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River morphology hierarchical classification (RMHC)

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Abstract

The River Morphology Hierarchical Classification (RMHC) framework with seven taxonomic levels – catchment-drainage network, zone, segment, channel-floodplain unit, river reach, geomorphic unit and morphohydraulic unit – has been presented. The RMHC framework shows good potential as a standardised method for classifying river morphology over a range from catchment scale to channel, reach and morphohydraulic scale. It represents a good research tool for any stream investigation and assessment as well as for river management applications.

Key words: river, geomorphology, hierarchy, classification

1. Introduction

Historically, most fields of science have gone through a classification phase. The classification phase usually occurs during the early stages of development of a scientific discipline as a means of ordering observations and descriptions. As fluvial geomorphology is a relatively young science, classification continues to play an important role. Much of the desire to classify rivers may thus derive from fluvial geomorphology's composite heritage from geography – a field where observation, description and classification have played major roles (Goodwin, 1999). Geomorphologists utilize classification to understand river and to select representative segments when undertaking assessments of stream conditions. For river and stream management, classification is used to simplify what would otherwise be impractical tasks, including taking an inventory of resources, periodically reviewing the impacts of human actions, judging stream conditions against criteria or legislative requirements, describing the resource in simple and common terms so that stakeholders can debate trade-offs and separating streams into management classes that have different objectives. Some classification models attempt to rate the likelihood of being able to restore a disturbed channel form to a previous or alternative state (Gordon et al., 2004).

The aim of this article is then to provide a general overview of river classification schemes and to present our classification scheme which is called River Morphology Hierarchical Classification (RMHC). It is characterised by spatially levels (taxons) of resolution, which recognise that the structure and dynamics of river systems are determined by the surrounding catchment. The RMHC consists of seven taxonomic levels, i. e. catchment-drainage network, zone, segment, channel-floodplain unit, river reach, geomorphic unit and morphohydraulic unit.

2. A brief review of river classification systems

Fluvial geomorphology developed from the tradition of explaining long-term landscape evolution. W. M. Davis described landscape evolution in terms of youth, maturity and old age using his now discarded "geographical cycle". The Davisian approach dominated the geomorphology for the first half of twentieth century. A shift in approach to geomorphological investigation was signalled mid-way through the twentieth century by Strahler, who argued that progress required adoption of a quantitative process-based approach. Since that time, investigation of processes has overwhelmed the interest in historical geomorphology. Most process-based research has been empirical in nature, resulting in numerous generalized models, such as relationships between aspects of channel morphology and discharge indices. Others have attempted to understand causal mechanisms through physically based models and used findings on physics of particle dynamics, hydraulics and fluid mechanics to explain the observed sediment transport. Although geomorphic research has largely moved on from classification and other simple descriptions of landforms, the same cannot be said for some branches of applied geography. River classification has become a popular method for designing river restoration works. This approach is intended to help to "predict a river's behaviour from its appearance", and proposes that, by assigning a classification to a reach of stream, it would be possible to assess the channel's stability and prospects for change under restoration. Almost since their inception, the classification schemes have been roundly criticized as a design tool by research geomorphologists, who argue that they oversimplify the complexity of the fluvial system and can produce misleading results, which may carry significant economic safety implications. This has not prevent a growing interest in application of the procedure, especially in the USA, Canada, U. K., South Africa and Australia where classification methods are commonly endorsed by government agencies (Gordon et al., 2004).

Geomorphic classification systems have traditionally been based on river shape. The best one known is the division of streams into straight, meandering and braided ones (Leopold and Wolman, 1957). Schumm (1977) envisaged a broad-scale system of three-channel zones based on sediment transport: an upper zone of sediment production (source), a middle zone (transfer) and a lower zone (depositional area). Feeling that the planform classification of Leopold and Wolman (1957) was unsatisfactory, Kellerhals et al. (1976) devised a system combining channel pattern, islands, channel bars, and major bedforms and proposed that channels generally become straighter with an increasing discharge of sediment and/or water. Later, Schumm (1985) combined morphological and sediment models to create six-class model of channel forms. In a similar model, Church (1992) separated large channels into three phases (a bed material supply-dominated phase, a transitional phase and a wash material supply

