A Contribution to Hydromorphological Typification of Slovenian Streams

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INTRODUCTION

In recent years, many efforts in the field of water management have been oriented towards defining the stream natural state. Stream reference conditions are the basis for assessing the degree of stream alteration caused by any of the anthropogenic pressures. Furthermore, reference conditions are one of the crucial starting-points for estimation of ecological status of water bodies, as defined in the Directive 2000/60/EC (hereinafter called WFD).

In order to get an overview of the reference conditions of Slovenian streams a study on hydromorphological (hereinafter called HM) reference conditions and the subsequent HM typification of selected Slovenian streams has been performed.

MATERIALS AND METHODS

Inventory

As about 40% of the Slovenian streams is antrophogenically undisturbed or minimally disturbed in terms of ecosystem physical disruption, the survey data are one of the most straightforward methods for a detailed delineation of HM reference conditions. For that very reason a field study was carried out on 92 pre-selected Slovenian stream sections having a catchment area of the order 10 to 100 km² (Figure 1). These sections were chosen according to the morphological and hydrological criteria for selecting such reference sites. The level of direct morphological alteration has to be equivalent to unmodified, natural water bodies and the level of abstraction or flow regulation has no more then very minor effects on the quality elements. The length of suchlike section was 500 m, meaning that 46 km of stream sections were studied.

The field gathering of HM variables required the preparation of a HM reference record sheet. It included 65 HM variables (Table 1), 45 on- and 20 off-site work variables. The emphasis of the record sheet is on the morphological conditions that are defined in the WFD (river depth and width variation, structure and substrate of the river bed, structure of the riparian zone).

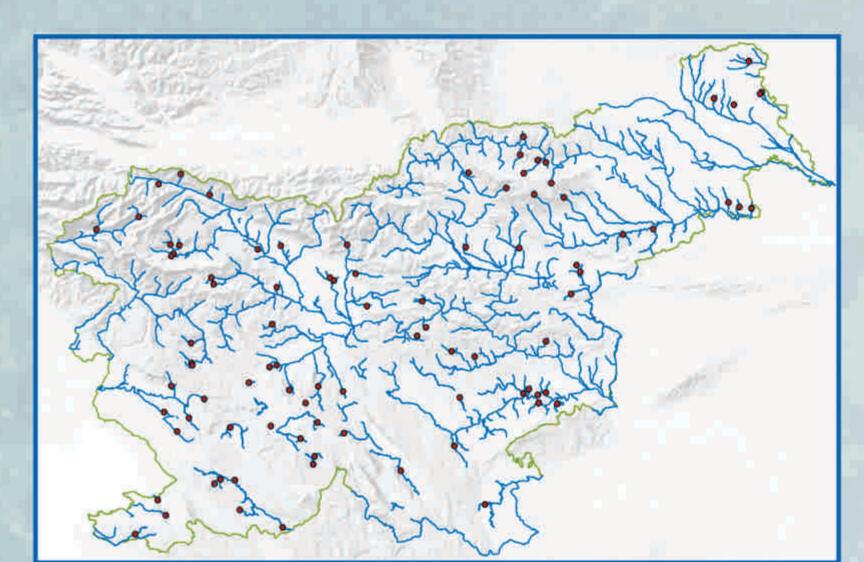


Figure 1: Pre-selected Slovenian stream sections

Riparian zone width River width variation - lateral Remnant channel River width variation - longitudinal Scroll system Instream vegetation and organic matter

Table 1: HM variables included in HM reference record sheet

... (1)

