Ecohydrological and Morphological Relationships of a Regulated Lowland river; Based on Field Studies and Hydrological Modeling

Author names and affiliations.

Csaba Zsolt Pregun

Corresponding author:

Pregun, Csaba Zsolt

University of Debrecen

Faculty of Agricultural and Food Sciences and Environmental Management

Institute of Water and Environmental Management

Tel.: 00-36-52-508444/88182

E-mail: cpregun@agr.unideb.hu

http://portal.agr.unideb.hu/oktatok/preguncsaba

Abstract

The planning of the correct channel reconstruction is a priority in the rehabilitation of regulated surface streams. The present study examines the most important morphological and ecohydrological factors of a highly modified watercourse. A comparative analysis was performed among modelled and measured morphological, river geometrical, hydraulic, and vegetation status indicators. Reduction of data redundancy and examination of the relationships was done by factor analysis. This was found during the data reduction to six or seven attributes (component) and it was sufficient for imaging the original information content. There are mathematically derived hydrological background variables that are extremely significant in characterizing the watercourses, for example; the Reynolds number, Froude number, ratio of slope Froude-number, speed-to-depth ratio, depth-to-width ratio, etc. The partially regulated and artificial river sections were numerically separated from each other in the analysis. The functional aquatic plant habitats *and Manning's n* Roughness have got a higher factor weight in the less regulated river section, than in artificial stage. The weakest factor weights were those status indicators which were most changed by the regulations. The results provide support for defining and monitoring the required environmental geometric riverbed interventions.

Keywords

River restoration, river classification, fluvial geomorphological, hydraulical and hydroecological factors, river modelling, redundancy and data reduction, multivariate analysis

1 Introduction

The river regulations, usually, are the most common reasons for conflicts between environmental protection and water management. Until recently, while ensuring the economical water needs was a priority, the ecological water demands were secondary. One-third of the world's largest rivers are significantly regulated by hydro-technical interventions, in North America, Mexico, Europe and in the former Soviet Union (Dynesius et Nilsson, 1994).

The spatial and temporal physical characteristics of rivers are determined by static or slowly changing morphological and dynamic hydraulic factors and a complex relationship exists in this system.

The basic conditions of effective river ecological interventions (Wohl et al. 2003):

1. The exploration of the uncertainty and complexity of the problems; 2. The development of theoretical background, measurement methods and scaling; 3. Selection of the most adequate range of variables; 4. The practical application of scientific results; 5. The consideration of social and economic aspects. It becomes possible to provide the ecological and economic water demands of the river basins, if the hydro-ecological and morphological bases of river rehabilitation activities are correct (Zalewski, 2000). The morphological, hydrological and ecological characteristics are influenced by a lot of independent variables, which are heterogeneous in space and time, often not quantifiable and scalable, the responses are difficult to understand, or the reaction time is too long, and the different water demands and uses result in social and economic conflicts of interests (Shields et al. 2003). All watercourses are individual environmental entities, so that the experiences gained from other rivers are limited to apply. The surface streams are dynamically structured systems where each dimension has a key role. Several concepts have evolved according to which more significant dimensions were considered by researchers. The complex and varied patterns and processes of streams significantly make it difficult to discuss them. The main theories, without completeness: 1. Stream zonation (Illies and Botosaneanu, 1963); 2. River continuum concept-RCC (Vannote et al., 1980); 3. Hyporheic corridor (Stanford and Ward, 1983); 4. Serial discontinuity (Ward and Stanford, 1995); 5. Flood pulse concept-FPC (Junk et al., 1989, Junk and Wantzen, 2004); 6. Synthesis of RCC and FPC (Sedell et al., 1989) 7. Telescoping ecosystem (Fisher et al., 1998); 8. Aquatic-terrestrial ecotones (Naiman and Decamps, 1990); 9. Catchment hierarchy (Frissell et al., 1986); 10. Hydrologic connectivity (Amoros and Roux, 1988, Amoros and Bornette, 1999, Larned et al. 2011), Spatial and temporal modelling of 3D structural characteristics and

