hydraulic structures mentioned above have been widely used to regulate water-courses in Poland in the past years. The regulation works done mainly before 1980 were performed thoughtlessly or even unnecessarily, as the structures were only built to achieve short-term economic goals and without a holistic approach to this issue. In case of small rivers, regulation works were carried out along the greater part of their course (Żelazo, 2006). As far as Carpathian water-courses were concerned, this led to multiple hydromorphological changes (Korpak et al., 2009; Korpak, 2012).

Causes and consequences of the regulation of Carpathian water--courses

The upper Vistula basin extends from the Vistula source to the estuary of the Sanna River and it covers the area of 50.700 km^2. The river network consists of 149 rivers and streams whose basins are bigger than 100 km^2. 33 rivers have a basin larger than 500 km^2, whereas the basins of 15 rivers, 9 of which are direct Vistula tributaries, are greater than 1000 km^2 (Winter et al., 2010). The right-bank part of the basin is almost three times bigger than the left-bank part. The Carpathian territory covers about 45% of the upper Vistula basin, whereas the major part of this area consists of slopes. Atmospheric precipitation which falls on the slopes turns into surface and subsurface run-off, but a part of the water is directed into the water-courses. The rivers and streams which drain the Carpathian part of the Vistula basin generally have their sources in the flysch area of the Carpathians (an exception can be e.g. the Dunajec River). These are usually water-courses with a high gradient and a channel made of coarse material (gravel, stones, boulders, outcrops). They are characterized by big fluctuactions in flows between the period of low-water in autumn and winter and the period of high-water in spring (thaw waters) and early summer (torrential or extensive rains). High-water occurring in the western part of the Polish Carpathians is more often caused by an increased surface run-off, which is brought about by intensive rainfalls (Wyżga, 2008; Winter et al., 2010). Basins of Carpathian water-courses are shaped more or less like a circle, which accelerates the formation of freshet waves and is responsible for their significant height. In 20th century it was observed that the channels of water-courses in the Polish Carpathians had been significantly deepened as a result of intensive processes connected with the vertical erosion. This process has particularly intensified since the 1970's (Litewka, 2005; Gorczyca and Krzemień, 2010; Łapuszek, 2011). This was caused by several factors. Firstly, riverside areas, including floodplains, were used for agricultural and development purposes. That is why, it was necessary to regulate water-courses to protect inhabited areas from flooding. The channels became narrower, the value of river sinuosity decreased, the gradient became higher and the overall length of water-courses grew smaller. For example, in case of the Dunajec River, the course was shortened by 10%, whereas the channel width shrank by 1/3 (Zawiejska and Wyżga, 2008; Wyżga et al., 2008; Korpak et al., 2009). Rivers which had previosly had braided or anastomosing channels, became single-thread water-courses. Straightening of the water-courses and increasing of the flow energy caused alluvial forms to be destroyed in the channel and the river to cut into the valley (Łapuszek and Ratomski, 2008), which led to the impoverishment of ecosystems. As a way of preventing vertical erosion, it was deemed advisable to build hydraulic structures – bars and drop hydraulic structures – which does not, however, sufficiently prevent the increased outflow of high-water, but poses an obstacle to the migration of water organisms and disturbs the natural pool-riffle sequence (Tarwid et al., 1988; Owsiany et al., 2011). The rapid acceleration of the outflow and the impoverishment of existing biotic communities were also results of lining channels up with stone and concrete (Wyżga et al., 2008).

Regulation works (e.g. anti-debris dams) coincided in time with a decrease in debris supply from the basin as a result of a smaller amount of rainfalls and changes in the cultivation of the basin, e.g. an increase in woodiness (Tarwid et al., 1988) or expansion of meadows and pastureland in the areas previously covered by arable lands (Kopacz and Twardy, 2006; Korpak et al., 2009). The amount of debris in bigger rivers was also limited by dammed reservoirs, which serve as a kind of settlement tanks for debris. The transportation capacity of water-courses decreased and the amount of material used in fluvial transportation became smaller.