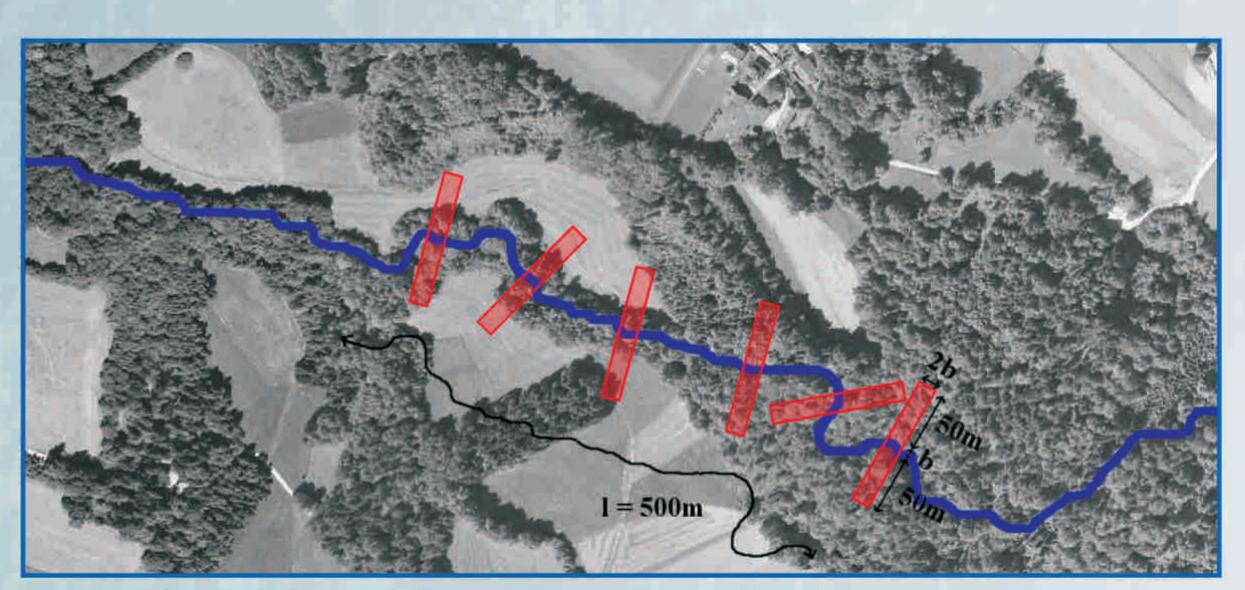


Figure 2: The transect data gathering technique – stream section and 6 transects

The field inventory was performed using the transect data gathering technique (Bizjak, 2003) that anticipate an inventory in 6 transects for every HM reference stream section (Figure 2). All the HM variables were observed, measured, counted or estimated for each transect. The final section values, which were the input data for the HM typification, were acquired as the average of 6 transect values (1).

$$\overline{HM}_{\text{var}iable_x} = \frac{1}{6} \sum_{i=1}^{6} HM_{\text{var}iable_x_i} = \frac{1}{6} (HM_{\text{var}iable_x_1} + ... + HM_{\text{var}iable_x_6})$$

HM variable x...HM section value

 $HM_{\text{var}iable}$...HM transect value

Typification

As the starting point for the HM typification general characteristics of the stream section were used - basin relief, cl slope and valley type. Three types of relief were differentiated - very high and high relief (mountainous and hilly su moderately high relief (hummocky surface) and low relief (flat surface). Further delineation criteria were based on the two levels of the Rosgen typification of streams. Channel patterns, sinuosity, channel shape, width/depth ratio, sul composition and bedform features were included in the typification. Other observed HM variables were used for f detailed definition of the stream type.

By considering 9 primary geomorphic and morphological variables (Rosgen, 1996) the combinations of different s values were acquired. Several illogical combinations such as low relief and channel slope greater than 4 % were prelir eliminated from further co-appearance analysis. The analysis was carried out with the geographic information system software package ArcGIS v 9.

On Figure 3 the determination of the 2 stream types in very high and high relief is shown. The binary numeral system represents numeric values "0" and "1" was used. Some combinations are illogical or they were not observed and assigned "0". On the other hand the observed combinations have "1" and are determined as a stream type on condition the substrate composition and bedform features have the same values within the section. (Figure 4, 5, 6).