variables, for example; the mosaic pattern, the zonality, hydraulics, etc. support for environmental design (Bockelmann et al 2004, Pregun et al 2008). The following independent variables were considered the most significant factors in the classic river-morphological studies (Schumm 1969, 1973, 1979 1985; West 1978, Richards 1982, Knighton 1987, 1998, Nanson and Knighton 1996): the slope of the water surface and/or riverbed, the changes of the water level and flow, the quality and quantity of transported sediments, the riverbed and bank material, aquatic, wetland and coastal vegetation and human interventions. Based on the previous criteria, researchers have tried to separate the different riverbed types (straight, meandering, braided, etc.) Leopold and Wolman (1957) based on the discharge and the slope separated the straight, meandering and braided channel types. Parker (1976) applied the same classification, based on the relationship of the slope-Froude number ratio (S/Fn) and depth - width ratio (D/W). It was found that the S/Fn<D/W relation creates the meandering type while the D/W<S/Fn produces braided riverbed types. These correlations support the observation that while meandering streams have generally gentle slopes and their bed relatively narrow, the braided riverbed patterns usually have steep and wide. Thus a braided pattern is formed in mountainous sections, but the meandering pattern occurs in the lower reaches, in the same stream. The depth-width ratio tends to decrease with reduction of bank cohesivity (Schumm 1963). These results can explain the fact why some rivers are meandering, while others are braided, in the case of the same slope. Brice and Blodgett (1978) introduced the anastomosed type on the basis of sinuosity and braiding. Schumm (1985) involved the particle size of the sediments in the studied factors, and identified five major riverbed types. Montgomery and Buffington (1993), for the smaller streams, produced a useful classification system,

but it is mainly applicable in mountain rivers and mountain streams. The Rosgen (1994, 1997) method establishes seven typical riverbed patterns on the basis of the entrenchment ratio, depth-width ratio, sinuosity, slope, and the particle size of sediments. The generally used classification system in the river restoration activities, however, has often been criticized because applications often result in an unstable riverbed form and line. The system can be successfully used to describe and analyse the riverbed, but long-term forecasting and analysis is only partially applicable. (Simon et al., 2007). The dynamic hydraulic and energetic characteristics only later appeared in the classification. Bledsoe and Watson (2001), Van den Berg and Bledsoe (2003) use the stream energy per unit area and the average particle size of the sediment to describe the transition between meandering and braided streams. According to several authors, the bankfull discharge is the main riverbed forming factor, however Bridge and Gabel (1992) and Bridge (2003) highlight the importance of the average discharge, and the return of the maximum discharge in a few years. A quantitative analysis of macrophytes (aquatic plants) and aquatic invertebrates is a valuable support in the synthesis of relationships among river morphological, hydrological and biological characteristics of the streams, when compared with the researches of ecologically oriented functional habitats and hydrologically based flow biotopes.

Functional habitats are objectively defined habitat units, made up of substrate or vegetation types, which have been identified as distinct by their invertebrate assemblages, and related eco-hydrological and water quality indicators.

The previous studies it appears likely that ‘functional habitats’ are affected by in-stream hydrological factors. The erosion or deposition is known to be influenced by velocity and aquatic macrophyte growth has been shown to be influenced by both velocity and depth. (Gordon et al., 1994, Harper et al., 2000, Kemp et al., 2000).

The two groups have different roles: the macroinvertebrate communities which are primarily bioindicators and macrophytes may be a determining factor in the riverbed and bank stabilization and formation, influence the conveyance, riverbed roughness and flow conditions, establish functional habitats. (Rowntree and Dollar, 2002, Simon and Collison, 2002, Murray and Paola, 2003).

2 Materials and methods

There are two main objectives of the combined analysis of morphological and ecohydrological parameters in the longitudinal profile of the river: the general objective to identify any attribute that form the stream ecohydrological character, the specific objectives determine the required and sufficient hydrotechnical interventions in the river rehabilitation. The significance order of factor groups is correctly defined by the explained total variances. The first step was the study of the whole river section. The differences in hydraulic characters warrant a separate examination of the totally artificial lower section, and the more natural, only regulated upper section.

2.1 Study area and sampling sites

The River Berettyó is a strongly modified small and medium lowland river (type 18, according to WFD Annex II.), its hydrogeochemical character is calcareous, with medium-fine bed material, and medium river basin (100-1000 km^2). The river belongs to the Tisza River catchment, which is a part of the Danube river system. The geomorphological formation of Berettyó was mainly affected by surface and near-surface alluvial geomorphological processes in the prehistoric times. The river sediments have been biodegradable components, therefore organic deposits had not accumulated during the centuries (Cummins 1975). The total original river length was 364 km, the existing length is 198 km, and the studied, most regulated Hungarian section is 75 km. The lowland part of the river resembles an artificial canal, due to the hydrotechnical interventions. The 34 km long lower section is completely different from the original lines of the river (Figure 1).

