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HYDROMORPHOLOGICAL CLASSIFICATION OF SLOVENIAN RIVERS

HIDROMORFOLOŠKA TIPIZACIJA SLOVENSKIH REK

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Veliki Obrh Creek, Stari Trg pri Ložu.
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ABSTRACT: This paper provides an overview of hydromorphological and related classifications of rivers in Slovenia and elsewhere. The Rosgen classification is presented in greater detail; it was used in the study as the basis for developing the first Slovenian hydromorphological classification. A hydromorphological survey form was designed to classify rivers and used in the office and field survey of hydromorphological variables in the 95 river sections selected in Slovenia. In the river sections studied, hydromorphological types were identified by analyzing the co-occurrence of selected hydromorphological variables. This method was used to identify 10 hydromorphological types, for which the main hydromorphological features are presented in this paper. Based on the results of the first hydromorphological classification of Slovenian rivers, guidelines are provided for future work.

KEYWORDS: hydrology, rivers, classification, hydromorphological types, hydromorphological variables, co-occurrence analysis, Slovenia

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1 Introduction

River systems are complex features on the Earth's surface whose creation and changes depend on the geological base, lithologic structure, climate, and topographic factors (Knighton 1998; Fogg and Wells 1998). Although every river system is a unique phenomenon, they are generally defined as tripartite systems (Schumm 1977), in which energy is converted into various forms of organic and inorganic matter, creating three typical zones: the uppermost zone or crenon, the central or upstream portion or rhithron, and the downstream stretch or potamon. The uppermost zones of rivers are dominated by mountain relief and V-shaped valleys, and characterized by rough sediment with large grain diameter, high slope, narrow channels, and consequently high velocities of current and erosion as the predominant process. These characteristics gradually change in the central and downstream parts of the river, with increasingly wider valleys, wider and deeper channels, and a higher characteristic flow. The predominant processes in the central parts include the transport of sediment eroded in the uppermost parts, which then accumulates in the downstream parts of the river systems. Here floodplains usually develop in the wide valleys, with widely sinuous or in places even meandering channels, oxbow lakes, distributary channels, and wetlands.

Macrofactors such as climate, lithologic base, erosion, accumulation, and vegetation shape processes at the level of the entire drainage basin and consequently also at lower levels (i.e., parts of the basin, river section, habitat, or microhabitat) and control the microfactors (Frissell et al. 1986; Naiman et al. 1992). In areas with comparable macrofactors, comparable hydromorphological characteristics also develop. These can be determined using classification schemes, which provide a systematic overview of hydromorphological characteristics and make it possible to categorize river systems into manageable groups according to their similarity and connectedness (Platts 1980).

Classification schemes enable an in-depth understanding of complex processes, from those occurring at the level of the drainage basin to those at the level of a micro-habitat. In order to better understand river systems, classifications have thus been developed that define river systems according to the geomorphological characteristics of the valley and the catchment area, the characteristics of the hydrological regime, valley floor and floodplain dynamics, the pattern and morphological characteristics of the channel, morphodynamic processes, and forms of adaptation to morphological changes, erosion intensity, sediment accumulation, and so on (Rosgen 1996; Kondolf et al. 2003).

In the past decades, the applicability of classification schemes has also spread to the management level. Using classification schemes, guiding views can be determined for individual river sections (Zumbroich et al. 1999; Detering et al. 2003; Patt et al. 2008). These are compared with the state of the hydromorphological characteristics of anthropogenic modifications to river sections and, from this viewpoint, also suitably categorized into modification classes. A guiding view is also used as a reference in preparing rehabilitation measures to improve the hydromorphological condition of rivers (Palmer et al. 2005; Montgomery 2006).

Given the numerous classifications already developed around the world, which also include the hydromorphological characteristics of rivers, this paper provides an overview of them. The Rosgen classification of rivers is presented in greater detail because it deals with hydromorphological characteristics most thoroughly and has therefore been used as the basis for preparing the Slovenian hydromorphological classification. This study verified whether the sections of Slovenian rivers classified according to the main geomorphological and morphological characteristics following the Rosgen classification are also similar in terms of certain more detailed hydromorphological characteristics. In addition, the purpose of the study was also to verify whether, based on these characteristics, it is possible to identify the characteristic hydromorphological types of Slovenian rivers and prepare detailed hydromorphological descriptions and analyses of the types identified.

2 Established river classifications

2.1 International river classifications

River classifications have been developed since the end of the nineteenth century and many of them are partly or entirely based on hydromorphological factors. The earliest classification that classified rivers according to the characteristics of mountainous and lowland channels was developed in 1850 by James Dwight Dana. In 1875, John Wesley Powell developed a classification based on the genetic connection with geological structure, and in 1899 William Morris Davis presented his theory of channel development, whereby he classified rivers according to their development stage. In the early twentieth century, the connection between the form of the river network and the geological and lithologic characteristics of river systems began to be explored. In 1914, Grove Karl Gilbert developed a hypothesis about the structure of the riverbed, which became the premise for further classifications. In 1932, Emilie R. Zernitz developed a classification of rivers according to the form of the river network.

Classifications gradually began to include river processes. In 1957, Leopold and Wolman used the ratio between the channel slope and flow rate to classify rivers according to channel pattern. A number of authors further improved their classification, whereby they emphasized the differences between anastomosed and braided channels. Schumm (1963; 1977) also dealt with classifying alluvial channels. He classified rivers from the viewpoint of channel stability and mode of sediment transport (e.g., suspended, bedload, or a combination of both). In 1992, Nanson and Croke explained the connection between the channel and floodplain by classifying rivers according to the type of floodplain.

Rivers were classified according to detailed characteristics of the channel by Howard (1980; 1987), who distinguished between alluvial channels and bedrock channels, and further divided them according to channel substrate; Downs (1994; 1995), who classified rivers according to the channel's adaptation to processes; Church (1992), who classified rivers according to the ratio between the (sediment) grain size and channel depth; Grant et. al (1990), and Whiting and Bradley (1993), who developed a classification based on the predominant structures in the uppermost part of the river; Montgomery and Buffington, who presented their classification of rivers in mountainous regions in 1997, taking into account the predominant hydromorphological forms of the riverbed that develop in correlation to transport capacity. Henderson (1963) classified alluvial channels based on grain size and the characteristics of transporting sediments. Brice and Blodgett (1978) described four types of river channels in greater detail: braided, braided point-bar, wide-bend point-bar, and equi-width point-bar. Culbertson et al. (1967) developed a classification based on the structures that form through depositional features, channel pattern, sinuosity, floodplain types, bank heights, and levee formation. Khan (1971) developed a quantitative classification for sand-bed streams based on sinuosity, slope, and channel pattern. Mollard (1973) and later on Church (1992) divided rivers with floodplains into a number of types according to flow, slope, sediment supply, and channel stability. Kellerhals et al. (1976) also explored alluvial channels and classified them according to channel pattern, frequency of islands, bar types, and lateral channel migration. Later on, Church and Jones (1982) presented a classification of rivers according to bar types and channel pattern, and determined that the typical channel morphology results from the gradient and volume of sediment supply. Selby (1985) established connections between channel pattern, gradient, and the type, supply, and dominant textures of sediments. Also Paustian et al. (1992) presented a process-based classification that identifies morphology at the regional level (Rosgen 1994; Kondolf et al. 2003; Bizjak 2003). In 1994, Rosgen developed a detailed classification of rivers based on geomorphological and hydromorphological characteristics of rivers.

Based on the recognition that stream flow is the key variable in hydromorphology, a number of classifications have been developed at a smaller, regional level, and included findings about downstream changes in the flow. In addition to these classifications, hierarchical classifications have also been developed such as ones based on eco-regions, ones that are used to improve water management, and those developed according to the characteristics of individual zones of the river basin or river sections. One of the best-known classifications that proceed from studying zones is Schumm's classification (1977), which classifies rivers into three functional zones: the erosion, transport, and deposition zones. However, the most frequently used classification is that of Horton (1945) or Strahler (1957), which divides rivers according to stream order.

New, more general classifications have developed together with a number of methods for assessing the hydromorphological condition of rivers. For example, the German method known as Gewässerstrukturgütebewertung (Assessment of Watercourse Structure, GSGB; Zumbroich et al. 1999) distinguishes between rivers in gorges and V-shaped valleys, rivers in wide U-shaped flood valleys, meandering rivers, rivers in troughlike flood valleys, rivers in gravel-bed valleys, and lowland rivers (which are further divided by substrate); the British River Habitat Survey (RHS, Raven et al. 1998) distinguishes between peatbog streams, steep streams, upland plateau streams, coastal streams, mountain valley rivers, small lowland riffle-dominated rivers, clay rivers, and so on. Modern-day classifications of rivers primarily aim to improve water management and are used primarily in Germany, France, the UK, and the US (Gordon et al. 2004; Palmer et al. 2005; Gurnell et al. 2006).

In the EU member states, biotic classifications of rivers began to develop for implementing the Water Framework Directive (Directive 2000/60/ES); they serve as the basis for assessing the ecological condition of rivers (Dodkins et al. 2005; Urbanič 2007; Brown 2009). The Directive stipulates two possible systems of river classifications: system A or a fixed typology with typology descriptors defined in advance, and system B or an alternative characterization with obligatory and optional river classification factors. In EU member states, the process of implementing the Water Framework Directive resulted in a number of studies of river types, whereas the wide selection of factors of the most frequently used classification under system B resulted in a wide selection of biotic river classifications. The latter are also a necessary prerequisite for evaluating the ecological condition of rivers (Dodkins et al. 2005; Urbanič 2007; Brown 2009).

2.1.1 The Rosgen classification of rivers

The purpose of the Rosgen classification is to predict fluvial processes based on a hydromorphological analysis of the river, to determine specific hydraulic and sediment relations for a given morphological channel type and state, to develop a mechanism to extrapolate site-specific data to mutually comparable rivers, and to provide a consistent frame of reference for more correct water management. The classification con-