phase). Nanson and Croke (1992) developed a floodplain classification scheme based on energy-resistance concept, where energy was defined by stream power, while resistance in those of bank cohesivity. The three level hierarchical channel unit model by Hawkins et al. (1993) goes step further down in scale to describe hydraulic conditions within channel geomorphic units. Whiting and Bradley (1993) proposed a process-based classification scheme for headwater streams. The forty-two classes were process interpretation of dimensional properties of morphological features, which included channel gradient, channel width, valley width and median sediment size. Rosgen (1994) used stream channel geometry to define eight primary stream channel types and included management interpretations for each stream type, in term of sensitivity to disturbance, recovery potential, sediment supply, streambank erosion potential and vegetation controlling influence on the width/depth stability. The similar models have been presented in works by Thorne et al. (1997), Kaszowski, Krzemień (1999). Downs (1995) reviewed a number of classification schemes that interpret channel processes specifically for management purposes. Montgomery and Buffington's (1997) process-based classification scheme defined seven channel reach types based on the overall geomorphic character. This model couples reach-level processes with their down-stream spatial arrangement, their links to hillslope processes, and eternal forcing by confinement, riparian vegetation and wood debris. Rowentree and Wadeson (1998) developed a hierarchical geomorphic classification modelbased on a modification of the model of Frissell et al. (1986), which provides a scale-based framework that can be applied to any river system. The River style classification framework (Brierly et al., 2002, Fryirs et al., 2003) is another model that is based on the hierarchical model of Frissell et al. (1986). Thoms and Seldon (2002) applied a geomorphic-based scheme to dryland river in Australia. Pool (2002) recently proposed a general framework for fluvial landscape ecology, which is concerned with integration of pattern, process, hierarchy, scale, directionality and connectivity in order to derive relationships between the fluvial system structure and the system function. Pool's hierarchical framework acknowledges that rivers form a patchy discontinuum from headwaters to mouth, and attempt to integrate the ecological relevance of discontinuum by highlighting the importance of uniqueness of fluvial landscape.

2.1. Conceptual framework of the RMHC

Over the "modern" time scale, channel-floodplain morphology can be conceived as dependant upon representative catchment hydrological conditions, relief, vegetation, sedimentology and so on. Understanding of geomorphic processes and determination of appropriate river structure and function at differing position in catchment are critical components in sustainable rehabilitation of riverine landscape. The geomorphic structure and function of many, especially middle and small-size rivers are tied innately to vegetation cover and composition, and loading of large woody debris. These interactions induce direct controls on the distribution of flow energy, dictating local-scale patterns of erosion and deposition at differing flow stages. When tied to sediment availability and flow variability, the geomorphic structure dictates the diversity of hydraulic units and associated habitats along river courses, and many other facets of riverine landscape functioning.

According to Haigh (1987), the principles of hierarchy in the systemic holistic approach in physical geography and landscape ecology are used in three areas: in delimitation of landscape units and their classification, classification of river networks and in determination of age of landscape systems. Similar to all spatial entities, landforms are also organised in certain ways. First of all, every landform developed, passes from one state into another, it has its age, it is getting older and determines the development of young forms. In accord with Davis's theory of geographic cycles, it reflects the temporal dimension of organisations. As all landforms are associated with our planet, they must be organised in a positional choric way (they always possess a neighbour). The dimension of hierarchic organisation of landforms determines the basic features of their taxonomic system, while each of its levels is defined by a set of classification criteria on base of which it was formed. If we take into account that geosystem taxons are presented as areas and representing cells of the geomorphological network, then hierarchisation can be understood as a picture analysis expressed in a simplified way by the relationship between texture (granularity) and structure (pattern). Texture at a higher hierarchic level represents the structure at a lower level and vice versa. Expressed by geographer's language, the analysis of an area at one scale represents wholes, systems that become sub-wholes or subsystems at another level. The origin, location, spatial distribution, functioning and disappearance of forms are not at all accidental. A specific choric organisation responds to a differentiated action of endogenous and exogenous agents at every hierarchic level. Parameters of organisation of a higher taxon or higher taxons simultaneously form the matrix for organisation of lower taxons. Organisation of lower taxons inserted into the matrix of a higher taxon or higher taxons and it more or less agrees with it. It is used for parameterisation and description of higher taxons.

