GEOGRAFIJA. 2008. T. 44. Nr. 2. P. 9–14

River Channel structure research in the Carpathian Mountains

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Gorczyca E., Kamykowska M., Krzemień K. River Channel structure research in the Carpathian Mountains. *Geografija.* 2008. T. 44. Nr. 2. ISSN 1392-1096.

Morphodynamic zones in river channels, which have evolved over a long time, build the structures of a channel system. The study of entire channel systems helps understand their current condition and predict future development trends. Carpathian river and stream channels have been undergoing considerable transformation both within the mountains and in their foreland. In areas with strong anthropopressure, channel system structures of rivers and streams have been adjusting to the changing environment on the valley slopes and bottoms. The changes were caused by river channel draining, building of river dams, extraction of rubble directly from the channels and by land use changes in the basins.

Key words: channel system, channel structure, Carpathian rivers

INTRODUCTION

A channel system structure consists of morphodynamic and morphostatic reaches in the channel's long profile and of morphodynamic zones in its cross-section. Knowledge about Carpathian river channel systems is still limited to their sections. Available research suggests that modifications introduced in one channel reach can trigger changes, sometimes unpredictable, in other reaches. It is therefore very important that the entire systems are investigated to identify their current condition and to forecast their development trends. Indeed, as river channels are actively trained, it seems sensible to start investigating a channel's structure before any modifications are attempted. Alongside river training, rubble extraction and changes in the land use have been causing anthropogenic transformation of river channels, especially following the changes in 1989. Rubble extraction operations continue despite having been legally banned. Far-reaching changes to channel systems, especially in the Carpathian Mountains, make comprehensive research of entire river channel systems paramount.

CHANNEL STRUCTURE RESEARCH

A method developed by the Geomorphology Department of the Institute of Geography and Spatial Management of the Jagiellonian University in Kraków (Kamykowska et al., 1999) involved a specially designed protocol with a manual (Fig. 1). The manual was designed to help prepare a comprehensive description of channel systems in fieldwork conditions. This helps establish the systems' spatial patterns and to understand their morphodynamic functions. The manual is instrumental in the collection of large amounts of quantitative and qualitative data in a uniform way. The method is quick and easy, with answer choices provided next to each protocol item. Information is mainly gathered during fieldwork, but also from the analysis of maps and aerial photos. River channels normally consist of morphodynamically uniform reaches forming certain sequences, and the data is collected for those uniform reaches once they have been identified using maps and aerial photos.

There are five groups of data in the mapping protocol: 1) preliminary information, 2) channel characteristics (location, geology, landform dimensions, cross sections, long-sections, banks, bottom landform, deposits, engineering structures and channel type), 3) hydrodynamic characteristics of the channel, and 4) river basin characteristics. There are approximately 105 information items in the protocol, including 48 qualitative and 57 quantitative (Fig. 1). This is the basic-level information. The quantitative information is used to calculate numeric indicators used in channel analysis (Kaszowski, 1980; Krzemień, 1991). The protocol comes with a manual providing assistance to the users to enable them to choose the right answer and write it down in an abbreviated and coded format in an appropriate column of the protocol. The channel features collected, the number and size of the landforms, characteristics of the rubble and of engineering structures can then be used to understand the structure and dynamics of the channel system investigated. The same information can also be used to derive the rate of morphogenetic processes. Other data included river levels from water gauges and information about any changes in the channel cross-sections at the water gauges.

1.1. Mapping date	1.2. Persons name

DESCRIPTION OF THE CHANNEL

2.1. CHANNEL LOCATION

2.1.1. River drainage basin	2.1.2. Working number	2.1.3. Unified number	2.1.4. Symbol of topographic map

2.3. CHANNEL CROSS-SECTION

2.2. GEOLOGY

	2.2.2. Litho-logy and tecto-nics	2.2.2.1. Channels in sedimentary material		2.2.2.2. Channels in solid bedrock				
2.2.1. Stratigraphic unit		2.2.2.1.1. Gen. type of sed.	2.2.2.1.2. Size compos.	2.2.2.2.1. Outcrops surface	2.2.2.2.2. Bedrock lithology	2.2.2.2.3. Channel course	2.2.2.2.4. Long. prof.patt.