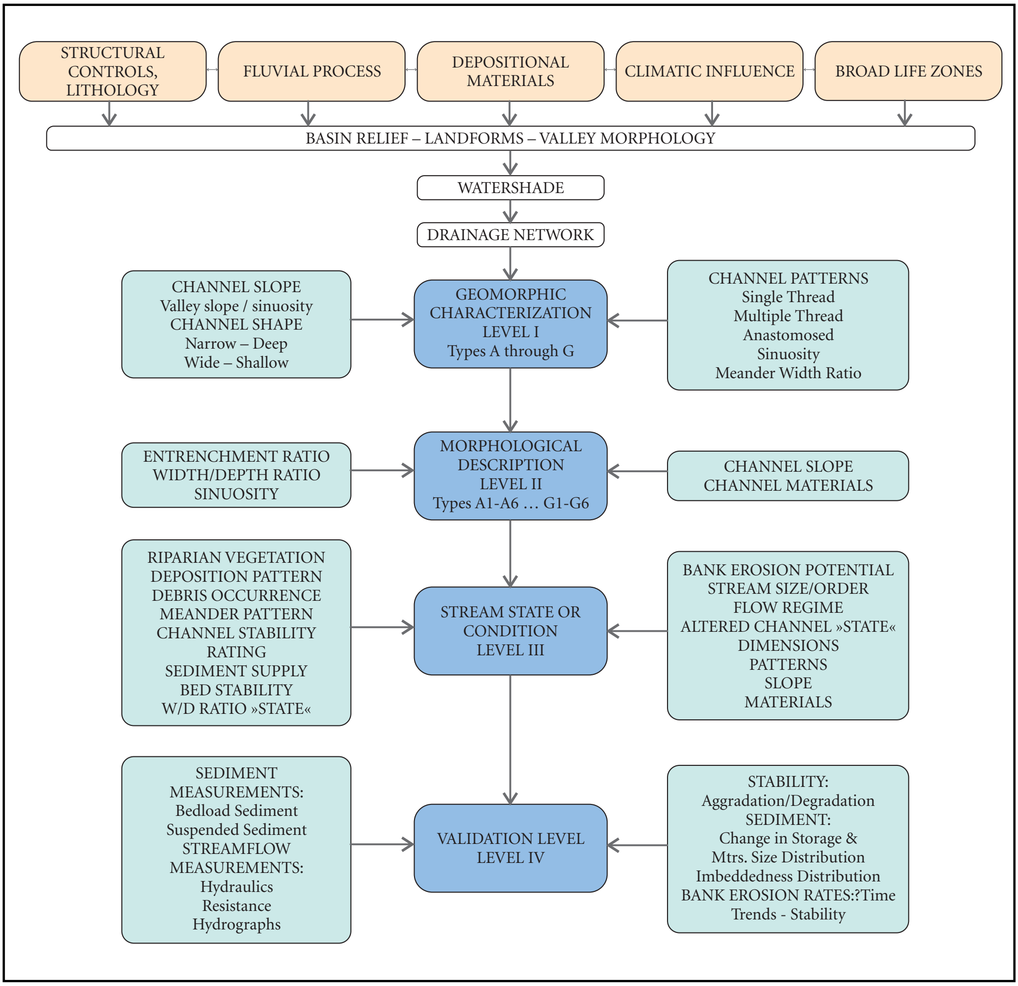


Figure 1: Hierarchical river inventory levels (Rosgen 1996).

sists of four levels (Figure 1), which gradually move from the first, general geomorphological, description to extremely detailed hydromorphological descriptions and evaluations. At the first two levels, the Rosgen classification defines seven main types and 42 subtypes of rivers.

The first level includes a geomorphological description with variables such as channel slope, channel shape, channel pattern, and sinuosity. Characteristics at this level are identified and quantified from topographic maps and aerial photographs. The second level focuses on more detailed morphological features collected through a field analysis of sections: entrenchment ratio, channel dimension, channel pattern and shape, and predominant substrate. It thus provides a quantitative morphological definition that has an applied value in management. The third level describes the stream conditions and includes a number of additional variables: riparian vegetation, sediment supply, flow regime, debris occurrence, deposition pattern, channel stability, bank erosion potential, and direct anthropogenic disturbances. At the fourth and last level, variables are defined with individual measurements that verify the relations established at previous levels.

2.2 Classifying rivers in Slovenia

In Slovenia, classifying rivers based on hydromorphological factors is still at the initial stage of development. In addition to the hydromorphological classification of rivers presented in this paper (Repnik 2006), a hydrogeomorphological classification is also underway (Natek 2006). In general, hydromorphological characteristics of rivers can be partly defined using a number of similar examples of classifications of water-related natural phenomena that have been performed in Slovenia: Slovenian Flood Classification (Gams 1973), Regional-Ecological Regionalization (Gams 1986), Typology of Landscapes and Definition of Special-Value Landscapes in Slovenia (Hudoklin 1994), Landscape Regionalization (Marušič 1998 a–e), Landscape Characteristics of Slovenian Watercourses (Bratina Jurkovič 1999), Watercourse Categorization According to Ecomorphological Importance (Fazarinc et al. 2002), Surface Water Typology (Brilly et al. 2003), and Surface Water Body Typology (Urbanič 2007).

3 Method and results

3.1 Data capture technique

Given that to date no detailed hydromorphological databases have been created in Slovenia that would make it possible to classify rivers, extensive collection of hydromorphological variables took place as part of this study. Data can be captured using techniques such as inventorying hydromorphological variables in the field (a field approach), modeling reference hydromorphological conditions, analyzing historical hydromorphological data, and analyzing paleolimnological data (CIS 2003). The expert-opinion technique is also often used in combination with these techniques, but it is often subjective and thus more difficult to repeat. If the preserved state of rivers is suitable for defining reference hydromorphological characteristics in the field, the field approach is the most appropriate technique for capturing data despite the great amount of time this requires. Other techniques prove to be useful primarily in cases when field data cannot be obtained.

In Slovenia, the overall length of rivers with a catchment area of more than 10 km^2 is 4,797.4 km. Of this, 1,328.7 km or 27.7% of the river network exhibits only few anthropogenic changes (Fazarinc et al. 2002). A large share of barely changed river network is a good argument for selecting a spatial approach in preparing the classification. According to the results of the study Categorization of Watercourses by Eco-Morphological Importance (Fazarinc et al. 2002), which categorizes rivers according to degree of anthropogenic impact, sections belonging to class 1 (i.e., natural watercourses) or class 1–2 (only slightly changed watercourses) are identified as suitable for capturing data (Figure 2). Among the suitable sections, sections for studying hydromorphological types were selected according to the following additional criteria:

- River catchment area at sample location of 10 to 100 km^2;
- Even distribution of sample locations across the entire hydrographic network;
- Even distribution of sample locations in individual bioregions;
- Representativeness of sections according to landscape hydromorphological features;
- Accessibility of sample locations for the purposes of fieldwork.

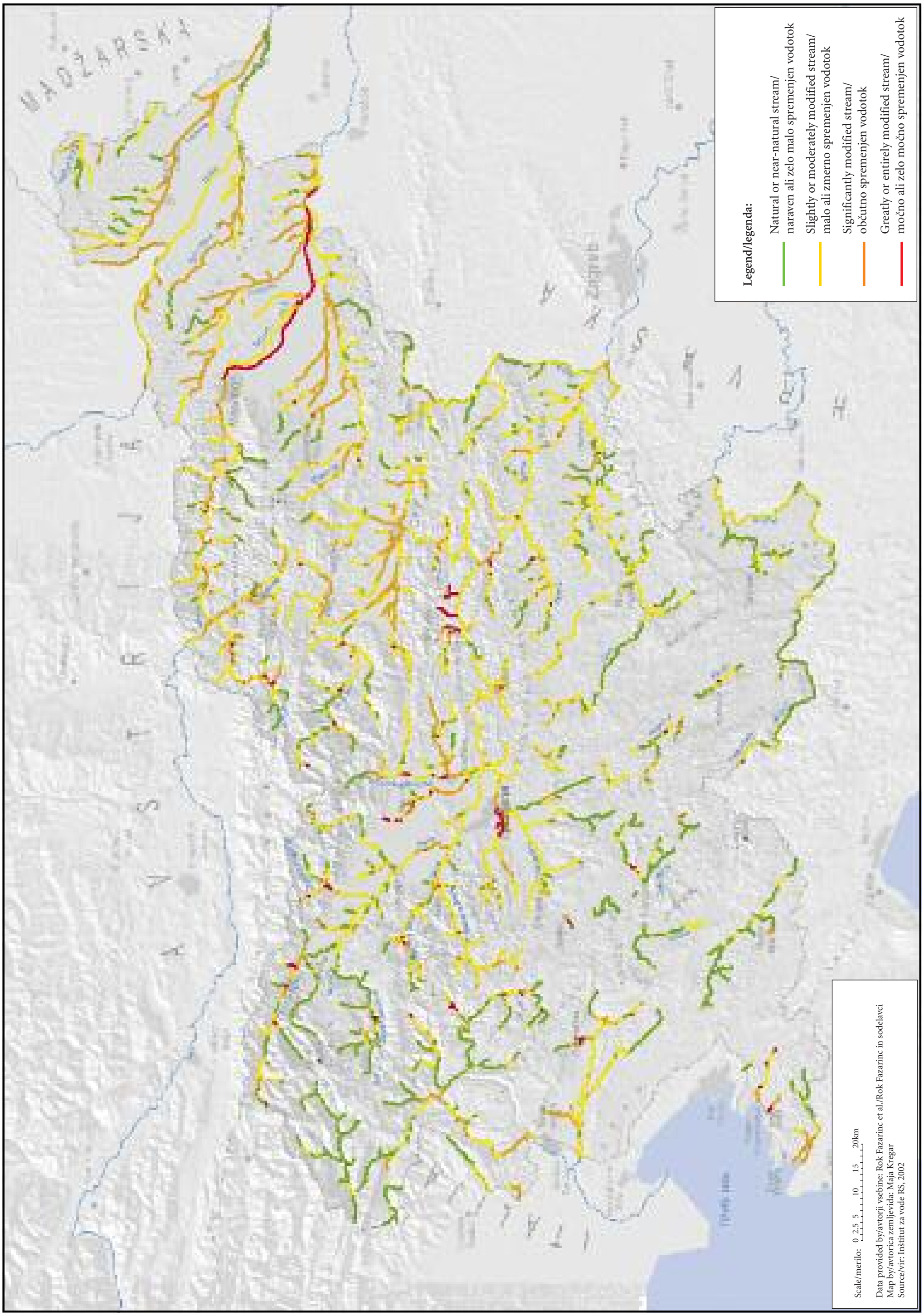


Figure 2: Degrees of anthropogenic alteration of watercourses (adapted from Fazarinc et al. 2002).

In the sections selected, data were captured using the transect method (Bizjak 2003; Mikoš and Bizjak 2007), which reduces and optimizes the scope and time complexity of gathering data. Transects are rectangular transverse sections of the channel cartographically defined in advance. Their width equals the channel width times two, and their length also includes a 50-meter riparian zone in addition to the channel width. They are distributed 100 m apart. In the area of a selected 500-meter section, six transects were recorded. A total of 95 river sections or 570 transects were analyzed in the study.

Table 1: Overview of hydromorphological variables gathered in the office and in the field.