Those two factors were aggravated by the third one – exploitation of alluvial material in the channels (mainly gravel) and removal of thick wooden debris, which was later used , among other things, for fuel. The channel alluvia were sometimes exploited on an industrial scale, e.g. in the water-courses draining the eastern part of the Polish Carpathians. Above and below the place of exploitation, intensive bottom erosion (washing away of alluvia) and vertical erosion (cutting into solid rock) take place, which leads to the lowering of the river bottom (Korpak et al., 2009; Wyżga et al., 2010; Krąż, 2012). Removal of gravel bars from the channel intensifies the lateral erosion and jeopardizes hydraulic structures and bridges. Sometimes channels are destroyed by engineering works connected with the erection of "nature-friendly" reinforcing structures, which are made from rock material taken from the channel instead of raw material from a quarry, e.g. a metal net basket filled with pebbles from the Jamne stream in the Gorce mountains (Bucała and Radecki-Pawlik, 2011). Many Carpathian tributaries of the Vistula, especially in their upstream course, have now paved channels. Under the paving there is tightly packed finer material. Regulation works, or even the sole movement of heavy equipment within the channel, destroy the paving and activate the alluvia, which results in the intensification of bottom and vertical erosion. Changes in the structure of channels and dynamics of flow as well as in the intensity of erosion processes and transport of debris in Carpathian watercourses occur also in a natural way, most often under the influence of extreme phenomena. Violent freshets and floods sometimes cause damage to regulation structures and start morphogenetic processes, as it was in the case of the Łososina River in The Island

Beskids (Gorczyca and Krzemień, 2010) or the Mszanka, the Porębianka and the Biały Dunajec River (Korpak, 2008; Korpak et al., 2009). In places where regulation structures are not damaged by the destructive power of water, the deepening of the channel progresses steadily. In places where the structures are destroyed, vertical erosion periodically gives way to lateral erosion, e.g. in the Raba River in 1955 (Wyżga, 2008).

The watercourses whose significant part is straightened and regulated and which have deepened channels cutting into solid rock drain large amounts of water from the basin, serving as a kind of drainage ditches. This, as well as other factors mentioned above, causes smaller retention of water in the basin and bigger flows which intensify even more vertical erosion and increase the risk of freshets and flooding. In the 1960's and 1970's there were attempts to counteract negative effects of the increased transport capacity of watercourses, bigger flows and intensified erosion in the upper Vistula basin. One of such attempts was the erection of low-head dams, which produce lower gradients of the channel in specific locations. Such solutions help to stabilize the river bottom and prevent bottom and vertical erosion, but also create a series of unfavourable conditions, e.g. accumulation of debris in the section above the dam and its deficiency in further sections of the watercourse, lack of counter measures against the increased and accelerated outflow, disruption of the continuity of the watercourse and its permeability which are necessary for the migration of water organisms (especially in case of low-head dams of significant height). According to the data presented by the District Authority of Water Management in Cracow, the percentage of hydraulic structures in the upper Vistula basin averaged 28% in 1995 (Bojarski et al., 2005), but most of the structures were fit for reconstruction or renovation. It can be concluded that after disastrous floods in the Vistula basin in 1997, 2001 and 2010, the plans to increase the amount of structures in the upper parts of the basin have not been abandoned, although it was necessary to comply with the regulations connected with the implementation of the EU Water Framework Directive (Winter et al., 2010; Naprawa, 2012).

Paradoxically, although regulation works were meant to reduce the risk of flooding, they have increased it (Michalec, 2007). In addition, freshets destroy hydraulic structures and infrastucture, which can be illustrated by the example of the upper Vistula basin in 2010 (Raport o ostanie środowiska w województwie małopolskim w 2010). Bridge piers are undermined, regulation structures are damaged, river bank water intakes emerge from water, etc. For example, a railway bridge on the Poprad River in Nowy Sącz was completely destroyed during the flood in 2010 mentioned above. Intensified draining of the basin and river-side areas also leads to the lowering of the level of ground waters (also in drinking water intakes) and changes in riverine ecosystems, ecoton and the river itself. An example of this can be the elimination of riverine wooded areas, which causes changes in the shading of the channel, as well as the increase in water temperature, which influences most negatively the population of salmonids (Allan, 1998; Wyżga et al., 2008). The exchange of water between the channel itself and the waters flowing in the alluvia bacomes less intense. Moreover, old river beds dry out and the biodiversity of riverine ecosystems decreases. In general, aggravation of hydromorphological conditions results in deterioration of the ecological status (Wyżga et al., 2008; Mazurkiewicz-Boroń and Starmach, 2009).