2.4. LONGITUDINAL PROFILE

2.5. RIVER BANKS

2.5.1.Appearance	2.5.2. Predominant height	2.5.3. Bank slope	2.5.4. Bank fixation

2.6. CHANNEL MORPHOMETRY

2.6.1. Order	2.6.2.Altitude

2.6.3. River length	2.6.4. Chord length	2.6.5. Develop. index	2.6.6. Diff. elevation	2.6.7. Channel gradient	2.6.8. Bankfull width	2.6.9. Floodplain width	2.6.10. Width of sinuosity belt	2.6.11.Maximum bankfull depth	2.6.12. Channel shape index	2.6.13.River braiding index

2.7. RIVER-BED FORMS

2.7.1. River bed forms	2.7.1.1. Bedrock forms	2.7.1.2. Sedimentary material forms

2.7.2. Steps and step systems	2.7.2.1. Number	2.7.2.2. Predominant height	2.7.2.3. Maximum height	2.7.2.4. Step pattern	2.7.2.5. Lithology	2.7.2.6. Step pattern	2.7.2.7 Rel. to strata dip

2.7.3. Potholes and pothole system	2.7.3.1. Number	2.7.3.2. Predominant depth	2.7.3.3.Maximum depth	2.7.3.4. Structure	2.7.3.5. Situation	2.7.3.6. Groupings

2.7.4. Riffles and pools	2.7.4.1. Number	2.7.4.2. Predominant distance	2.7.4.3. Riffle and pool pattern

2.7.5. Cutbanks	2.7.5.1. Number	2.7.5.2 Predominant length	2.7.5.3. Maximum length	2.7.5.4. Predominant height	2.7.5.5. Maximum height	2.7.5.6. Material supplied	2.7.5.7. Situation

2.7.6. Bars and islands	2.7.6.1. Number	2.7.6.2. Predominant length	2.7.6.3. Maximum length	2.7.6.4. Predominant width	2.7.6.5. Maximum width	2.7.6.6. Size composition

2.7.7. Floodplain	2.7.7.1. Microrelief	2.7.7.2. Natural levees	2.7.7.3. Abandoned channels	2.7.7.4. Vegetation cover

2.8. CHANNEL DEPOSITS

2.8.1 Deposits thickness	2.8.2. Size composition	2.8.2.2. Maximum size												
	2.8.2.1. Predominant size												Sum	Mean

2.8.3. Petrographic composition	2.8.4. Channel bed sedimentary structure	2.8.5. Bed armour

2.9. CHANNEL REGULATION STRUCTURES

2.9.1. System of lining	2.9.1.1. Number of water structures

2.9.1.2. Structure height	2.9.1.3. Structure width	2.9.1.4. Structure length	2.9.1.5. Building material	2.9.1.6. Lining year

2.9.1.7. Preservation condition	2.9.1.8. Degree of basin filling

2.10. RIVER-BED TYPE

HYDRODYNAMIC CHARACTERISTICS OF THE STREAM

3.1. STANDING WAVE 3.2. MAXIMUM WATER STAGES

	3.2.1. Information source	3.2.2. Water stage value, date	3.2.3. Measurement methods

HYDROMETEOROLOGICAL CONDITIONS OF THE REASERCH PERIOD

4.1. Water stages	4.1.1. Actual water stages	4.1.2.Water stages in period preceding the research	4.1.3. Water stages during last very high flood

MORPHOMETRY OF THE RIVER DRAINAGE BASIN

5.1. Catchment area	5.2. Maximum catchment length	5.3. Catchment shape index	5.4. Valley system length	5.5. Drainage density	5.6. Integration index
5.7. Forested area	5.8. Woodiness index	5.9. Grassland area	5.10. Arable land area	5.11. Others	

Note

Fig. 1. Protocol for mapping river channel reaches

An investigation of the structure and function of morphodynamic reaches requires a wider focus including the river basin environment (Klimek, 1979). Alongside fieldwork, researchers need to analyse cartographic material, aerial photos and other materials offering data on the channels and their basins. Basin data can be recorded in the fifth and last column of the protocol that can also be modified as needed. The protocol method was developed for research in the Polish Carpathian Mountains, but has subsequently been used elsewhere in Poland, the Alps, the Massif Central in France and in Scotland (Krzemień, 1981, 2004; Chełmicki, Krzemień, 1998).