Category		Hydromorphological variables
General data (section)		River name and code, bioregion, landscape unit, nearby settlement, section coordinates, elevation Elevation zone, geological base, precipitation Catchment area size, channel width class Date of inventory, person inventorying
Data on stream flow quantity and dynamics		Hydrometric station, flow Q (m^3/s), water level h (cm), T (°C), flow decile, mean flow Q_{sr} (m^3/s), minimum specific flow with a 20-year return period $q_{min,20}$, flow regime
General data	General data (transect)	Transect coordinates and length
	Changes in channel width and depth	Channel-forming width b_s (m), changes to channel-forming width Δb_s (m), entrenched channel width b_u (m), longitudinal depth changes Δh_v (m), lateral depth changes Δh_p (m), mean water depth h (m), maximum water depth h_{max} (m), entrenched channel depth h_u (m), width/depth ratio w/d
	Channel structure	Entrenchment ratio, bank height h_b (m), bank slope α (°), channel slope I (%)
	Predominant relief	Plain, hummocks, hills, mountains
	Valley type	Gorge, V-shaped valley, U-shaped valley, shallow valley, broad valley
	River type	Karst, plain, hummocky, hilly, mountainous biotic type
	Depth changes	Not perceptible, small, moderate, great, extremely great
	Width changes	Not perceptible, small, moderate, great, extremely great
Channel and substrate structure	Channel pattern	Single-thread, multiple-thread, anastomosed
	Sinuosity	Flat or slightly sinuous, moderately sinuous, extensively sinuous, meandering
	Channel shape	U, flat U, deepened U, broad or widened, double trapezoid, steps
	Substrate	Clay, silt, sand, gravel, pebble, cobble, bedrock, boulder
	Island (no.)	No island, bare island, vegetated island – young successive stage, vegetated island – mature successive stage
	Pebble, gravel, and sand bar (no.)	None, lateral or alternating, longitudinal, at a bend, center, at a confluence
	Other forms (no.)	Pool (pool illuminance), cascade, step, gentle cascade, rapid, riffle, shallow
	Form sequences	Colluvium, bedrock, cascade, step-pool, flat bed, pool-rapid, pool-riffle, dune-ripple
	Bed roughness	Not perceptible, small, moderate, great, extremely great
	Water stream diversity	Not perceptible, small, moderate, great, extremely great
	Bank materials	Bedrock, rock, soil, combination
	Erosion (shares)	Not evident, erosion in bends and narrows, longitudinal erosion
	Bank forms	Root clumps, tree deflectors
	Channel vegetation cover (share)	Overgrown with terrestrial vegetation, overgrown with aquatic vegetation
	Presence of fallen trees and woody debris	None, small, medium, great
Riparian zone structure	Type of riparian vegetation	None, autochthonous, allochthonous
	Riparian vegetation distribution	No vegetation, autochthonous-continuous, autochthonous-segmented, autochthonous-dispersed, autochthonous-thinned, allochthonous
	Riparian vegetation age	No vegetation, young successive stage, intermediate successive stage, mature successive stage
	Riparian forms	None, side flow, standing water, oxbow, swamp, combination
	Transitional upland fringe land use	Autochthonous forest, overgrown land, meadow or uncultivated land, allochthonous forest, other land use
	Distribution and width of transitional upland fringe vegetation	No vegetation, autochthonous-continuous, autochthonous-segmented, autochthonous-dispersed, autochthonous-thinned, allochthonous
	Transitional upland fringe vegetation age	No vegetation, young successive stage, intermediate successive stage, mature successive stage

3.2 Field and office data capture

A survey form (Table 1) was developed to inventory the hydromorphological variables in the river sections and transects selected in advance. The selection of hydromorphological variables on the survey form includes the selected variables listed in the Rosgen and Montgomery classifications (Rosgen 1996, Montgomery et al. 1997) and the selected methods for evaluating the hydromorphological condition: the RCE method (Petersen 1992), the SVAP method (Newton et al. 1998; Lavrenčič 2005; Lavrenčič et al. 2006), the RHS method (Raven et al. 1998), the GSGB method (Zumbroich et al. 1999), the IFF method (Siligardi et al. 2000; Batistič 2005; Batistič et al. 2006), the AUSRIVAS method (Parsons et al. 2001), and the synthesis method (Bizjak 2003; Mikoš and Bizjak 2007). During the study, the survey form was further optimized and target hydromorphological variables were added to it.

The majority of hydromorphological variables were captured in the field, although some were also captured through office work. The hydromorphological equipment used included the following: GPS navigation, a level staff, an electronic rangefinder, a tape measure, and a clinometer for estimating the channel bed slope. The channel dimensions were measured, on the basis of which the channel width/depth and entrenchment ratios were then calculated. The predominant relief of the river sections was determined based on the relative differences in elevation and valley type was determined based on the form of the valley cross-sections (Leksikon, Geografija 2001); in addition, channel patterns, sinuosity, and channel shape (Parsons et al. 2001) were determined as well as the predominant substrate according to the typical grain classes (Mikoš 2000). Individual hydromorphological forms of bed were determined based on structural descriptions (Zumbroich et al. 1999; Parsons et al. 2001), and the sequences of bed forms were determined according to their classification (Montgomery et al. 1997). Depending on the bed forms, sections also differ from one another in terms of bed form roughness and variety of stream flow surface, which were qualitatively estimated. Bank materials, erosion, and bank forms were identified for individual sections (Zumbroich et al. 1999); in addition, vegetation cover, and the presence of fallen trees and woody debris

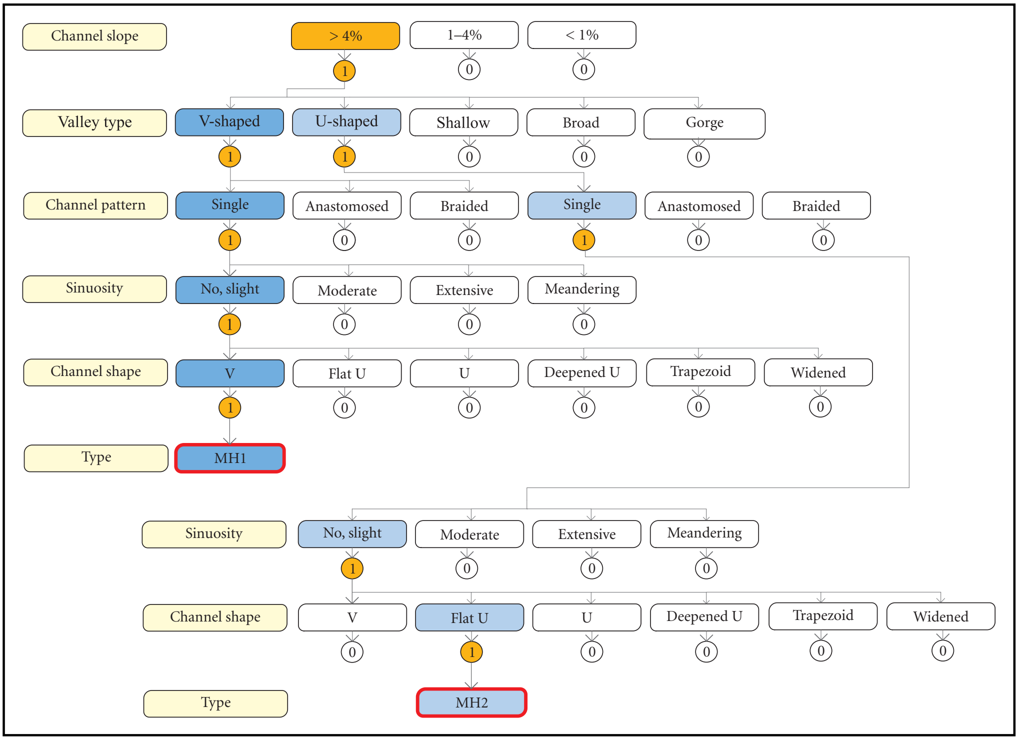
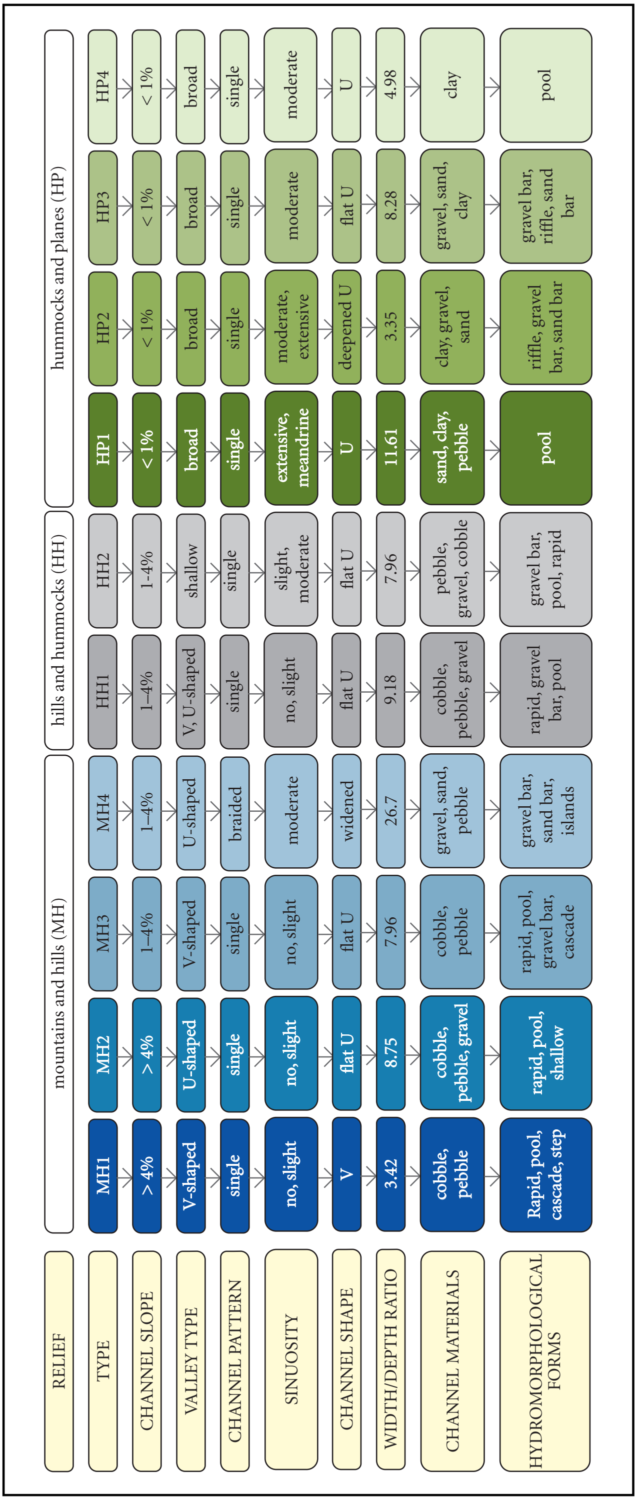
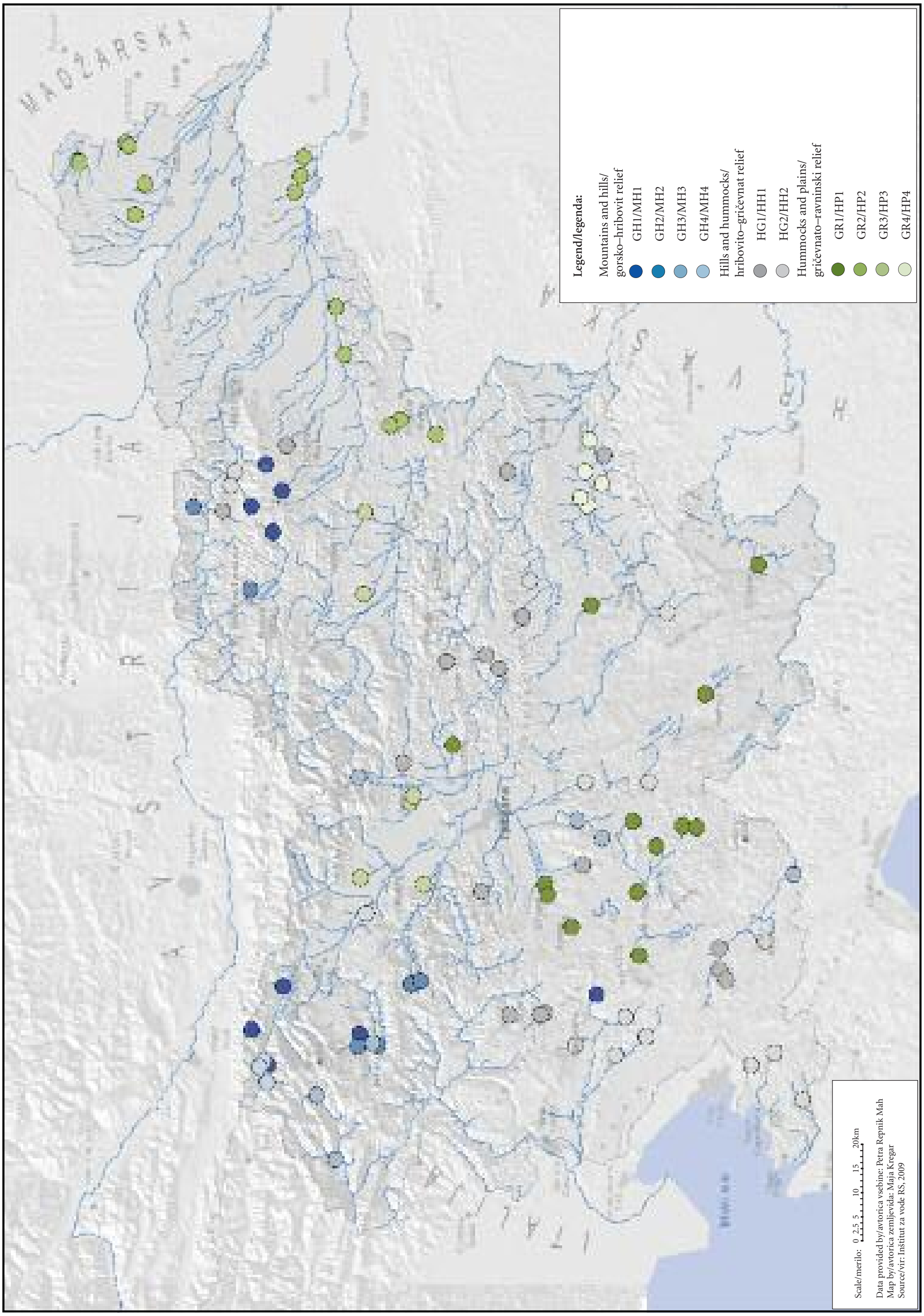