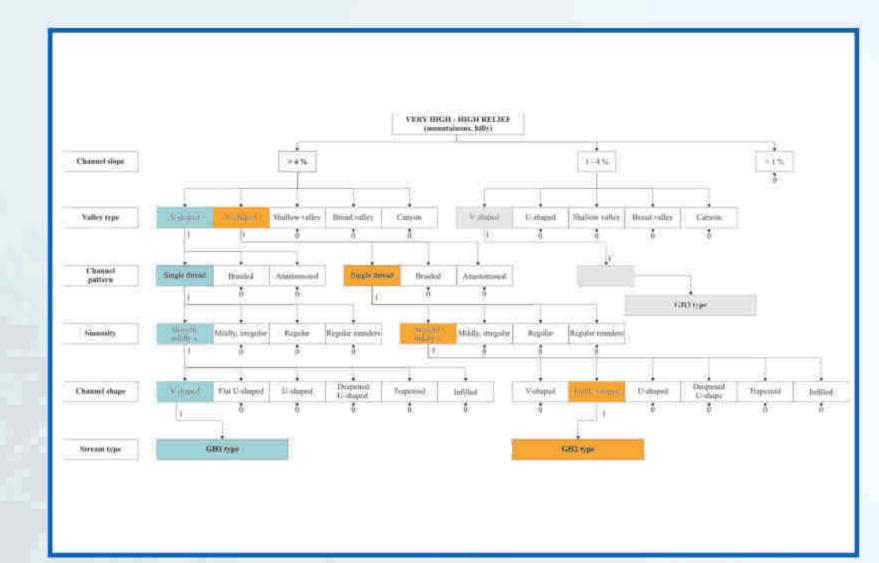


Figure 3: Determination of the 2 stream types in mountainous-hilly relief

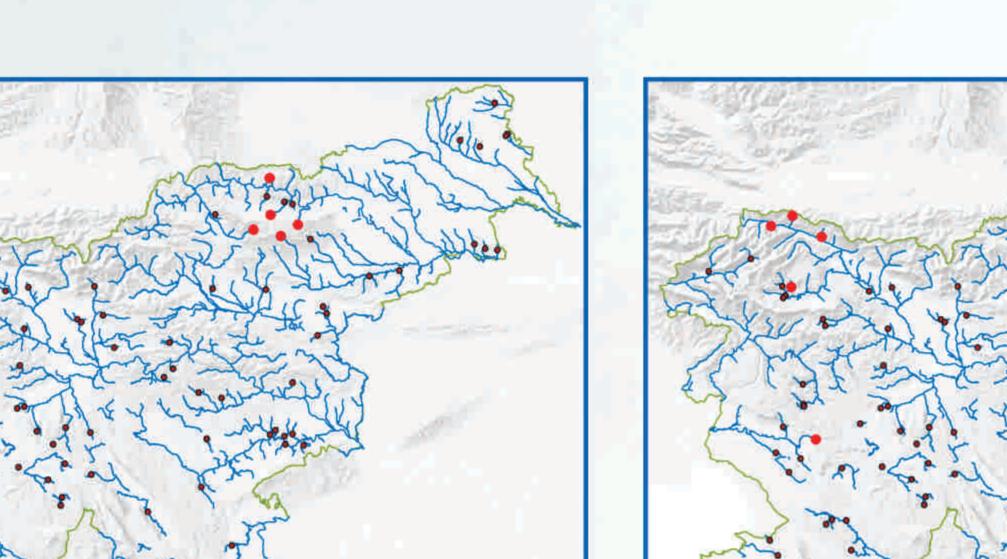


Figure 5: Co-appearance analysis - stream sections in mountainous-hilly relief, channel slope > 4%

Figure 6: Co-appearance analysis – stream sections in

Figure 4: Co-appearance analysis – stream sections in

mountainous-hilly relief, channel slope > 4%, V-shaped valley

RESULTS

With the co-appearance analysis of the selected HM variables 9 HM types of Slovenian streams were identified (Fig 17, Table 2). 3 of them are typical for mountainous-hilly relief (GH1, GH2, GH3), 2 for hilly-hummocky relief (HG1, and 4 for hummocky-plane relief (GR1, GR2, GR3, GR4). Types mostly differentiate at valley type, channel sinuosity, channel shape, substrate composition and presence of bedform features.