As rivers demonstrate remarkably different characters, behaviours and evolutionary traits (both between and within catchments), individual catchment need to be managed in a flexible manner, recognizing what forms and processes occur where, why and how often, and how these processes have changed over time. According to Frissel et al. (1986), we need to answer the following questions: How do we select representative or comparable sampling sites in streams? How we can interpret in the broader context, or how far can we reasonably extrapolate information gathered at specific sites? How do we assess the past and possible future states of a stream? To achieve this, a physical template is required upon which to assimilate and order information, identify gaps and, most importantly, highlight linkages of river biophysical processes and their management applications. Without this template, management programmes are applied in an ad hoc manner. It is not unduly cynical to ask how management strategies can work within a sustainable framework if the principles adopted do not "work with nature", building on catchment-framed understanding of river character and behaviour (Brierly et al., 2002).

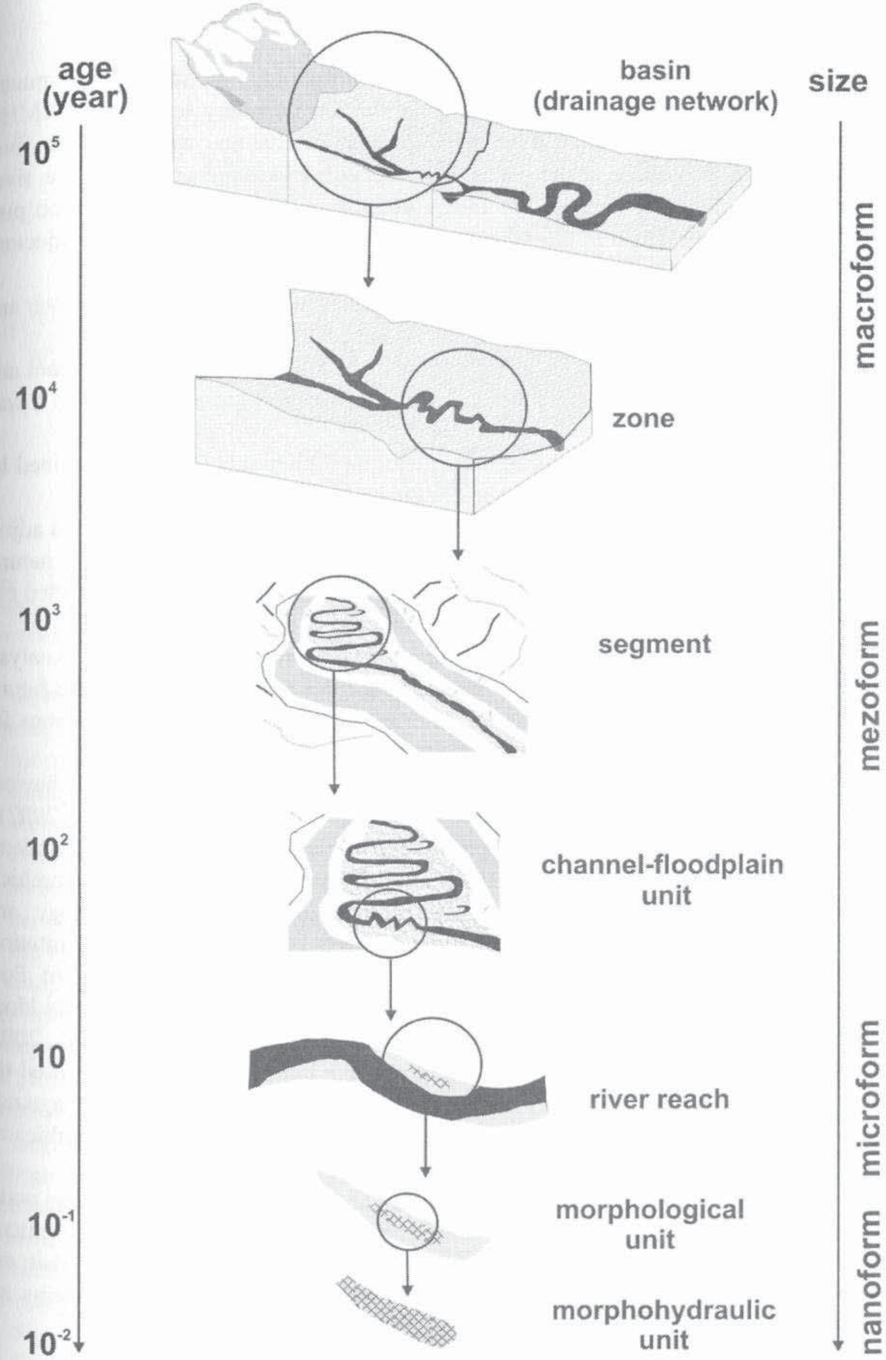

Fig. 1 River Morphology Hierarchical Classification Scheme (RMHC)

The identification and characterization of river morphology hierarchy is a summary understanding of how river operates or behaves within its valley setting. The RMHC framework endeavours to more beyond visual and mechanical approaches to river classification to provide a more process-based procedure for analysing the river character and behaviour. Perspective and regionally specific river classification procedures provide little sense of river process, river change, river condition or trajectory and restoration measure. Unlike these schemes the RMHC framework is:

- *Catchment-based.* Linkage of biophysical processes in catchment, such as water and sediment fluxes and vegetation dispersal can be analysed.
- *Process-based.* Understanding of the character and behaviour of both channel and floodplain zones provides the process-based knowledge to manage rivers in a way that "works with nature".
- *Structured hierarchically.* Processes occurring at a finer scale can be explained by those occurring at higher levels-taxons in the hierarchy.
- *Set within the context of river evolution.* Understanding a river's capacity to adjust within its valley setting provides the basis for assessing how far from its natural conditions the river sits, and why that type of the river has changed. Only then can the contemporary condition of river be realistically assessed.
- *Directly linked to assessment of the trajectory of the future river condition.* Analysis of river change provides a basis to predict how river will be adjusted in the future. This provides a geomorphic basis for determination of future target conditions for river rehabilitation and creating catchment-framed visions.