Figure 3: Decision tree for types MH1 and MH2.



RELIEF	mountains and hills (MH)				hills and hummocks (HH)		hummocks and planes (HP)			
TYPE	MH1	MH2	MH3	MH4	HH1	HH2	HP1	HP2	HP3	HP4
CHANNEL SLOPE	> 4%	> 4%	1–4%	1–4%	1–4%	1-4%	< 1%	< 1%	< 1%	< 1%
VALLEY TYPE	V-shaped	U-shaped	V-shaped	U-shaped	V, U-shaped	shallow	broad	broad	broad	broad
CHANNEL PATTERN	single	single	single	braided	single	single	single	single	single	single
SINUOSITY	no, slight	no, slight	no, slight	moderate	no, slight	slight, moderate	extensive, meandrine	moderate, extensive	moderate	moderate
CHANNEL SHAPE	V	flat U	flat U	widened	flat U	flat U	U	deepened U	flat U	U
WIDTH/DEPTH RATIO	3.42	8.75	7.96	26.7	9.18	7.96	11.61	3.35	8.28	4.98
CHANNEL MATERIALS	cobble, pebble	cobble, pebble, gravel	cobble, pebble	gravel, sand, pebble	cobble, pebble, gravel	pebble, gravel, cobble	sand, clay, pebble	clay, gravel, sand	gravel, sand, clay	clay
HYDROMORPHOLOGICAL FORMS	Rapid, pool, cascade, step	rapid, pool, shallow	rapid, pool, gravel bar, cascade	gravel bar, sand bar, islands	rapid, gravel bar, pool	gravel bar, pool, rapid	pool	riffle, gravel bar, sand bar	gravel bar, riffle, sand bar	pool

Figure 4: Main hydromorphological features of identified hydromorphological types.



Data provided by/avtorica vsebine: Petra Repnik Mah
Map by/avtorica zemljevida: Maja Kregar
Source/vir: Inštitut za vode RS, 2009

Figure 5: Hydromorphological types of stream sections.

Figure 6: Type MH1 – Jesenica Creek, Jesenice.

Figure 7: Type MH2 – Suha Creek, Stara Fužina.

Figure 8: Type MH3 – Iška River, Iška Vas.

Figure 9: Type MH4 – Pišnica Creek, Kranjska Gora.

Figure 10: Type HH1 – Blanščica Creek, Blanca.

Figure 11: Type HH2 – Osp Creek, Osp.

Figure 12: Type HP1 – Lipsenjščica Creek, Grahovo.

Figure 13: Type HP2 – Lipnica Creek, Murska Sobota.

Figure 14: Type HP3 – Tunjščica Creek, Komenda.

Figure 15: Type HP4 – Senuša Creek, Kostanjevica na Krki.

were defined. Vegetation type, distribution, and age, and the presence of hydromorphological forms such as wetlands, side flows, and oxbows were analyzed for the riparian zone and transitional upland fringe. The predominant land use was explored separately for the transitional upland fringe.

The following data were inventoried in the office for the selected river sections: bioregion code and name (Urbanič 2007), settlement, landscape unit (Marušič 1998a–e), elevation zone, geological base, precipitation, and minimum specific flow with a twenty-year return period (Brilly et al. 2003), catchment area size (Šraj 2001), hydrometric station, flow characteristics (www.arso.gov.si), and flow regime (Hrvatin 1998).

3.3 Data analysis and hydromorphological types identified

The data obtained were used to calculate the average values of the hydromorphological variables measured for individual river sections and to determine the predominant characteristics of the hydromorphological variables observed. These were also used as the input data for further spatial analysis. A co-occurrence analysis was applied to analyze the overlapping of data layers and spatial characteristics. This included the hydromorphological variables listed at the first level of the Rosgen classification: channel slope, channel pattern, sinuosity, and channel shape; in addition, valley type was also taken into account. Decision trees were developed for individual combinations of selected hydromophological variables (Figure 3).

Ten hydromorphological types were identified using co-occurrence analysis: four types in regions with mountains and hills regions (Type MH), two types in regions with hills and hummocks (Type HH), and four types in regions with hummocks and plains (Type HP; Figures 5–15). Following this, from all of the hydromorphological variables recorded that define individual types the similarity of three hydromorphological variables was tested in greater detail: the width/depth ratio, substrate, and hydromorphological forms (Figure 4).

4 Discussion

This study revealed that the hydromorphological types defined based on the main hydromorphological variables selected are also characterized by a similarity between more detailed hydromorphological variables. The following variables in particular reflect a similarity within individual hydromorphological types: channel materials, width/depth ratio, and the type and number of hydromorphological forms. Hydromorphological types also differ the most in terms of these features (Figure 16).

Within the types identified, the greatest co-occurrence among the hydromorphological variables analyzed is typical of the type and number of hydromorphological forms. The greatest diversity and number was determined for the mountain-hill types, in which rapids and pools are especially typical, although

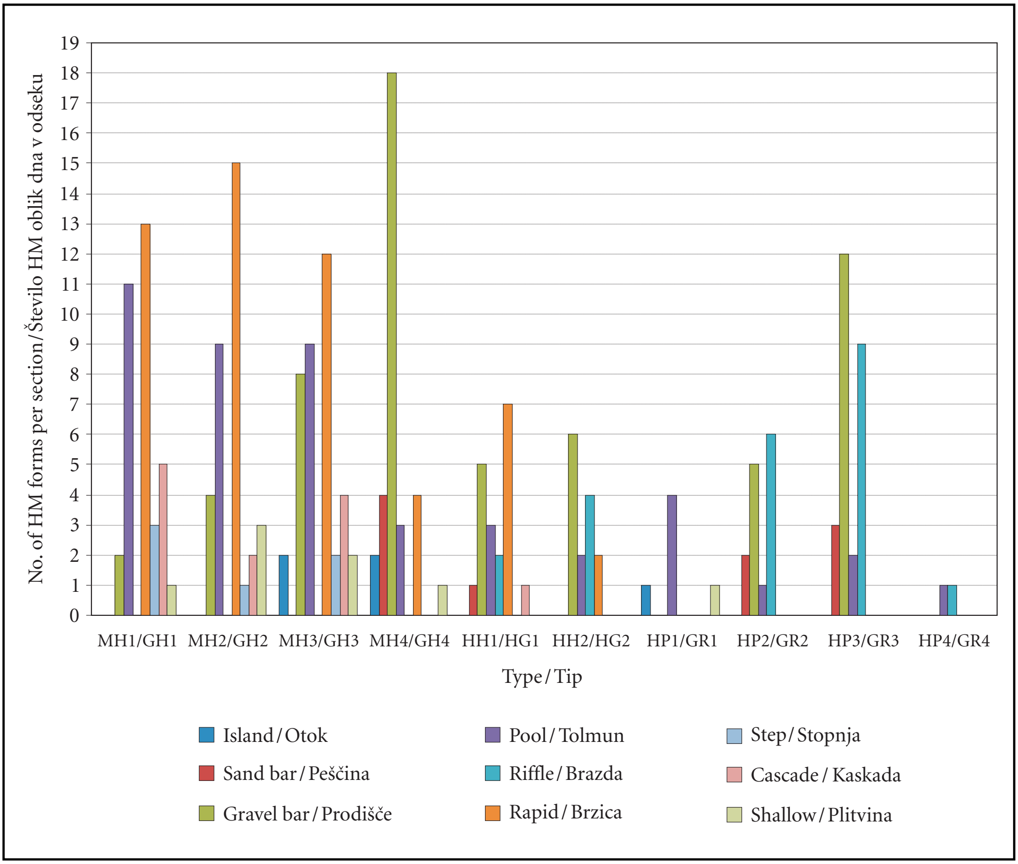


Figure 16: Type and number of hydromorphological forms in the hydromorphological types analyzed.

the step-pool and pool-rapid sequences are also present. Gravel bars stand out in Type MH4 (mountains and hills) because the channel is braided and crisscrossed with gravel bars due to its reduced slope, great width, and reduced transport capacity. The diversity and number of hydromorphological forms decreases from hill-hummock types towards hummock-plain types. In addition to gravel bars and rapids, riffles or pool-rapid and pool-riffle sequences typically occur in the hill-hummock types. In the last type group, sand bars and deep pools also occur in addition to riffles and gravel bars.

Analysis of the findings showed that detailed hydromorphological variables are more similar in the group of types identified in the mountain-hill and hummock-plain regions; minor deviations occur in the group of types in the hill-hummock regions, which indicates a need for a further breakdown or classification of types. In the event of deviations of a type's individual features, the following question always arises: To what extent should the classification be expanded to include new hydromorphological variables? Every classification is limited by its own unlimitedness (Wright et al. 1984) and thus demands a selection of only target variables, which justify the purpose of classification.

The hydromorphological features in selected river sections were similar to the extent that in no case was more than one hydromorphological type identified within a section. If longer sections had been analyzed, transitions from one type into another would have definitely been established because streams are systems, in which features and processes change downstream. Only exceptionally can a stream be defined by only one hydromorphological type from its source to its mouth; in Slovenia, this could be primarily expected with rivers on karst poljes.