Figure 7: Typification key for selected stream sections

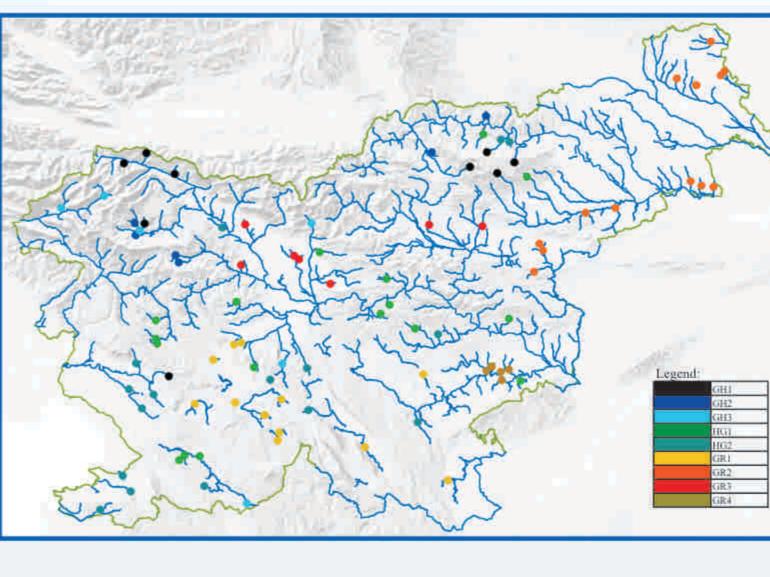


Figure 8: Co-appearance analysis - stream types

	STREAM TYPE Table 2a: GH1 - section characteristics	GH1
	RELIEF VALLEY TYPE	Mounta V-shape
channel	CHANNEL SLOPE (%) CHANNEL PATTERN	> 4 Single
urface),	SINUOSITY CHANNEL SHAPE	Straigh V-shap
the first	AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO	6,8 2,03
ubstrate	WIDTH/DEPTH RATIO BANK MATERIAL	3,42 Boulde
further	BANK HEIGHT (m) SUBSTRATE COMPOSITION	3,26 Boulde
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section		
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m using		
em that	Figure 9a: GH1 stream	ı type
nd were		
ion that	STREAM TYPE	GH2
	Table 2b: GH1 - section characteristics RELIEF	Mounta
	VALLEY TYPE CHANNEL SLOPE (%)	U-shap > 4
	CHANNEL PATTERN SINUOSITY	Single Straigh
	CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m)	Flat U- 7,2
	ENTRENCHMENT RATIO WIDTH/DEPTH RATIO	2,47 8,75
	BANK MATERIAL BANK HEIGHT (m)	Boulde 2,16
SE	SUBSTRATE COMPOSITION	Boulde
South		
b		(107)
One		
		45
	Figure 10a: GH2 strea	m typ
1.		7.17
	STREAM TYPE	GH3
	Table 2c: GH1 - section characteristics RELIEF	Mounta
	VALLEY TYPE CHANNEL SLOPE (%)	V-shape
	CHANNEL PATTERN SINUOSITY	Single
	CHANNEL SHAPE	Straight Flat U-
	AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO	15,7 2
J.	WIDTH/DEPTH RATIO BANK MATERIAL	7,96 Boulder
3	BANK HEIGHT (m) SUBSTRATE COMPOSITION	2,13 Boulder
5		
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	Figure 11a: GH3 stream	m tyn
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	Figure 11a: GH3 streateristics STREAM TYPE Table 2d: GH1 - section characteristics	m typ
	STREAM TYPE	
ev type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%)	Hilly, h V and U
ey type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY	Hilly, h V and I 1-4 Single Straigh
ey type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m)	Hilly, h V and U 1-4 Single
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ey type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO	Hilly, h V and U 1-4 Single Straigh Flat U- 8,1
ey type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO WIDTH/DEPTH RATIO BANK MATERIAL	Hilly, h V and U 1-4 Single Straigh Flat U- 8,1 2 9,18 Fines, 6
ey type	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO WIDTH/DEPTH RATIO BANK MATERIAL BANK HEIGHT (m)	Hilly, h V and U 1-4 Single Straigh Flat U- 8,1 2 9,18 Fines, 6 1,62
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	STREAM TYPE Table 2d: GH1 - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO WIDTH/DEPTH RATIO BANK MATERIAL BANK HEIGHT (m)	Hilly, h V and U 1-4 Single Straigh Flat U- 8,1 2 9,18 Fines, 6 1,62
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igure 7- 1, HG2)	STREAM TYPE Table 2d: GHI - section characteristics RELIEF VALLEY TYPE CHANNEL SLOPE (%) CHANNEL PATTERN SINUOSITY CHANNEL SHAPE AVERAGE CHANNEL WIDTH (m) ENTRENCHMENT RATIO WIDTH/DEPTH RATIO BANK MATERIAL BANK HEIGHT (m) SUBSTRATE COMPOSITION Figure 12a: HG1 strea	Hilly, h V and U 1-4 Single Straigh Flat U- 8,1 2 9,18 Fines, 6 1,62 Boulde