IDENTIFICATION OF CHANNEL TYPES

River channels are often characterised and classified using aerial photos, topographic and geological maps and hydrological materials. It is imperative that such a desk study is supplemented by fieldwork (Kellerhals et al., 1976). A number of approaches and systems of codes and protocols have been used to characterise river channels during fieldwork (Tille, 1970; Kamykowska et al., 1975, 1999; Witt, 1976; Kaszowski, 1980; Krzemień, 1981, 1984; Rączkowska, 1983). This normally involved breaking down the channel into uniform morphostatic or morphodynamic reaches which are then characterised in detail. The protocol described above (Fig. 1) can be used in this type of work.

The channel typology is determined on the basis of the channel parameters, channel landforms and rubble type identified in conjunction with calculated indicators. River channels are often analysed using features providing direct or indirect information about the channel dynamics, i. e. about the processes that form and modify the channel. Features used in such analysis may include:

1. The type of geology which determines the bedrock, bedrock-rubble or presence of alluvial reaches.
2. Horizontal channel pattern.
3. Channel mobility.
4. Ratio of bars per kilometre in sq. m.
5. Ratio of cutbanks per kilometre in sq. m.
6. Maximum rubble granularity.
7. Braiding ratio, i. e. median bars and islands per kilometre.
8. Channel shape ratio calculated as the average width divided by average depth.
9. Floodplain width.
10. Engineering ratio, i.e. the number of engineering structures in the channel per kilometre.

In the next step of this analysis, a map is used to mark channel types identified according to a particular main criterion. This process is shown here using the example of the River Wilsznia. Its basin is located in the central part of the Beskid Niski range (Fig. 2). The Wilsznia channel was divided on a map into the following channel types:

- bedrock, straight-line, with numerous rocky steps and evorsion kettles; intensive downcutting is the dominant process;
- bedrock-alluvial, winding, cutting into the bedrock, but with a massive local accumulation in the form of rubble bars;
- bedrock-alluvial, partly winding partly straight-line, the accumulation reach with rubble bars and a minor role played by downcutting;
- alluvial cutting into alluvial covers, an accumulation reach with a large area of bars.

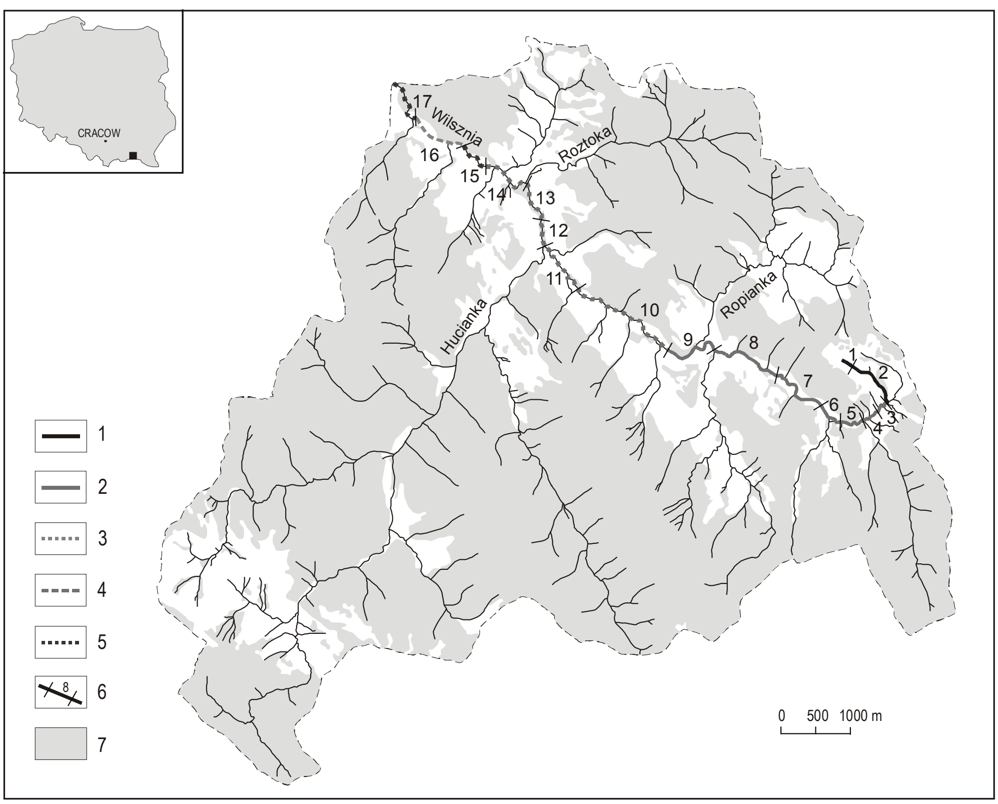

Fig. 2. I – Study area, II – Wilsznia river basin and types of morphodynamic channel reaches in the River Wilsznia: *1* – erosion reach, bedrock channel mainly shaped by downcutting, *2* – bedrock-alluvial channels with downcutting and local accumulation, *3* – bedrock-alluvial channels with lateral erosion and local intensive accumulation, *4* – alluvial channels with intensive accumulation, *5* – alluvial channels with intensive accumulation and local lateral erosion, *6* – channel reaches, *7* – forests