5 Conclusion

The creativity of hydromorphological classification studies in Slovenia and the broad applicability of classification schemes were the main motivations in preparing the Slovenian hydromorphological classification of rivers. In the process of classifying rivers, hydromorphological sample images will also be developed in order to provide better insight into the hydromorphological diversity of Slovenian rivers. The hydromorphological classification will also serve as a basis for defining the concepts of renovations and implementing renovation measures in anthropogenically modified river sections.

In further steps of hydromorphological classification of rivers, the hydromorphological types identified must also be ascribed to the river sections not included in the analysis. Here, it is of key importance to produce individual data layers concerning channel slope, valley type, channel pattern, sinuosity, and channel shape in advance. This would significantly reduce the timeframe of fieldwork, which would only be performed for the purposes of verifying the key hydromorphological features of individual types. As part of future hydromorphological classification of rivers, it is also necessary to define those hydromorphological variables for which no official names and explanations yet exist in Slovenian.

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Hidromorfološka tipizacija slovenskih rek

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IZVLEČEK: V prispevku je podan pregled hidromorfoloških in sorodnih tipizacij rek v svetu in v Sloveniji. Podrobneje je predstavljena Rosgenova tipizacija, ki je bila v raziskavi privzeta kot izhodišče za izdelavo prve slovenske hidromorfološke tipizacije. Za potrebe tipizacije rek je bil izdelan hidromorfološki popisni list, ki je bil uporabljen pri kabinetnem in terenskem zajemu hidromorfoloških spremenljivk na izbranih 95 rečnih odsekih po Sloveniji. Na obravnavanih rečnih odsekih so bili z analizo sopojavljanja izbranih hidromorfoloških spremenljivk določeni hidromorfološki tipi. Z omenjeno metodo dela je bilo opredeljenih 10 hidromorfoloških tipov, za katere so v prispevku navedene glavne hidromorfološke značilnosti. Na osnovi rezultatov prvega hidromorfološkega tipiziranja slovenskih rek so podane smernice za nadaljnje delo.

KLJUČNE BESEDE: hidrologija, reke, tipizacija, hidromorfološki tipi, hidromorfološke spremenljivke, analiza sopojavljanja, Slovenija

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Vsebina

1 Uvod

Rečni sistemi so kompleksni pojavi na zemeljskem površju, ki so nastali in se spreminjajo v odvisnosti od geološke podlage, litološke zgradbe, podnebja in topografskih dejavnikov (Knighton 1998; Fogg in Wells 1998). Čeprav je vsak rečni sistem edinstven pojav, so v splošnem opredeljeni kot trodelni sistemi (Schumm 1977), kjer se energija pretvarja v različne oblike žive in nežive narave in ustvarja tri značilna območja – povirni del ali zgornji tek (krenon), osrednji del ali srednji tek (ritron) in nižinski del ali spodnji tek (potamon). Za povirne dele rek, kjer običajno prevladujejo gorski relief in doline V-oblike, so značilni grob sediment z velikim premerom zrna, velik padec, ozke struge in posledično velike hitrosti vodnega toka ter erozije kot prevladujočega procesa. Te značilnosti se v srednjih in nižinskih delih rek postopno spreminjajo, saj naraščajo širina doline, širina in globina struge ter karakteristični pretok. Prevladujoči proces v srednjih delih je premeščanje v povirnih delih erodiranega sedimenta, ki se nato akumulira v nižinskih delih rečnih sistemov. Tu se v širokih dolinah običajno razvijejo poplavne ravnice s široko vijugajočimi ali ponekod tudi meandrirajočimi strugami, mrtvicami, stranskimi rokavi in mokrišči.

Makro-dejavniki, kot so podnebje, litološka podlaga, erozija, akumulacija in vegetacija, oblikujejo procese na ravni celotnega porečja in posledično na nižji ravni, to je na ravni dela porečja, rečnega odseka, habitata in mikrohabitata ter nadzirajo mikro-dejavnike (Frissell in ostali 1986; Naiman in ostali 1992). V območjih s primerljivimi makro-dejavniki se tako oblikujejo tudi primerljive hidromorfološke značilnosti. Te se lahko določajo s pomočjo tipizacijskih shem, ki podajajo sistematičen pregled hidromorfoloških značilnosti in omogočajo kategoriziranje rečnih sistemov v obvladljive skupine glede na njihovo medsebojno podobnost in povezanost (Platts 1980).

Tipizacijske sheme omogočajo poglobljeno razumevanje kompleksnih procesov – od tistih, ki potekajo na ravni porečja do procesov na ravni mikrohabitata. Z namenom boljšega razumevanja rečnih sistemov so bile tako razvite tipizacije, ki opredeljujejo rečne sisteme glede na geomorfološke značilnosti doline in prispevnega območja, značilnosti hidrološkega režima, značilnosti dolinskega dna in dinamiko poplavne ravnice, obliko struge, morfološke značilnosti struge in morfo-dinamične procese ter oblike prilagajanja na morfološke spremembe, intenziteto erozije, akumuliranja sedimentov ipd. (Rosgen 1996; Kondolf in ostali 2003).

V zadnjih desetletjih se je uporabnost tipizacijskih shem razširila tudi na upravljavsko raven. S pomočjo tipizacijskih shem se lahko za posamezne rečne odseke določijo referenčne hidromorfološke podobe (nem. Leitbild, ang. Guiding View) (Zumbroich in ostali 1999; Detering in ostali 2003; Patt in ostali 2008). Te se primerjajo s stanjem hidromorfoloških lastnosti antropogeno spremenjenih odsekov rek in s tega vidika tudi primerno kategorizirajo v razrede spremenjenosti. Referenčna hidromorfološka podoba je tudi vodilo pri pripravi ukrepov obnov ali rehabilitacij, ki se uporabljajo za izboljšanje hidromorfološkega stanja rek (Palmer in ostali 2005; Montgomery 2006).

Glede na v svetu številne že izdelane tipizacije, ki obravnavajo tudi hidromorfološke značilnosti rek, je v članku pripravljen pregled teh. Izmed teh tipizacij je podrobneje opisana Rosgenova tipizacija rek, ki hidromorfološke značilnosti najbolj podrobno obravnava in je bila zato privzeta kot izhodišče za pripravo slovenske hidromorfološke tipizacije. V raziskavi je bilo preverjeno ali so si odseki slovenskih rek, tipizirani glede na glavne geomorfološke in morfološke značilnosti po Rosgenovi tipizaciji, podobni tudi glede na nekatere podrobnejše hidromorfološke značilnosti. Prav tako je bil namen raziskave preveriti, ali je možno na podlagi teh prepoznati značilne hidromorfološke tipe slovenskih rek ter pripraviti podrobnejše hidromorfološke opise in analize prepoznanih tipov.

2 Uveljavljene tipizacije rek

2.1 Mednarodne tipizacije rek

Tipizacije rek se v svetu razvijajo že od konca 19. stoletja dalje, mnoge med njimi v celoti ali delno temeljijo na hidromorfoloških dejavnikih. Prvo znano tipizacijo, ki je reke tipizirala glede na značilnosti gorskih in ravninskih strug, je razvil James Dwight Dana leta 1850. John Wesley Powell je leta 1875 razvil tipizacijo na podlagi genetske povezanosti z geološko strukturo, leta 1899 je William Morris Davis predstavil teorijo razvoja struge in reke tipiziral glede na razvojni stadij. V zgodnjem 20. stoletju so pričeli proučevati povezavo med obliko rečne mreže in geološkimi ter litološkimi značilnostmi rečnih sistemov. Leta 1914 je Grove Karl Gilbert razvil hipotezo o strukturi dna reke, ki je postala izhodišče za nadaljnje tipizacije. Tipizacijo rek glede na obliko rečne mreže pa je razvil Emilie R. Zernitz leta 1932.

Postopoma so tipizacije pričele vključevati rečne procese. Leta 1957 sta Leopold in Wolman na podlagi razmerja med padcem in pretokom tipizirala reke glede na obliko struge. Njuno tipizacijo so številni avtorji nadgradili, pri čemer so poudarili razlike med razcepljenimi in deljenimi strugami. S tipizacijo aluvialnih strug se je ukvarjal tudi Schumm (1963, 1977). Reke je tipiziral z vidika stabilnosti struge in vrsto premeščenih plavin (lebdeče, rinjene oziroma kombinacija). Povezavo med strugo in poplavno ravnico sta v tipizaciji rek glede na vrsto poplavne ravnice pojasnila Nanson in Croke leta 1992.

Glede na podrobne značilnosti struge so reke tipizirali Howard (1980, 1987), ki je ločil aluvialne struge in struge na matični kamnini ter jih nadalje členil glede na substrat; Downs (1994, 1995), ki je reke tipiziral glede na procesno prilagajanje struge; Church (1992), ki je reke tipiziral glede na razmerje med velikostjo zrna (sedimenta) in globino struge; Grant et. al (1990) ter Whiting in Bradley (1993), ki so izdelali tipizacijo glede na prevladujoče strukture v povirnem delu; Montgomery in Buffington pa sta leta 1997 predstavila tipizacijo rek v goratih predelih in sicer glede na prevladujoče hidromorfološke oblike rečnega dna, ki nastanejo v odvisnosti od premestitvene zmogljivosti. Aluvialne struge je na osnovi velikosti premera zrna in značilnosti premeščanja plavin tipiziral Henderson (1963). Brice in Blodgett (1978) sta podrobneje opisala štiri tipe strug – deljene struge, struge s prodišči v zavoju, struge s širokimi zavoji in prodišči in struge z enakomernimi zavoji in prodišči. Glede na strukture, ki nastajajo z odlaganjem plavin, obliko struge, vijugavostjo, obliko poplavne ravnice, višino brežin in izoblikovanje nasipov je tipizacijo izdelal Culbertson s sodelavci (1967). Kvantitativno tipizacijo za reke s peščenim dnom je ob upoštevanju vijugavosti, padca in oblike struge izdelal Khan (1971). Mollard (1973) in kasneje Church (1992) sta reke s poplavnimi ravnicami razvrstila v številne tipe glede na pretok, padec, razpoložljivost plavin in stabilnost struge. Aluvialne struge je proučeval in na podlagi oblike struge, pogostosti otokov, vrste prodišč in prečne migracije členil tudi Kellerhals s sodelavci (1976). Church in Jones (1982) sta kasneje predstavila tipizacijo rek glede na tipe prodišč in obliko struge in ugotovila, da je značilna morfologija rezultat padca dna in količine razpoložljivih plavin. Povezave med obliko struge, padcem ter vrsto, razpoložljivostjo in prevladujočim substratom je poiskal Selby (1985). Tudi Paustian s sodelavci (1992) je podal procesno osnovano tipizacijo, ki prepoznava morfologijo na nivoju regije (Rosgen 1994, Kondolf in ostali 2003, Bizjak 2003). Leta 1994 je glede na geomorfološke in hidromorfološke značilnosti rek podrobno tipizacijo izdelal Rosgen.