HG2
Hilly, hummocky, plain
Shallow valley
1-4
Single Thread
Mildly, irregular
Flat U-shaped
7,2
1,85
7,96
Fines, cobble
1,47
Cobble, gravel, boulder

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Figure 13b: HG2	THE REPORT OF

Figure 12b: HG1 stream type

BEDROCK OUTCROPS

BOULDER WATER SURFACE

ISLAND (number) AND BAR (number)

GRAVEL BAR (number)

SHOAL (number) STEP-POOL SEQUENCE POOL-RAPID SEQUENCE POOL-RIFFLE SEQUENCE	Not present
	Not typical
	Not present
SHADING OF CHANNEL (%)	75 – 100
INSTREAM VEGETATION	Not present
FALLEN TREES	Moderate
WOODY DEBRIS	Moderate
ROOT SYSTEM	Not typical
RIPARIAN VEGETATION	Wood
FLOODPLAIN FEATURE (number)	1
LOCAL LANDUSE	Native forest, meado

P-POOL SEQUENC

L-RAPID SEQUENCE

ADING OF CHANNEL (

TREAM VEGETATI

IPARIAN VEGETATION

EP-POOL SEQUENCE

OL-RAPID SEQUENCE

ODY DEBRIS

DING OF CHANNEL (%

OODPLAIN FEATURE (number)

DL-RAPID SEQUENCE

LADING OF CHANNEL (9)

IPARIAN VEGETATION

OODPLAIN FEATURE (number)

Figure 11c: GH3 stream type

P-POOL SEQUENCE

RIPARIAN VEGETATION

LOODPLAIN FEATURE (number)

L-RAPID SEQUENCE

L-RIFFLE SEQUENCE

DING OF CHANNEL (% TREAM VEGETATION

L-RIFFLE SEQUENCE

DL-RIFFLE SEQUENCE

TER SURFACE

.AND (number)

VATER SURFACE

SLAND (number)

ND BAR (number)

RAVEL BAR (number

ND BAR (number)

Figure 11b: GH3 stream type

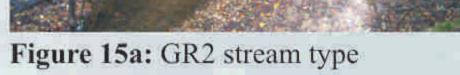
ATER SURFACE

ND BAR (number)

AVEL BAR (number)

	GR1		
section characteristics			
	Plane	BEDROCK OUTCROPS	Not present
	Broad valley	BOULDER	Not present
OPE (%)	< 1	WATER SURFACE	Smooth
FTERN	Single Thread	ISLAND (number)	1
	Regular meanders	SAND BAR (number)	0
APE	U-shaped	GRAVEL BAR (number)	0
ANNEL WIDTH (m)	10,8	COBBLE BAR	Not present
ENT RATIO	2,07	POOL (number)	4
H RATIO	11,61	RIFFLE (number)	0
IAL	Fines	RAPID (number)	0
T (m)	1,35	STEP (number)	0
OMPOSITION	Sand, clay, gravel	CASCADE (number)	0
			No. 10 also





LEY TYPE ANNEL SLOPE (%)

NNEL PATTERN

RAGE CHANNEL WIDTH (m

TRENCHMENT RATIO

TH/DEPTH RATIO

ANNEL SHAPE

NK MATERIAL

NK HEIGHT (m)

ANNEL SLOPE (%)

ANNEL PATTERN

TH/DEPTH RATIO

NK MATERIAL

ANK HEIGHT (m)