Based on these data the following dynamic channel reach types were identified in the Wilsznia channel system (Fig. 3): A – erosion reaches shaped mainly by downcutting; B- erosion reaches with downcutting and strong local accumulation; C – accumulation reaches with local lateral erosion.

Bordering on geomorphology, geology and hydrology, fluvial research features a number of approaches. Five general approaches to channel classification utilise the following main typological criteria: morphostatic, morphodynamic, hydrological, sedimentological and physiographic.

These approaches could be regarded as typological methods, even if some of the authors may not have seen them as such. Fluvial literature offers a number of procedures used in the identification of channel types and reaches. The following typological methods are found: a) single criterion method leading feature method, c) parallel criteria method, d) indicative feature analysis method, e) reach boundary analysis method, f) channel structure analysis method, g) basin environment analysis method, and h) numerical taxonomy method (Kaszowski, Krzemień 1999).

The channel reach analysis method seems very useful and simple (Fig. 3). It starts with a selection of features to characterise the channel. The features are then summarised in groups according to the group breakdown adopted, and quantitative features are summarised by intensity categories. Qualitative and quantitative features are then summarised in each channel reach. The numbers of boundaries between channels are compared, the significance of these boundaries is assessed, and the most significant boundaries are selected. Finally, the types and subtypes identified are given names and briefly described. Examples of channel typologies derived in this way include the River Plimy in the Alps and River Couze Pavin in the Massif Central (Krzemień, 1991; 2004).