S spoznanjem, da je moč vodnega toka ključna spremenljivka v hidromorfologiji, so nastale številne tipizacije na podrobnejšem, regionalnem nivoju, ki so vključevale dognanja o dolvodnem spreminjanju moči vodnega toka. Poleg omenjenih tipizacij so bile izdelane tudi hierarhične tipizacije, npr. na osnovi ekoregij, tipizacije, ki služijo boljšemu upravljanju voda ter tipizacije, ki so narejene glede na značilnosti posameznih con v porečju oziroma rečnih odsekov. Ena najbolj znanih tipizacij, ki izhaja iz preučevanja con, je Schummova tipizacija (1977), ki reke razdeli na tri funkcionalna območja – območja erozije, premeščanja in akumuliranja, medtem ko je pogosto uporabljena Hortonova (1945) oziroma Strahlerjeva (1957) tipizacija, ki reke razvršča glede na red reke.

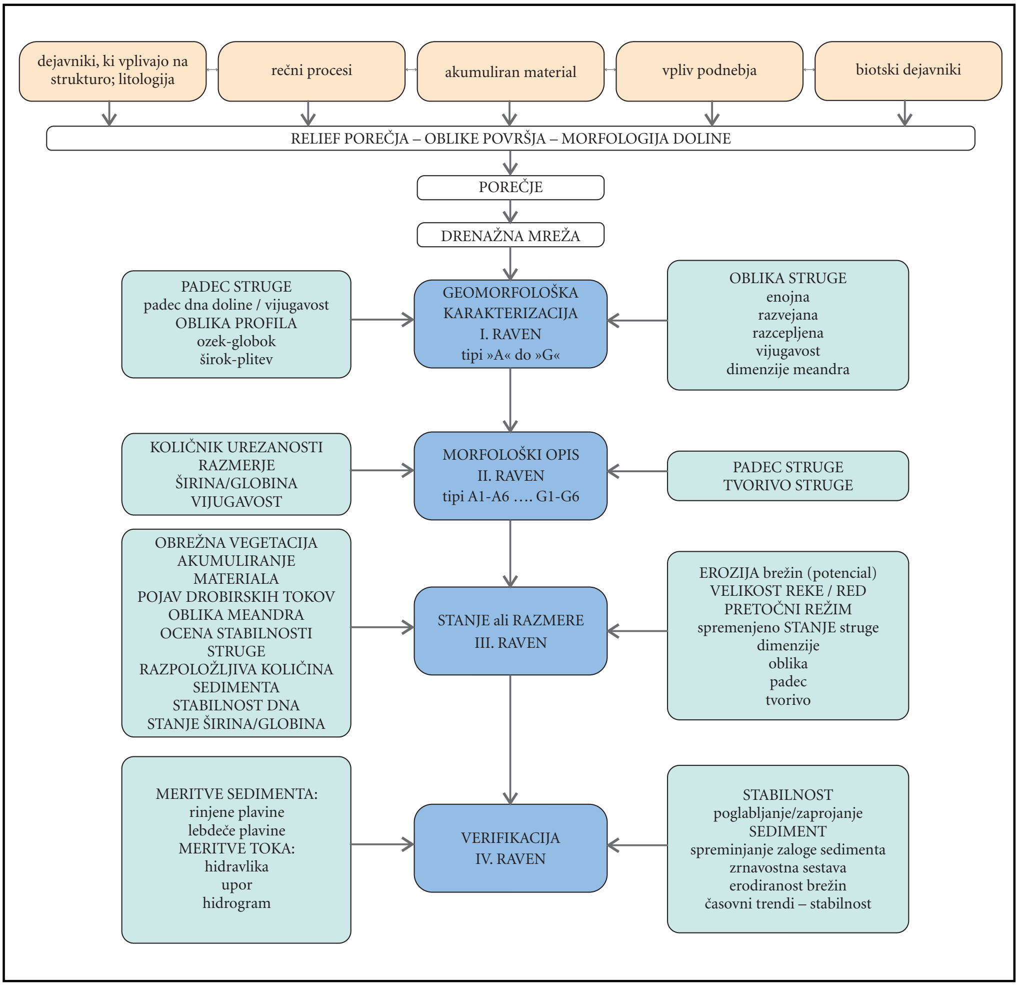
Z razvojem številnih metod za ocenjevanje hidromorfološkega stanja rek so se za potrebe tega razvile tudi nove, bolj splošne tipizacije. Kot primer navajamo nemško metodo Gewässerstrukturgütebewertung (GSGB) (Zumbroich in ostali 1999), ki razlikuje reke v soteskah ali V-dolinah, reke v širokih poplavnih U-dolinah, meandrirajoče reke, reke v poplavnih kadunjastih dolinah, reke v prodnatih dolinah in ravninske reke (ki so nadaljnje podrobneje členjene glede na substrat) in britansko metodo River Habitat Survey (RHS) (Raven in ostali 1998), ki razlikuje reke s šotastim dnom, reke z velikim padcem dna, reke na planotah, obalne reke, reke v gorskih dolinah, nižinske reke s prevladujočimi vodnimi brazdami, reke z glinenim dnom, itd. Sodobne tipizacije rek, ki so namenjene predvsem boljšemu upravljanju voda, so v uporabi predvsem v Nemčiji, Franciji, Veliki Britaniji in Združenih državah Amerike (Gordon in ostali 2004, Palmer 2005, Gurnell in ostali 2006).

Vodna direktiva (Direktiva 2000/60/ES) določa dva možna sistema tipizacije rek, sistem A ali fiksno tipologijo z vnaprej določenimi deskriptorji tipizacije in sistem B ali alternativno opredelitev z obveznimi in izbirnimi dejavniki tipizacije rek. Implementacijski proces vodne direktive je v državah članicah Evropske unije botroval številnim raziskavam tipov rek, širok izbor dejavnikov največkrat uporabljene tipizacije po sistemu B pa širokemu izboru biotskih tipizacij rek. Te so tudi nujno izhodišče za oceno ekološkega stanja rek (Dodkins 2005, Urbanič 2007, Brown 2009).

2.1.1 Rosgenova tipizacija rek

Namen Rosgenove tipizacije je predvideti rečne procese na podlagi hidromorfološke analize reke, ugotoviti specifične hidravlične povezave in značilnosti premeščanja sedimentov za posamezne tipe rek in njihovo stanje, razviti mehanizem, ki bo omogočal ekstrapolacijo podatkov na medsebojno primerljive reke in izdelati konsistenten okvir referenčnih razmer, ki bi služil pravilnejšemu upravljanju rek. Tipizacija je sestavljena iz štirih ravni (Slika 1), ki od prvega splošno geomorfološkega opisa postopoma prehajajo do zelo podrobnih hidromorfoloških opisov in ocen. Rosgenova tipizacija na prvih dveh ravneh opredeli 7 glavnih tipov in 42 podtipov rek.

Prva raven je geomorfološki opis, ki vključuje spremenljivke kot so padec reke, oblika profila, oblika struge in vijugavost. Značilnosti na tej ravni so prepoznane in kvantificirane iz topografskih kart in aero-posnetkov. Druga raven obravnava podrobnejše morfološke značilnosti, ki so zbrane s terensko analizo odsekov – urezanost struge, dimenzija struge, oblika struge in profila in prevladujoč substrat. Tako poda-



Slika 1: Ravni rečnega popisa (Rosgen 1996).

ja kvantitativno morfološko opredelitev, ki ima uporabno vrednost za upravljavske namene, medtem ko tretja raven opisuje stanje reke. Na tej ravni so obravnavane številne dodatne spremenljivke – obrežna vegetacija, razpoložljiva količina sedimenta, pretočni režim, pojavnost drobirskih tokov, akumuliranje materiala, stabilnost struge, erodiranost brežin in neposredne antropogene motnje. Na zadnji, četrti ravni, so spremenljivke določene s posameznimi meritvami, ki verificirajo povezave iz predhodnih ravni.

2.2 Tipizacije rek v slovenskem prostoru

V slovenskem prostoru so tipizacije rek na osnovi hidromorfoloških dejavnikov še v začetnih fazah razvoja. Poleg v tem prispevku predstavljene hidromorfološke tipizacije rek (Repnik 2006) je v pripravi tudi hidrogeomorfološka tipizacija (Natek 2006). Sicer pa lahko hidromorfološke značilnosti rek delno opredelimo iz številnih sorodnih primerov tipizacij z vodo povezanih naravnih pojavov, ki so bile opravljene v Sloveniji, med njimi: Klasifikacija poplav v Sloveniji (Gams 1973), Pokrajinsko-ekološka regionalizacija (Gams 1986), Tipologija krajin in opredeljevanje krajin posebnih vrednosti v Sloveniji (Hudoklin 1994), Krajinska regionalizacija (Marušič 1998 a-e), Krajinske značilnosti vodotokov v Sloveniji (Bratina Jurkovič 1999), Kategorizacija vodotokov po ekomorfološkem pomenu (Fazarinc in ostali 2002), Tipologija površinskih voda (Brilly in ostali 2003) in Tipologija površinskih vodnih teles (Urbanič 2007).

3 Metoda dela in rezultati

3.1 Tehnika zajema podatkov

Glede na to, da v Sloveniji še ni izdelanih podrobnih hidromorfoloških podatkovnih zbirk, ki bi omogočale tipizacijo rek, je bil v sklopu raziskave izveden obsežen zajem hidromorfoloških spremenljivk. Zajem podatkov je možen s tehnikami kot so popis hidromorfoloških spremenljivk na terenu (terenski pristop), modeliranje referenčnih hidromorfoloških razmer, analiza zgodovinskih hidromorfoloških podatkov in analiza paleolimnoloških podatkov (CIS 2003). Pogosto je uporabljena tudi tehnika ekspertnega mnenja v kombinaciji z naštetimi tehnikami, ki pa je mnogokrat subjektivna in zato težje ponovljiva. V kolikor je ohranjenost rek tako dobra, da je možno opredeliti referenčne hidromorfološke značilnosti na terenu, je terenski pristop kljub časovni zahtevnosti najprimernejša tehnika za zajem podatkov. Ostale tehnike so uporabne predvsem v primerih, ko podatkov na terenu ni možno pridobiti.

V Sloveniji je dolžina rek s prispevno površino večjo od 10 km^2 4797,4 km. Izmed teh je 1328,7 km ali 27,7 % obravnavane rečne mreže antropogeno zelo malo spremenjenih (Fazarinc in ostali 2002). Velik delež zelo malo spremenjene rečne mreže je argument za izbiro prostorskega pristopa pri pripravi tipizacije. Glede na rezultate raziskave Kategorizacija vodotokov po ekomorfološkem pomenu (Fazarinc in ostali 2002), ki reke kategorizira glede na stopnjo antropogenega vpliva, so bili kot primerni odseki za zajem podatkov identificirani tisti, ki sodijo v 1. (naravni vodotoki) ali 1.–2. razred (zelo malo spremenjeni vodotoki) (Slika 2). Izmed primernih odsekov so bili odseki za preučevanje hidromorfoloških tipov določeni z dodatnimi kriteriji:

- prispevna površina reke na lokaciji vzorčnega mesta od 10 do 100 km^2,
- enakomerna porazdeljenost vzorčnih mest po celotni hidrografski mreži,
- enakomerna porazdeljenost vzorčnih mest v posameznih bioregijah,
- reprezentativnost odsekov glede na pokrajinske hidromorfološke značilnosti in
- dostopnost vzorčnih mest za potrebe terenskega dela.