- *Directly linked to restoration measure.* Understanding of the character and behaviour of a river provides the ability to influence river engineering. (cf. Brierly et al., 2002)

The presented model of river morphological hierarchy improves our scheme (Lehotský, Grešková, 2003) and is methodologically based on the ideas of hierarchical composition of geosystems (patches) generally widespread in geoecology and landscape ecology. As to the description of main levels (taxons) and their delimitation, the classification scheme of instream habitats (Frissell, 1986), the work of Pool (2002), Rowentree and Wadeson (1998), Wadeson and Rowentree (1998), Maddock (1999), Thomson et al. (2001) models and River style framework (Brierly et al., 2002) have been used as good conceptual guides. From the top to bottom we identified the following seven taxons of channel-floodplain geosystems: 1. catchment-drainage network, 2. zone, 3. segment, 4. channel-floodplain unit, 5. river reach, 6. geomorphic unit and 7. morphohydraulic unit (examples of the Hybica river, Fig. 1, 2–6.)

Catchment-drainage network represents the land surface, which contributes water and sediments to any given stream network at a given river profile. Surface elements boundaries of catchment are determined by dividing the catchment into that one dominated either by hillslope or fluvial processes. Channel-floodplain systems are determined by variability of:

- the type of stream network,
- general genetic geomorphological and geological setting with respect to its position of surrounding large morphotectonic and its climatic geographical position.

Fig. 2 The crosswise setting of the Hybica watershed in the eastern part of the longitudinal relatively subsided, flyschoid intramountain tectonically influenced hilly depression of the Liptovská kotlina basin covered by glacifluvial fans

Zone is an area within a catchment adjacent to the river, which can be considered as homogenous with respect to:

- morphostructural and morphosculptural conditions, i.e. homogeneous from the viewpoint of the altitude, relief energy, slope and horizontal differentiation and tectonic features,
- conditions defined by chemical and granulometric composition, percolation, water transmission and soil properties,
- runoff properties and the potential of sediment production,
- the hydrological regime of the river.

A compact settlement of a size relevant to the river size is considered as a specific zone. The comparison among stream networks might focus the network efficiency, sediment transport, etc. Restoration measures in catchment and zone level can be significant in the removal or modification of man-made obstruction to sediment transport and aquatic animal migration (dams, torrent control device, etc.).