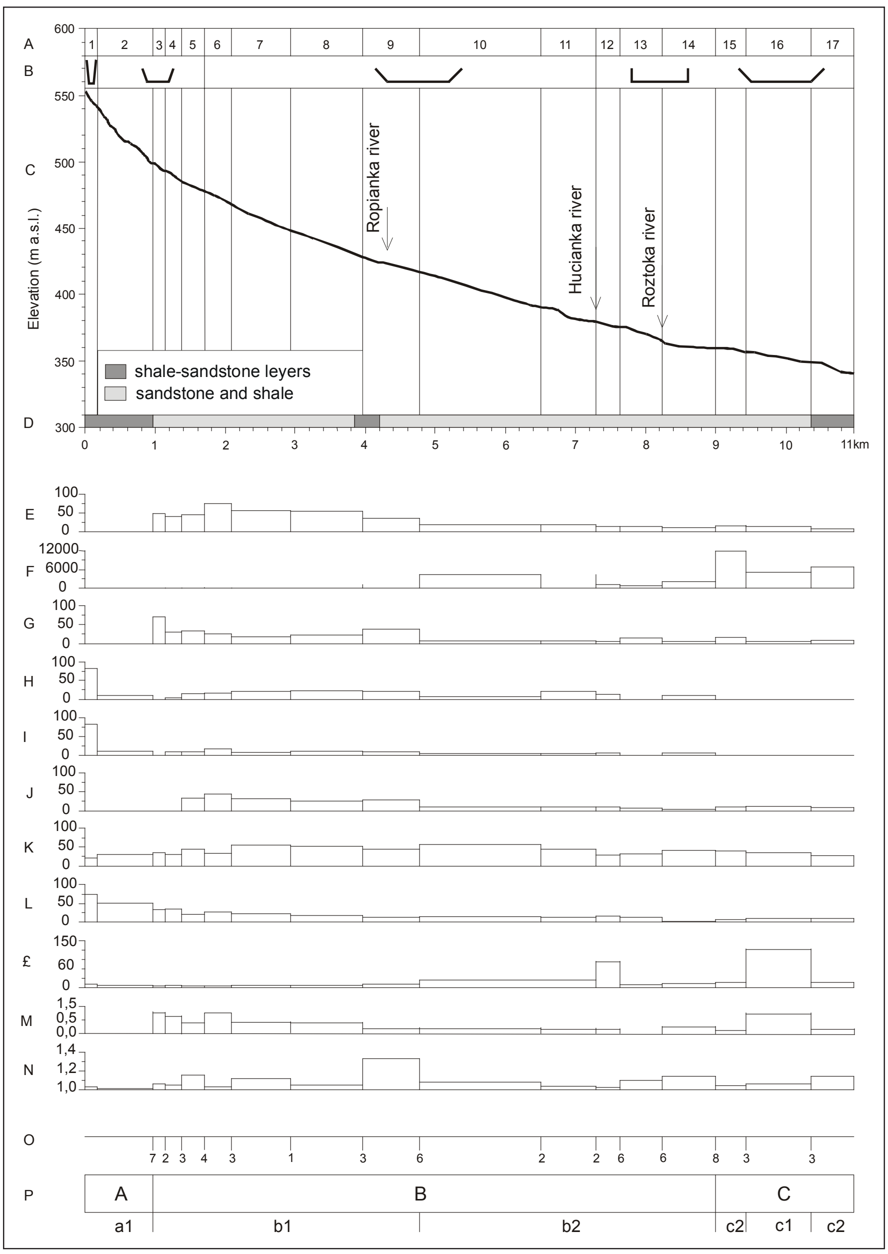

Fig. 3. Typological summary of the Wilsznia Channel: A – channel reach numbers, B – channel cross-profile, C – channel long-profile, D – geology, E – bars/km, F – bar area in m^2/km, G – cutbanks/km, H – rocky steps/km, I – kettles/km, J – pools and riffles/km, K – maximum grain size, L – gradient in %/10, Ł – channel shape ratio, M – braiding ratio, N – channel development ratio, O – number of boundaries, P – channel types and subtypes: A – bedrock channels: a1 – with downcutting, B – bedrock-alluvial with: b1 – downcutting and local intensive accumulation, b2 – lateral erosion and local intensive accumulation, C – alluvial channel with: c1 – intensive accumulation, c2 – intensive accumulation and local lateral erosion.

CARPATHIAN RIVER CHANNEL STRUCTURES AND THEIR DEVELOPMENT

The structures of Carpathian river channels vary in terms of the number of morphodynamic reaches in each system and the order in which these reaches occur. The contemporary shape of the channels is a result of both natural and human-induced forces. Deepening is the main feature of contemporary change along the entire length of channels. This process is less intensive in the mountains themselves than in their foreland where it takes the form of a regressive rejuvenation of the channels. As a result of the deepening process:

1. The channels become deeper but narrower.
2. Floodplains active in 1930s have stopped playing their role.
3. Old floodplains develop rocky banks.
4. Boulder fields and thaw river beds have become consolidated.
5. Rocky outcrops have appeared along alluvial reaches.
6. Alluvial channels have turned into rocky channels.

These effects are compounded by river training which has been leading to straightening and narrowing of the channels.

CONCLUSIONS

Carpathian river and stream channels have been undergoing major changes within the mountains and in their foreland. In areas featuring a strong anthropopressure, the rivers and streams are adjusting their channel system structures to the changing conditions in the valley bottoms and on the slopes as a result of channel training, river damming, channel rubble extraction and land use changes in the basins. Human activity has been causing large-scale transformation of the structures in the channel system, mainly through the operation of erosion processes. The chief outcome is a simplified and uniform structure of the fluvial system. Large river channels, including the Dunajec, Wisłoka and Raba, have been deepened by up to 2–4 metres over the last 20–30 years. Headward erosion has taken the deepening effect also into the side valleys. Deeper river channels have been affecting the larger environment by lowering the groundwater table and leaving the ground in the valley bottoms dry.

A natural channel structure, developed as a result of channel migration and the discharge of only a limited amount of bedload, has been considerably modified. Since the late 19th century, large Carpathian river beds and channels have been shrinking in width and increasing in depth. This process was particularly intense in the 1970s. Since 1989, the Carpathian Mountains have seen a considerable change in the land use that consolidated the slopes. The resulting reduction of the supply of clastic material from the slopes has caused greater rates of downcutting. Indeed, 1989 marks the beginning of a coincidence of two downcutting impacts: one coming from the river channel changes and the other from land use change.

In view of the adverse changes in the channel system, it is necessary to introduce a strict ban on channel rubble extraction and to provide protection to semi-natural channel reaches that have so far escaped degradation by excessive human intervention.