Slika 2: Stopnje antropogene spremenjenosti vodotokov (prilagojeno po: Fazarinc in ostali 2002).
Glej angleški del prispevka.

Zajem podatkov na izbranih odsekih je bil izveden z metodo transektov (Bizjak 2003; Mikoš in Bizjak 2007), s katero sta obseg in časovna zahtevnost zajema podatkov zmanjšana in optimizirana. Transekti so pravokotni in predhodno kartografsko določeni prečni odseki struge. Njihova širina je enaka dvokratniku širine struge, dolžina transekta pa poleg širine struge zajema tudi 50 m obrežni pas. Razmeščeni so na medosni razdalji 100 m. V območju izbranega 500 m odseka je bilo popisanih 6 transektov. V raziskavi je bilo skupno analiziranih 95 rečnih odsekov oziroma 570 transektov.

3.2 Terenski in kabinetni zajem podatkov

Za popis hidromorfoloških spremenljivk na predhodno izbranih rečnih odsekih in transektih je bil izdelan popisni list (Preglednica 1). Nabor hidromorfoloških spremenljivk v popisnem listu vključuje izbrane spremenljivke, ki so navedene v Rosgenovi in Montgomeryjevi tipizaciji (Rosgen 1996; Montgomery in ostali 1997) ter izbranih metodah za oceno hidromorfološkega stanja: RCE metodi (Petersen 1992), SVAP metodi

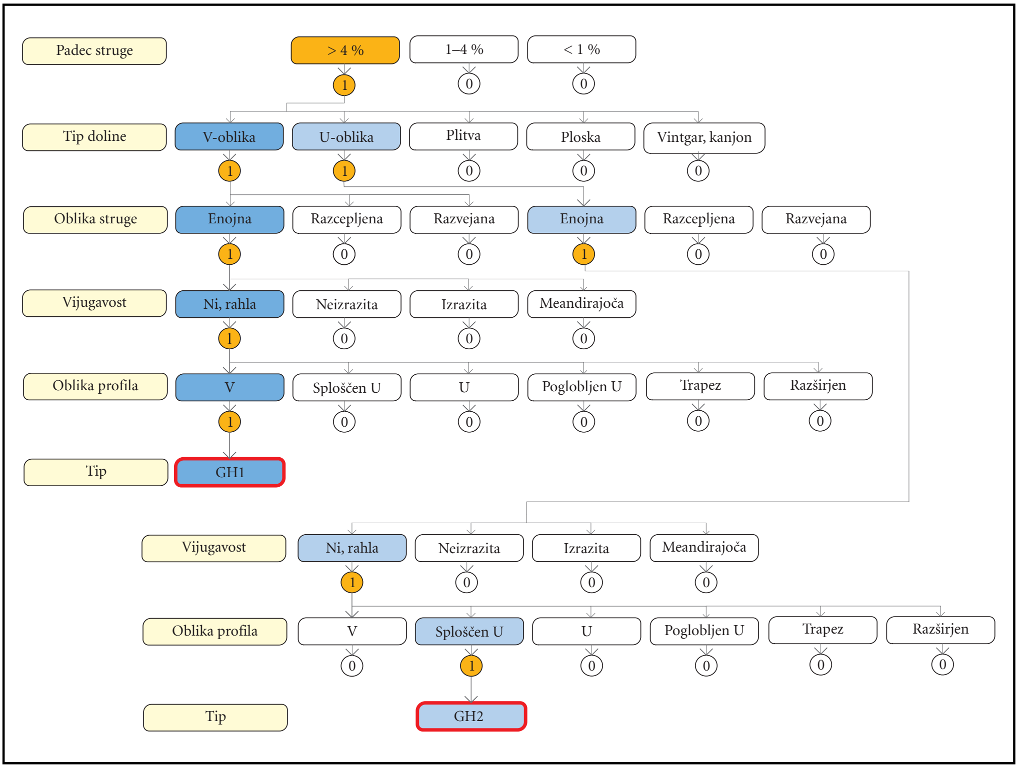
Preglednica 1: Pregled terensko in kabinetno zajetih hidromorfoloških spremenljivk.

	Kategorija	Hidromorfološke spremenljivke
	splošni podatki (odsek)	ime reke, šifra reke, bioregija, krajinska enota, naselje v bližini, koordinate odseka, nadmorska višina višinski pas, geološka podlaga, količina padavin velikost prispevne površine, razred glede na širino struge datum popisa, popisovalec
	podatki o količini in dinamiki vodnega toka	vodomerna postaja, pretok Q (m^3/s), vodostaj h (cm), T (°C), decil pretoka, srednji pretok Q_{sr} (m^3/s), minimalni specifični pretok z 20-letno povratno dobo $q_{min,20}$, pretočni režim
splošni podatki	splošni podatki (transekt)	koordinati transekta, dolžina transekta
	spreminjanje širine in globine struge	širina strugotvorne struge b_s (m), spreminjanje strugotvorne širine Δb_s (m), urezana širina struge b_u (m), vzdolžno spreminjanje globine Δh_v (m), prečno spreminjanje globine Δh_p (m), povprečna globina vode h (m), največja globina vode h_{max} (m), globina urezane struge h_u (m), razmerje širina/globina š/g
	struktura struge	količnik urezanosti, višina brežin h_b (m), naklon brežin α (°), padec struge I (%)
	prevladujoč relief	ravnina, gričevje, hribovje, gorovje
	tip doline	vintgar ali kanjon, V-dolina, koritasta ali U-dolina, podanja dolina, ploska dolina
	tip reke	kraški, ravninski, gričevnat, hribovit, gorski; biotski tip
	spreminjanje globine	neopazno, majhno, zmerno, veliko, zelo veliko
	spreminjanje širine	neopazno, majhno, zmerno, veliko, zelo veliko
struktura struge in substrata	oblika struge	enojna, razvejana, razcepljena
	vijugavost	ravna ali rahlo vijugasta, neizrazito vijugasta, izrazito vijugasta, meandrirajoča
	oblika profila	U-oblika, plitva U-oblika, poglobljena U-oblika, široka ali zaprojena oblika, dvojna trapezna oblika, stopničasta oblika
	substrat	glina, melj, pesek, prod, grušč, groblja, matična kamnina, samice
	otok (število)	ni otoka, nezaraščen otok, zaraščen otok – mlad sukcesivni stadij, zaraščen otok – zrel sukcesivni stadij
	gruščišče, prodišče, peščina (število)	ni oblike, stranska-izmenjujoča, vzdolžna, v zavoju, sredinska, na sotočju
	druge oblike (število)	tolmun (osvetljenost tolmuna), kaskada, stopnja, položna kaskada, brzica, brazda, plitvina
	zaporedja oblik	koluvij, matična kamnina, kaskada, stopnja-tolmun, ravno dno, tolmun-brzica, tolmun-brazda, dina-rebro
	razgibanost dna	neopazna, majhna, zmerna, velika, zelo velika
	pestrost vodnega toka	neopazna, majhna, zmerna, velika, zelo velika
	tvorivo brežine	matična kamnina, skala, zemljina, kombinacija
	prisotnost erozije (delež)	ni razvidno, erozija v zavojih in ožinah, vzdolžna erozija
	oblike na brežini	koreninski prepleti, drevesni odbijači
	prekritost struge (delež)	preraščenost s terestično vegetacijo, zaraščenost z akvatično vegetacijo
	prisotnost zapadlega drevja in plavnega lesa	ni oblike, majhna, srednja, velika
struktura obrežnega pasu	vrsta obrežne vegetacije	vegetacije ni, avtohtona, alohtona
	distribucija obrežne vegetacije	vegetacije ni, avtohtona-sklenjena, avtohtona-členjena, avtohtona-raztresena, avtohtona-razredčena, alohtona
	starost obrežne vegetacije	vegetacije ni, mlad sukcesivni stadij, vmesni sukcesivni stadij, zrel sukcesivni stadij
	obrežne oblike	ni oblike, obtok, zastala voda, mrtvica, močvirje, kombinacija
	raba pribrežja	avtohton gozd, zemljišče v zaraščanju, travnik ali ledina, alohton gozd, druga raba
	distribucija pribrežne vegetacije in širina	vegetacije ni, avtohtona-sklenjena, avtohtona-členjena, avtohtona-raztresena, avtohtona-razredčena, alohtona
	starost pribrežne vegetacije	vegetacije ni, mlad sukcesivni stadij, vmesni sukcesivni stadij, zrel sukcesivni stadij

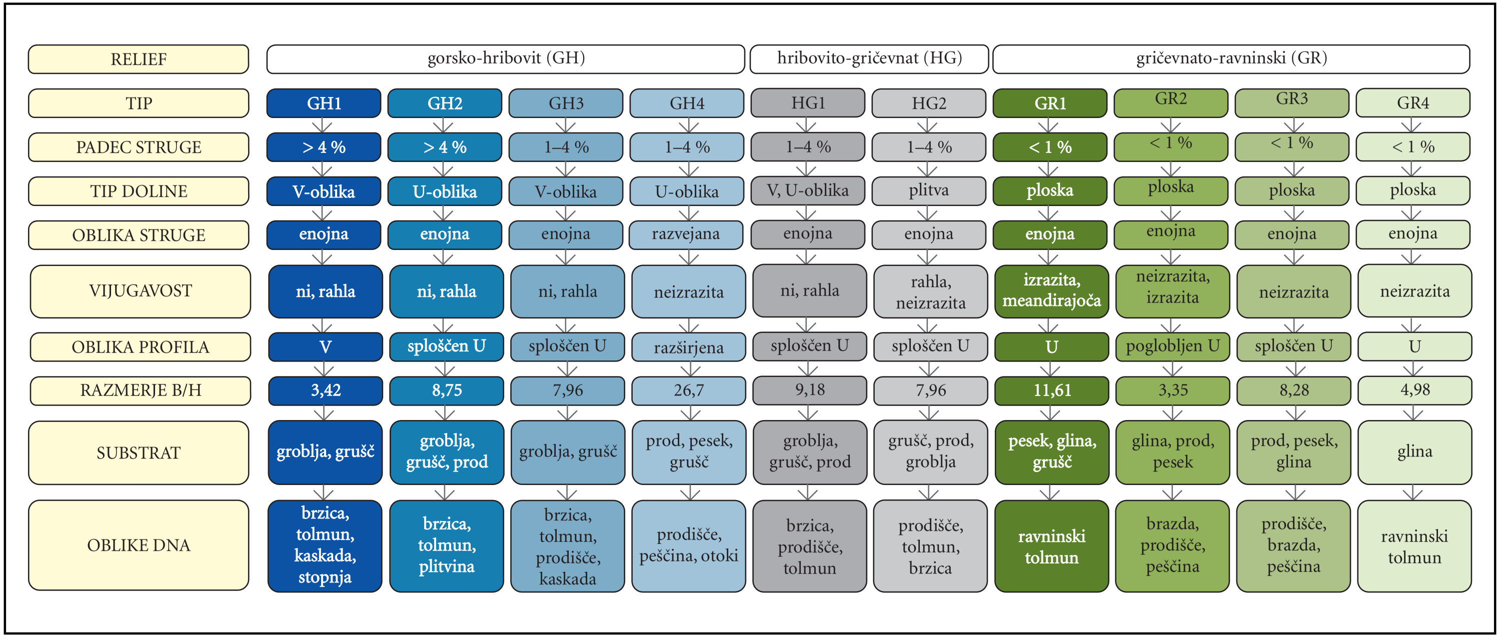
(Newton in ostali 1998, Lavrenčič 2005; Lavrenčič in ostali 2006), RHS metodi (Raven in ostali 1998), GSGB metodi (Zumbroich in ostali 1999), IFF metodi (Siligardi in ostali 2000, Batistič 2005; Batistič in ostali 2006), AUSRIVAS metodi (Parsons in ostali 2001) in Sintezni metodi (Bizjak 2003; Mikoš in Bizjak 2007). Popisni list je bil med raziskavo še optimiziran ter nadgrajen s ciljnimi hidromorfološkimi spremenljivkami.