Segment is a part of zone, a length of valley bottom where there is no significant change in the drainage network, i. e. a part of the river upstream or downstream to the next bigger tributary and in the imposed flow discharge or sediment load. It is classified in terms of:

- bed slope,
- valley confinement ratio,
- degree of sinuosity (measured along valley thalweg),
- discharge,
- index of the sediment/discharge ratio in relation to long profile,
- specific drainage network.

Fig. 3 The Hybica river basin with the dendritic asymetric drainage pattern (stream length – 21.47 km, surface area – 45.10 km^2, altitude – max. 1190 m, min. 658 m, ∅ 823 m, Q_a – 0.569 $m^3 \cdot s^{-1}$) and its seven zones: **1.** Moraine headwaters, **2.** upper basin, **3.** transitional – gorge I., **4.** upper foothills, **5.** urban, **6.** lower foothills, **7.** transitional – gorge II.

Widening of the riverbed in order to initiate braided or meandering and large-scale excavation of floodplain alluvium along severely entrenched river channels can be considered as an appropriate restoration measure on the segment and the next – channel-floodplain level.

Channel-floodplain unit represents the channel, riparian zone, floodplain and alluvial aquifer. It is viewed as a single, integrated corridor distinct form, but interacting with, the remaining catchment. Water residence time in the aquifer determines aquifer elements boundaries. Comparison among units might focus on water routing, relative

importance of longitudinal, lateral and vertical connectivity, etc. Unit boundaries are determined by:

- planform,
- coarse-scale geomorphological features such as islands, side-channels, cut-banks, bank breaks, etc.,
- inundation frequency,
- channel abut index,
- degree of sinuosity (measured along local thalweg),
- meander belt index,
- structure of floodplain geomorphic units,
- position of stream into floodplain.

River reach is understood as the length of channel where the constraints on channel form are uniform so that a characteristic assemblage of morphological units or landforms occurs. Taxon boundaries are determined by:

- morphometric and morphographic features of geomorphological units,
- substratum properties of riverbed and banks determining lateral movement of stream,
- amount and forms of wood debris.

Comparisons among reaches might focus on pattern and dynamics, habitat stability of river etc.

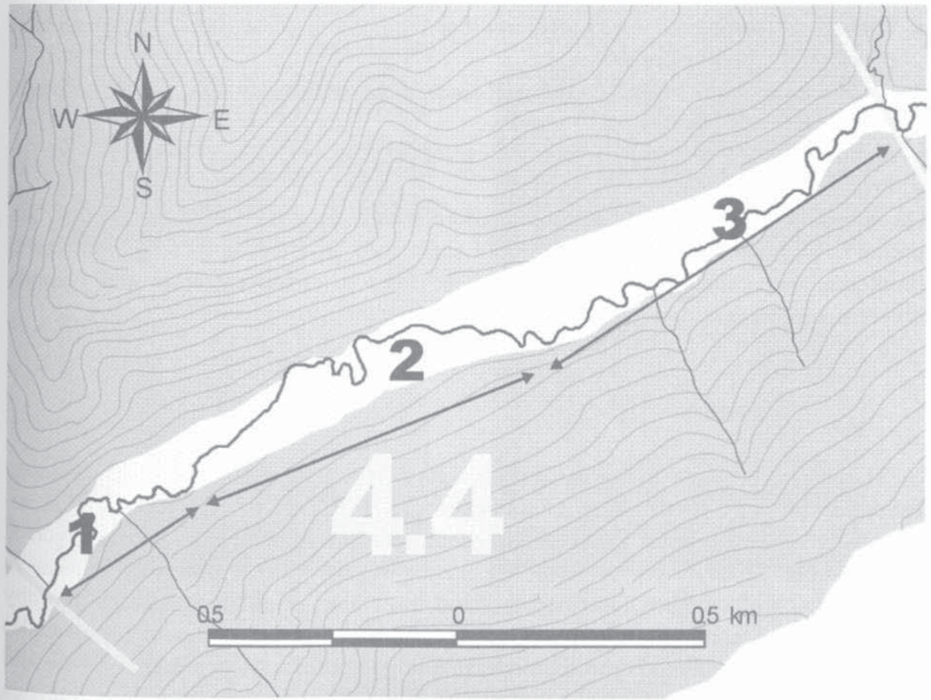

Fig. 4 Three types of channel-floodplain units differ mainly in channel abute index, stream position in valley bottom and floodplain morphology