Table 2i: GR1 - section characteristics

CHANNEL SLOPE (%)	< 1
CHANNEL PATTERN	Single Thread
SINUOSITY	Irregular
CHANNEL SHAPE	U-shaped
AVERAGE CHANNEL WIDTH (m)	5,2
ENTRENCHMENT RATIO	1,66
WIDTH/DEPTH RATIO	4,98
BANK MATERIAL	Fines
BANK HEIGHT (m)	1,38
SUBSTRATE COMPOSITION	Clay, sand
	- 14/

RAPID SEQUENCE RAPID SEQUENCE RIFFLE SEQUENCE NG OF CHANNEL (%) EAM VEGETATION NOT present N TREES Noderate Y DEBRIS SYSTEM LAN VEGETATION DPLAIN FEATURE (number) LANDUSE Not typical Wood Not typical	(number)	0
RIFFLE SEQUENCE Not present NG OF CHANNEL (%) 75 – 100 AM VEGETATION Not present N TREES Moderate V DEBRIS Moderate VSTEM Not typical AN VEGETATION Wood PLAIN FEATURE (number) 1		the state of the s
G OF CHANNEL (%) 75 – 100 AM VEGETATION Not present TREES Moderate DEBRIS Moderate YSTEM Not typical AN VEGETATION Wood PLAIN FEATURE (number) 1	Control of the Contro	
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AN VEGETATION Wood PLAIN FEATURE (number) 1	T TEST SECONDARIA	
PLAIN FEATURE (number) 1	CONTRACTOR OF THE PARTY OF THE	
		Market State Comments
LANDUSE Native forest, meadow		
	PLAIN FEATURE (number) LANDUSE	

am type	Figure 14c: GR1 stream type	
Not present	SHOAL (number)	0
	STEP-POOL SEQUENCE	Not present
	POOL-RAPID SEQUENCE	Not present
0	POOL-RIFFLE SEQUENCE	Not typical
2	SHADING OF CHANNEL (%)	75 - 100
5	INSTREAM VEGETATION	Not present
Not present	FALLEN TREES	Extensive
	WOODY DEBRIS	Extensive
6	ROOT SYSTEM	Not typical
0	RIPARIAN VEGETATION	Wood, shrubber
0	FLOODPLAIN FEATURE (number)	0
0	LOCAL LANDUSE	Meadow, fallow
	2 5 Not present 1 6 0	Not present Not present Wavy - smooth 0 POOL-RAPID SEQUENCE POOL-RIFFLE SEQUENCE SHADING OF CHANNEL (%) INSTREAM VEGETATION FALLEN TREES WOODY DEBRIS ROOT SYSTEM 0 RIPARIAN VEGETATION FLOODPLAIN FEATURE (number)

OOL-RIFFLE SEQUENCE

RIPARIAN VEGETATION

LOODPLAIN FEATURE (number)

OOL-RIFFLE SEQUENCE

NSTREAM VEGETATIO

Figure 15b: GR2 stream type Figure 15c: GR2 stream type

BEDROCK OUTCROPS	Not present
BOULDER	Not present
WATER SURFACE	Wavy - smooth
SLAND (number)	0
SAND BAR (number)	3
GRAVEL BAR (number)	12
COBBLE BAR	Not present
POOL (number)	2
RIFFLE (number)	9
RAPID (number)	0'
STEP (number)	0
THE PARTY OF THE P	
CASCADE (number)	0
CASCADE (number)	

Figure 16b: GR3 stream type

BEDROCK OUTCROPS	Not present
BOULDER	Not present
WATER SURFACE	Smooth
ISLAND (number)	0
SAND BAR (number)	0
GRAVEL BAR (number)	0
COBBLE BAR	Not present
POOL (number)	1
RIFFLE (number)	1
RAPID (number)	0
STEP (number)	0
CASCADE (number)	0

STREAM VEGETATION RIPARIAN VEGETATION

Figure 16c: GR3 stream typ



Figure 17c: GR4 stream type

CONCLUSIONS

The study has shown that the stream types, identified on the basis of the differences between the primary geomorphic and morphological variables, typically differ also on the level of more detailed "stream state" HM variables. That means that the first two levels of the Rosgen stream classification are appropriate as a starting point of hydromorphological stream typification that should be further developed for the purposes of the stream typification process in Slovenia.

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