Received 29 September 2008
Accepted 13 October 2008

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UPIŲ VAGŲ KARPATŲ KALNUOSE STRUKTŪROS TYRIMAI

Santrauka

Krokuvos Jogailos universiteto Geografijos ir aplinkos valdymo instituto Geomorfologijos sektoriuje sukurta morfodinaminių tyrimų metodika, pagal kurią lauko tyrimų metu vertinama upių vagų tinklo struktūra. Metodika paremta matricos pobūdžio klausimynu, atsakymai į kurį leidžia operatyviai sukaupti unifikuotus kokybinius ir kiekybinius duomenis. Dalis informacijos taip pat gaunama iš topografinių žemėlapių ir aerofotonuotraukų.

Skiriamos keturios kaupiamų duomenų grupės: preliminari informacija; vagų charakteristikos (padėtis, geologinė sandara, morfometriniai rodikliai, išilginiai ir skersiniai profiliai, krantai, dugno formos, nuosėdos, inžineriniai įrenginiai, vagos tipas); vagos hidrodinaminės charakteristikos; upės baseino charakteristikos. Iš 105 klausimyno klausimų 48 skirti kokybinėms ir 57 – kiekybinėms upių charakteristikoms apibūdinti.

Vagų morfodinaminių ypatumų nustatymui būtinas platesnės teritorijos vertinimas, paremtas kartografinių duomenų analize. Visi sukaupti duomenys leidžia įvertinti ir vagų morfodinaminių procesų intensyvumą. Remiantis šia metodika buvo įvertinti kalnų upių vagų ypatumai Karpatų kalnuose Lenkijoje, Centriniame Masyve ir Prancūzijos Alpėse, taip pat Škotijos kalnyne Didžiojoje Britanijoje.

Vagų tipologija paremta vagų morfometriniais rodikliais, vaginėmis reljefo formomis ir dugno nuogulomis. Šių duomenų kombinacijų analizė leidžia įvertinti vagoje vykstančius dinaminius procesus. Analizė vykdoma pagal tokią schemą: geologinė slėnio struktūra, nuogulų tipas ir vagoje susikaupusios nuogulos; vagų tinklo pobūdis; vagos kaita; aliuvinių sąnašynų tankis; atodangų tankis; maksimalus aliuvinių nuogulų dydis; vagos padėties kitimo (klaidžiojimo) dažnis, vagos tūrio kaita; salpos plotis; inžinerinių statinių tankis.

Atlikus tyrimus Vilšnios (Wilsznia) upės baseine buvo išskirti šie vagų ruožai (2 pav.):

1. Į kietas uolienas besigraužiančios tiesios upių atkarpos su gausybe slenksčių ir erozinių duobių.
2. Į kietas ir aliuvines nuogulas besigraužiančios vingiuojančios upių atkarpos su stambiomis akumuliacinėmis gargždo ir riedulių seklumomis.
3. Į kietas ir aliuvines nuogulas neintensyviai besigraužiančios tiesios ir vingiuotos upių atkarpos su gargždo ir žvirgždo seklumomis, kuriose vyrauja šoninė erozija.
4. Aliuvinėse nuogulose susidariusios akumuliacinės upių atkarpos, kuriose plačiai paplitusios žvirgždo ir smėlio seklumos.

Geologijos, geomorfologijos ir hidrologijos mokslų sąlytyje vykdomi fliuvialiniai tyrimai remiasi bendromis metodologinėmis nuostatomis (morfostatika, morfodinamika, hidrologija, sedimentologija ir fiziografija), atsispindinčiomis klasifikaciniuose kriterijuose. Naudojama keletas tipizavimo principų: vieno kriterijaus, vyraujančio bruožo, lygiagrečių kriterijų, indikacinių bruožų analizės, ribų analizės, vagų struktūros analizės, baseino aplinkos analizės, daugiataksonominio metodo.

Išanalizavus Karpatų kalnų upių vagų kaitą buvo įvertintas pagrindinis vagas keičiantis veiksnys – gilinamoji erozija, kurios dėka vagos tapo gilesnės ir siauresnės; po 1930 m. ėmė nykti upių salpos, o senosios virto akmeningais krantais; buvo mažiau ardomi pakrantės akmenynai ir išlyginti upių dugnai; akmeningi išnašų kūgiai plito ties upių vingiais; aliuvinės vagos virto akmeningomis. Ir visa tai lemia upių vagų transformaciją – jos tampa tiesesnės ir siauresnės.