Geomorphic unit is the basic structure recognised by fluvial geomorphologists as comprising the channel and floodplain morphology, formed by erosion of bedrock (waterfall, rapids, etc.) or by deposition of alluvium (sand and gravel bars, riffles, pools, etc.). Taxon boundaries are determined by:

- fine-scale geomorphic features recognized in the field,
- generally accepted geomorphological term (Lehotský, Grešková, 2004)

They are studied as individual, but interactive features of landscape.

Morphohydraulic unit represents a spatially distinct instream environment determined by the temporally variable hydraulic and substrate characteristics associated with each morphological unit. Nanorelief, individual habitat features (rocks, logs, gravel sediments, etc.) and hydraulic properties represent the lowest instream hierarchical level. Its assessment provides important tools for space of river health monitoring. Taxon boundaries are determined by:

- position in stream,
- substratum type through geomorphic unit (mean phi, sorting, packing),
- flow type (fall, chute, broken or unbroken standing waves, ripples, upwelling, smooth surface flow, scarcely perceptible flow, standing water),
- flow velocity,
- water depth,
- mean height of roughness elements above stream bed, vertical spacing as mean distance between the highest points of two clasts measured parallel to the flow,
- horizontal spacing as mean distance between the highest points of two clasts measured perpendicular flow,
- groove width, bank morphology (bank shape expressed as concave, convex, straight or undercut and bank slope),
- organic matter (wood debris, logs, twigs, leaves, detritus, roots character),
- Froude's and Reynold's numbers.

On the reach, geomorphic and morphohydraulic unit, formation of stream bends, initiation of channel widening or riffle-pool sequences, installation of single structures (boulders, tree stumps, pilings, groynes) in order to create substrate and velocity diversity represent restoration measures.

4. Conclusions

The article presents the classification scheme of channel-floodplain geosystems. River Morphology Hierarchical Classification (RHMC) framework represents a research tool developed on the basis of geomorphological understanding of river. It is applicable on any river system. The recent trends towards fine-scale studies in geomorphology have been described as a shift from description to explanation, thereby under-scoring the importance of bottom-up and top-down trans-taxon (trans-scale) linkages provides a foundation for understanding dynamics of taxonomic levels and their interactions with biological communities. Thus, the procedure provides a rigorous scientific basis for assessing a range of biophysical processes and provides consistently applied template upon which effective management decision-making can take place.