Despite significant freshets or even floods in the upper Vistula basin (e.g. 2001, 2010), no increase in flooding has been noticed in the section extending from the sources to Zawichost in the last fifty years. There has been even a decrease in flooding. Causes of this situation have not been unequivocally determined (Kasina et al., 2006, 2007). Certainly, in the last hundred years, there have been some major changes in the use of the basin and in the shape of channels. However, in the last fifty years, there have been changes neither in the hydrologic regime of the Carpathian watercourses as a whole (understood as changeability in the outflow of water from the basin within a yearly hydrologic cycle) nor in the periodicity in the outflow (Soja, 2002).On the other hand, the issue which can be further discussed concerns possible changes in the regime of particular watercourses, which depends on local conditions such as the use of the basin or hydraulic structures. As a result of the implementation of the Water Framework Directive in the recent years, many thoughtful proposals for integrated hydraulic actions within channels and basins have been put forward (Litewka, 2005; Ratomski, 2006). There are also, however, negative examples (Wyżga, 2008; Pielech et al. 2010; Bucała and Radecki-Pawlik, 2011).

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Summary

Regulation of mountain streams versus ecological balance as illustrated by the example of the upper Vistula basin (part I). Streams of the Polish Carpathians are characterized by a high gradient as well as a great changeability of their volume and velocity of flow. The processes which take place in these streams are those connected with lateral, bottom and channel erosion. In order to reduce those types of erosion, various methods of channel regulation are used. In mountain streams these are mainly: river bars, drop hydraulic structuresand anti-debris dams. Regulation works (straightening of the stream channel and hydraulic structures), changes in the use of the river basin, reduction in debris supplies and exploitation of river alluvia have led to a significant deepening of channels. This increases the risk of flooding associated with higher flows. Regulation works conducted within the channels and anthropogenic pressure in the areas adjacent to watercourses exert a negative effect on biotic communities. In most cases, changes in the structure of flows,in the stability of the river bottom and in the variety of habitats as well as disruption of the river continnum affect living conditions and diversity of vertebrates and invertebrates. The attempts at improving the ecological status of Carpathian water-courses through changes in hydromorphological conditions are connected with the implementation of European Union directives. Such actions include, among other

things, replacement of traditional hydraulic structures by biotechnical ones, which are more eco-friendly. Their usefulness, however, still requires long-term monitoring.

Streszczenie

Regulacja potoków górskich a równowaga ekologiczna na przykładzie dorzecza górnej Wisły (cz. I). Potoki Karpat polskich odznaczają się znacznym spadkiem oraz dużą zmiennością objętości i prędkości przepływu wody. W ciekach tych zachodzą procesy erozji korytowej, bocznej i dennej. Aby je ograniczyć, stosuje się różnorodne metody regulacji koryt. W potokach górskich są to głównie: progi, stopnie wodne i zapory przeciwrumowiskowe. Prace regulacyjne (wyprostowanie koryt i zabudowa hydrotechniczna), zmiany w charakterze użytkowania zlewni, zmniejszenie dostaw rumowiska i eksploatacja aluwiów rzecznych spowodowały znaczne pogłębienie koryt. Jest to przyczyną wzrostu ryzyka powodziowego, towarzyszącego większym przepływom. Prace regulacyjne w obrębie koryt i presja antropogeniczna na terenach przyległych do cieków wywołują negatywne skutki w biocenozach rzecznych. Zmiany w strukturze przepływów, stabilności dna, zróżnicowaniu siedlisk, przerwanie *continuum* rzecznego w większości przypadków rzutują na warunki życia oraz różnorodność fauny bezkręgowej i kręgowej. Próby poprawy stanu ekologicznego cieków karpackich poprzez zmianę warunków hydromorfologicznych podejmowane są w związku z wdrażaniem dyrektyw Unii Europejskiej. Do działań takich zalicza się m.in. zastępowanie tradycyjnych konstrukcji hydrotechnicznych przez budowle biotechniczne, przyjazne naturze. Ich przydatność wymaga jednak jeszcze wieloletniego monitorowania.

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