Hidromorfološke spremenljivke so bile zajete večinoma na terenu, posamezne tudi kabinetno. Pri delu je bila uporabljena hidromorfološka oprema – GPS navigacija, geodetska lata, elektronski razdaljemer, merilni trak in padomer za odčitavanje padca dna struge. Izmerjene so bile dimenzije struge iz katerih sta bila izračunana količnik širine in globine struge in količnik urezanosti struge. Za rečne odseke je bil na osnovi relativnih višinskih razlik določen prevladujoč relief, glede na obliko prečnega prereza doline tip doline (Leksikon Geografija 2001), določeni pa so bili tudi oblika struge, vijugavost in oblika profila (Parsons in ostali 2001) ter prevladujoč substrat glede na značilne zrnavostne razrede (Mikoš 2000). Posamezne hidromorfološke oblike dna so bile določene glede na opise struktur (Zumbroich in ostali 1999; Parsons in ostali 2001), zaporedja oblik dna pa glede na njihovo klasifikacijo (Montgomery in ostali 1997). V odvisnosti od oblik dna se odseki med seboj ločijo tudi po razgibanosti dna in pestrosti gladine vodnega toka, ki sta bili določeni kvalitativno. Za posamezen odsek je bilo prepoznano tvorivo brežine, prisotnost erozije ter oblike na brežini (Zumbroich in ostali 1999), opredeljena je bila prekritost struge z vegetacijo ter prisotnost zapadlega drevja in plavnega lesa. Za obrežni in pribrežni pas je bila analizirana vrsta, distribucija in starost vegetacije ter prisotnost hidromorfoloških oblik kot so mokrišča, obtoki, mrtvice ipd. Za pribrežni pas je bila ločeno obravnavana tudi prevladujoča raba.

Kabinetno so bili za izbrane rečne odseke popisani podatki: šifra in ime bioregije (Urbanič 2007), naselje, krajinska enota (Marušič 1998a–e), višinski pas, geološka podlaga, količina padavin in minimalni specifični pretok z 20-letno povratno dobo (Brilly in ostali 2001), velikost prispevne površine (Šraj 2001), vodomerna postaja in pretočne karakteristike (www.arso.gov.si) ter pretočni režim reke (Hrvatin 1998).



Slika 3: Odločitveno drevo za tip GH1 in tip GH2.



RELIEF	gorsko-hribovit (GH)				hribovito-gričevnat (HG)		gričevnato-ravninski (GR)			
TIP	GH1	GH2	GH3	GH4	HG1	HG2	GR1	GR2	GR3	GR4
PADEC STRUGE	> 4 %	> 4 %	1–4 %	1–4 %	1–4 %	1–4 %	< 1 %	< 1 %	< 1 %	< 1 %
TIP DOLINE	V-oblika	U-oblika	V-oblika	U-oblika	V, U-oblika	plitva	ploska	ploska	ploska	ploska
OBLIKA STRUGE	enojna	enojna	enojna	razvejana	enojna	enojna	enojna	enojna	enojna	enojna
VIJUGAVOST	ni, rahla	ni, rahla	ni, rahla	neizrazita	ni, rahla	rahla, neizrazita	izrazita, meandirajoča	neizrazita, izrazita	neizrazita	neizrazita
OBLIKA PROFILA	V	sploščen U	sploščen U	razširjena	sploščen U	sploščen U	U	poglobljen U	sploščen U	U
RAZMERJE B/H	3,42	8,75	7,96	26,7	9,18	7,96	11,61	3,35	8,28	4,98
SUBSTRAT	groblja, grušč	groblja, grušč, prod	groblja, grušč	prod, pesek, grušč	groblja, grušč, prod	grušč, prod, groblja	pesek, glina, grušč	glina, prod, pesek	prod, pesek, glina	glina
OBLIKE DNA	brzica, tolmun, kaskada, stopnja	brzica, tolmun, plitvina	brzica, tolmun, prodišče, kaskada	prodišče, peščina, otoki	brzica, prodišče, tolmun	prodišče, tolmun, brzica	ravninski tolmun	brazda, prodišče, peščina	prodišče, brazda, peščina	ravninski tolmun

Slika 4: Glavne hidromorfološke značilnosti prepoznanih hidromorfoloških tipov.

3.3 Analiza podatkov in prepoznani hidromorfološki tipi

Iz pridobljenih podatkov so bile za posamezne rečne odseke izračunane povprečne vrednosti merjenih hidromorfoloških spremenljivk in odčitane prevladujoče značilnosti opazovanih hidromorfoloških spremenljivk. Le-te so predstavljale tudi vhodne podatke za nadaljnjo prostorsko analizo. Uporabljena je bila analiza sopojavljanja, s katero se analizira prekrivanje podatkovnih slojev in prostorskih značilnosti. V analizo sopojavljanja so bile vključene hidromorfološke spremenljivke, ki so navedene na prvi ravni Rosgenove tipizacije – padec struge, oblika struge, vijugavost in oblika profila, dodatno pa je bila upoštevana oblika doline. Za posamezne kombinacije izbranih hidromorfoloških spremenljivk so bila izdelana odločitvena drevesa (Slika 3).

Z analizo sopojavljanja je bilo prepoznanih 10 hidromorfoloških tipov: štirje tipi v gorskem oziroma prehodnem hribovitem svetu (oznaka GH), dva tipa v hribovitem oziroma prehodnem gričevnatem svetu (HG) in štirje tipi v gričevnatem oziroma ravninskem svetu (GR) (Slika 5-15). Izmed vseh popisanih hidromorfoloških spremenljivk, ki definirajo posamezne tipe, je bila nadalje podrobneje preverjena podobnost treh hidromorfoloških spremenljivk: razmerje širine in globine struge, substrata in oblik dna (Slika 4).

Slika 5: Hidromorfološki tipi analiziranih rečnih odsekov.
Glej angleški del prispevka.

Slika 6-15: Hidromorfološki tipi.
Glej angleški del prispevka.

4 Diskusija

Z raziskavo je bilo ugotovljeno, da je za hidromorfološke tipe, ki so bili določeni glede na izbrane glavne hidromorfološke spremenljivke, značilna tudi podobnost podrobnejših hidromorfoloških spremenljivk. Znotraj posameznega hidromorfološkega tipa so si podobne predvsem hidromorfološke značilnosti – struktura substrata, razmerje med strugotvorno širino in globino ter vrsta in številčnost oblik dna. Glede na navedene značilnosti se hidromorfološki tipi medsebojno tudi najbolj razlikujejo (Slika 16).

Slika 16: Vrsta in število oblik dna v analiziranih hidromorfoloških tipih.
Glej angleški del prispevka.

Izmed vseh analiziranih hidromorfoloških spremenljivk je za prepoznane tipe največje sopojavljanje značilno za vrsto in številčnost hidromorfoloških oblik dna. Največja pestrost in številčnost je ugotovljena v gorsko-hribovitih tipih, kjer so značilno prisotne predvsem brzice in tolmuni, vidni pa sta tudi zaporedji hidromorfoloških oblik stopnja-tolmun in tolmun-brzica. Izstopajoče se pri gorsko-hribovitem tipu GH4 pojavljajo prodišča, saj je struga zaradi zmanjšanega padca dna, velike širine struge in zmanjšane premestitvene zmogljivosti razvejana in prepredena s prodišči. Pestrost in številčnost hidromorfoloških oblik se od hribovito-gričevnatih tipov zmanjšuje do gričevnato-ravninskih tipov. V hribovito-gričevnatih tipih se poleg prodišč in brzic značilno pričnejo pojavljati tudi brazde oziroma zaporedji tolmun-brzica in tolmun-brazda. V zadnji skupini tipov se poleg brazd in prodišč pojavljajo tudi peščine in globoki tolmuni.

Analiza rezultatov je pokazala, da so si podrobnejše hidromorfološke značilnosti bolj podobne v skupini tipov, prepoznanih v gorsko-hribovitem in gričevnato-ravninskem svetu, medtem ko do manjših odstopanj prihaja v skupini tipov hribovito-gričevnatega sveta, kar nakazuje na potrebo po nadaljnji členitvi oziroma določitvi tipov. Ob pojavu odstopanj posameznih značilnosti tipa pa se vedno zastavi vprašanje, v kolikšni meri tipizacijo razširiti z novimi hidromorfološkimi spremenljivkami. Vsaka tipizacija je namreč omejena z lastno neomejenostjo (Wright in ostali 1984) in zato zahteva izbor le ciljnih spremenljivk, ki opravičujejo namen tipizacije.

Hidromorfološke značilnosti na izbranih rečnih odsekih so si bile podobne v tolikšni meri, da v nobenem primeru ni bilo prepoznanih več hidromorfoloških tipov znotraj odseka. V kolikor bi obravnavali daljše odseke, bi nedvomno naleteli do prehodov med različnimi tipi, saj so reke sistemi, kjer se značilnosti in procesi dolvodno spreminjajo. Izjemoma je reka od izvira do izliva lahko opredeljena tudi z enim samim hidromorfološkim tipom, kar bi bilo v slovenskem prostoru pričakovati predvsem pri rekah na kraških poljih.

5 Sklep

Inovativnost hidromorfoloških tipizacijskih raziskav v domačem prostoru in široka uporabnost tipizacijskih shem sta bili osnovni motivaciji za pripravo slovenske hidromorfološke tipizacije rek. V postopku tipiziranja rek bodo kot nadgradnja izdelane hidromorfološke vzorčne podobe, ki bodo podale boljši vpogled v hidromorfološko pestrost slovenskih rek. Hidromorfološka tipizacija bo tudi izhodišče za določanje konceptov obnov in izvajanje obnovitvenih ukrepov antropogeno spremenjenih rečnih odsekov.

V nadaljnjih korakih hidromorfološkega tipiziranja rek je potrebno prepoznane hidromorfološke tipe pripisati tudi rečnim odsekom, ki niso bili zajeti v analizo. Pri tem je ključnega pomena vnaprejšnja izdelava posameznih podatkovnih slojev o padcu dna struge, tipu doline, obliki struge, vijugavosti in obliki profila. S tem bi bil zmanjšan obseg časovno zelo zahtevnega terenskega dela, ki bi se izvajal le za potrebe preveritve ključnih hidromorfoloških značilnosti posameznih tipov. V okviru hidromorfološkega tipiziranja rek je v prihodnje potrebno definirati tudi posamezne hidromorfološke spremenljivke, za katere v slovenskem jeziku še nimamo uradnega poimenovanja in obrazložitve.

6 Literatura

Glej angleški del prispevka.