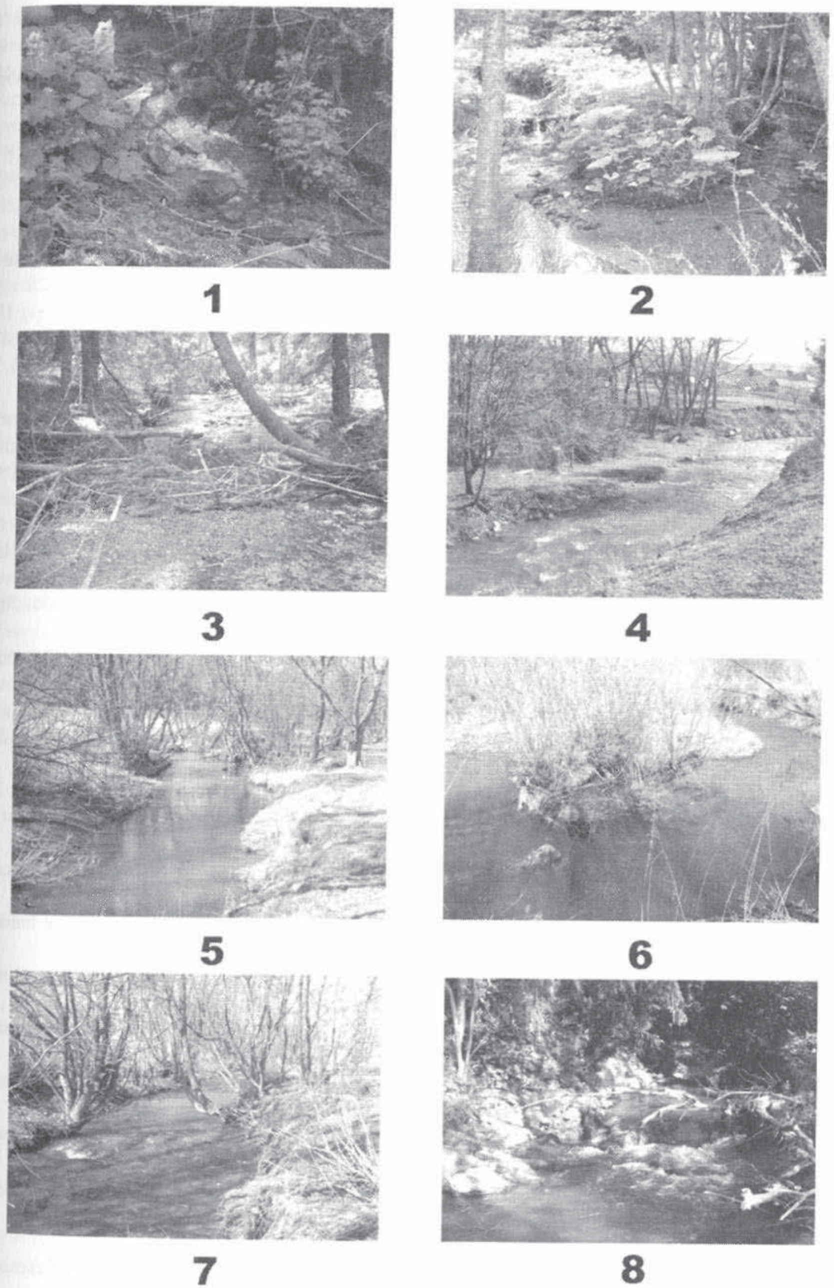

Fig. 5 Main types of the Hybica river reaches: **1.** step-pool, **2.** riffle-pool forced by woody debris, **3.** plain-bed forced by woody debris, **4.** plane-bed forced by engineering, **5.** dune-ripple, **6.** riffle-pool, **7.** plane-bed, **8.** bedrock pool-rapid.

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References

BRIERLEY, G., FRYIRS, K., OUTHET, D., MASSEY, C. (2002): Application of the River Styles framework as a basis for river management in New South Wales, Australia. Applied Geography, 22, 91–122.
CHURCH, M. (1992): Channel Morphology and Typology. In: Calow P., Petts G. E., eds.: The river Handbook – Hydrological and Ecological Principles. Blackwell Scientific Publications, London, 126–143.
DOWNS, P. E. (1995): River channel classification for channel management purposes. In: A. Gernel, G. Petts eds., Changing River Channels. John Wiley&Sons, Ltd., 347–365.
FRISSELL, C. A., LISS, W. J., WARREN, C. E., HURLEY, M. D. (1986): A hierarchical framework for stream habitat classification: viewing stream in watershed context. Environmental Management, 10, 199–124.
FRYIRS, K. (2003). Guiding principles for assessing geomorphic river condition: application of a framework in the Bega catchment, South Coast, New South Wales, Australia. Catena, 30, 1–36.
GOODWIN, C. G. (1999): Fluvial classification: Neanderthal necessity or needless normalcy. Wildland Hydrology. American Water Resources Association, 229–236.
GORDON, N. D., McMAHON, T. A., FINLAYSON, B. L., GIPPEL, CH. J., NATHAN, R. J. (2004). Stream Hyrology. An Introduction for Ecologists. John Wiley&Sons, Ltd., 429 p., Chichester.
HAIGH, M. J. (1987): The Holon: Hierarchy Theory and Landscape Research. Catena Supplement 10, 181–192.
HAWKINS, C. P., KERSHNER, J. L., BISSON, P. A., BRYANT, M. D., DECKER, L. M., GREGORY, S. V., McCULLOUGH, D. A., OVERTON, C. K., REEVES, G. H., STREEDMAN, R. J., YOUNG, M. K. (1993): A hierarchical approach to classifying stream habitat features. Fisheries 18, 3–12.
KASZOWSKI, L., KRZEMIEŃ, K. (1999): Classification systems of mountain river channels. In: K. Krzemień ed., River channels: pattern, structure and dynamics. Prace Geograficzne, zeszyt 104, Instytut Geografii Uniwersytetu Jagellońskiego, Krakow. 27–40.
KELLERHALS, R., CHURCH, M., BRAY, D. I. (1976): Classification and Analysis of River Processes. Journal of the Hydraulics Division 102, 813–829.
LEHOTSKÝ, M., GREŠKOVÁ, A. (2003): Geomorphology, fluvial geosystems and riverine landscape (methodological aspects). Geomorphologia Slovaca, 2, 46–59.
LEHOTSKÝ, M., GREŠKOVÁ, A. (2004): Slovensko-anglický hydromorfologický slovník (výkladový slovník hydromorfologických termínov). SHMÚ, Bratislava (in print).
LEOPOLD, L. B., WOLMAN, M. G. (1957): River channel patterns: Braided, Menadering and Straight. U.S. Geological Survey Professional paper 282-B, 39–85.
MADDOCK, I. (1999): The importance of physical habitat assessment for evaluation river health. Freshwater Biology, 41, 373–391.
MONTGOMERY, D. R., BUFFINGTON, J. M. (1997): Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109, 596–611.
NANSON, G. C., CROKE, J. R. (1992): A genetic classification of floodplains. Geomorphology, 4, 459–486.
SCHUMM, S. A. (1977): The Fluvial Systems. John Wiley&Sons, Ltd.. 338 p., New York.
SCHUMM, S. A. (1985): Patterns of alluvial rivers. Annual Review of Earth and Planetary Sciences 13, 5–27.
POOL, G. C. (2002): Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwater Biology, 47, 641–660.
ROSGEN, D. L. (1994): A classification of natural rivers. Catena 22, 169–199.
ROWNTREE, K. M., WADESON, R. A. (1998): A geomorphological framework for the assessment of instream flow requirements. Aquatic Ecosystems Health and Management 1, 125–141.

THOMS, M. C., SHELDON, F. (2002): An ecosystem approach for determining environmental water allocation in Australia dryland river systems: the role of geomorphology. Geomorphology 47, 153–168.
THOMSON, J. R., TAYLOR, M. P., FRYIRS, K. A., BRIERLY, G. J. (2001): A geomorphological framework for river characterization and habitat assessment. Aquatic Conservation: Marine and Freshwater Ecosystems, 11, 373–389.
THORNE, C. R., HEY, R. D., NEWSON, M. D. eds. (1997): Applied Fluvial Geomorphology for River Engineering and Management. John Wiley & Sons, Ltd. 375 p, Chichester.
WADESON, R. A., ROWNTREE, K. M. (1998): Application of the hydraulic biotope concept to the classification of instream habitats. Aquatic Ecosystems Health and Management, 1, 143–157.
WHITTING, P. J., BRADLEY, J. B. (1993): A process based classification system for headwater streams. Earth Surface Processes and Landforms 18, 603–612.

HIERARCHICKÁ KLASIFIKÁCIA MORFOLÓGIE RIEK

Résumé

Príspevok je venovaný prehľadu najznámejších klasifikačných systémov morfologických vlastností vodných tokov a prezentácii nami skoncipovaného modelu hierarchickej klasifikácie morfológie riek. Metodologicky model vychádza z princípov klasifikačných procedúr krajinného priestoru bežne používaných v geoekológii a krajinnej ekológii. Odlišuje sa špecifickým názvoslovím taxonomických úrovní a postihnutím diferenciácie krajiny od najvyššej úrovne – úrovne povodia až po úroveň najnižšiu – úroveň morfohydraulických vlastností vodného toku. Hierarchia je prezentovaná v podobe siedmych taxónov, a to: povodie-riečna sieť, zóna rieky, riečny segment, korytovo-nivná jednotka, riečny úsek, morfologická jednotka a morfohydraulická jednotka. Súčasne je každá taxonomická úroveň špecifikovaná súborom determinantných vlastností, ktorými sa jednotlivé taxóny od seba odlišujú. Model hierarchickej klasifikácie morfológie riek takto predstavuje štandardizovaný nástroj, prostredníctvom ktorého je možné pochopiť morfologické špecifiká akéhokoľvek vodného toku.