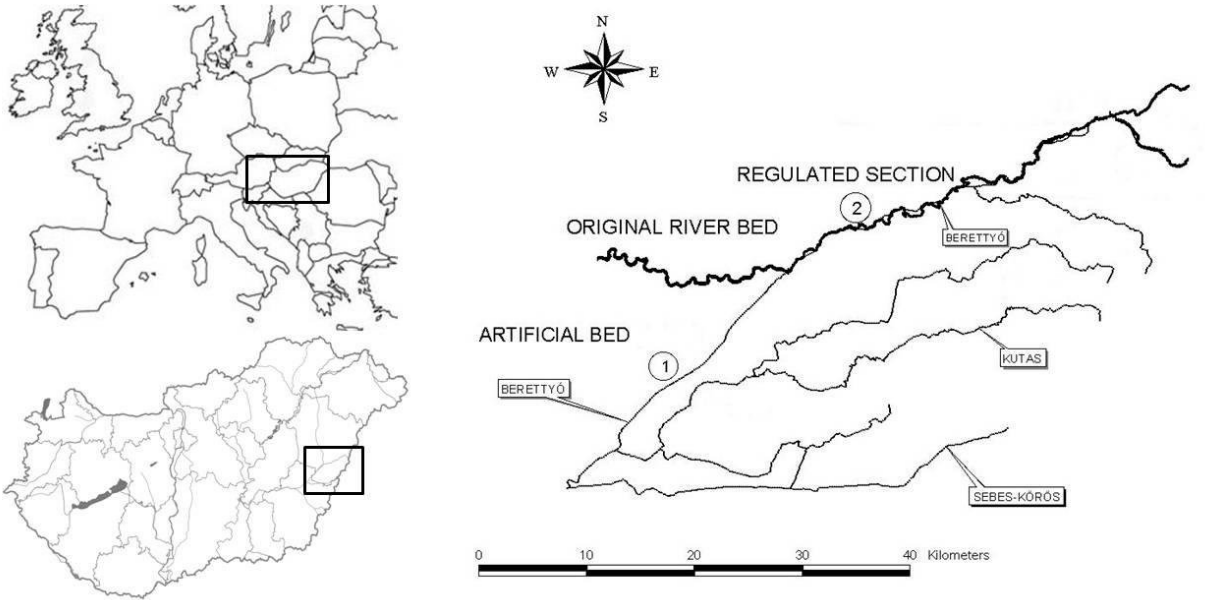


Figure 1: The Hungarian section of the River Berettyó

The change of direction was due to drainage of wetlands and termination of the swamps water supply. Where the aquatic habitats, connected wetlands and backswamps have degraded, the biodiversity has decreased. The river diversion has not caused significant erosion effects, due to the small average surface slope (0.0002). The bends have been cut through of the upper section, so its length was reduced by nearly half. The water-quality of the stream fluctuates between poor and good status; the most hazardous factors are the high organic matter content (TOC and BOD$_5$), the low oxygen content and the salt content (electric conductivity). The macroinvertebrate bioindicators show better environmental conditions than physical–chemical properties, because the river connects to the network of semi-natural channels, which function as a system of ecologic corridors. (Pregun and Tamás 2005; Pregun 2009).

2.2 Ecohydrological variables involved in the study

The studied 25 environmental variables and their derivatives: (for the explanation see "Glossary"): 1st Channel Length (Length), 2nd Depth-width ratio (DW), 3rd Energy Gradeline Elevation (EGElev), 4th Energy Gradeline Slope (Slope), 5th Entrenchment ratio (EntrRat), 6th Flow Area or Wetted Area (Area), 7th Friction loss (Frctnloss), 8th Froude number (Fr), 9th Headloss, 10th Hidraulic radius (HR), 11th Manning coefficient = Manning's-n (Mann), 12th Maximum Depth (Depth), 13th Functional Plant Habitat (FHabit), 14th Reynolds number (Re), 15th Shear Total (Shear), 16th Sinuosity (Sin), 17th Slope-Froude number Ratio (SlopeFr), 18th Top Width (TopWidth), 19th Total Flow = Discharge (Q), 20th Total Stream Power (Power), 21st Velocity-Hydraulic Radius Ratio (VelHR), 22nd Velocity Total (Vel), 23rd Water Surface Elevation (WSElev), 24th Wetted perimeter (WP), 25th Width-Depth Ratio (WD). These are geomorphic, hydraulic and vegetation parameters, some of them can be measured directly in real time and space, while others need to be modelled. Several analysis justified that many environmental attributes, which are determining environmental indicators, mathematically derived features only, i.e.
they have to be interpreted as dependent variables. In the redundant set of variables we can specify the necessary and sufficient range of parameters with corresponding grouping methods without relevant information loss. Measurement, evaluation and control of river morphological and geometrical data, the roughness factors, vegetation and functional habitat types were made by the large scale field study, remote sensing and maps, field sampling, modelling and in situ measurements. The hydro-

geomorphological classification has been performed by both the Rosgen’s and Parker's method. The Rosgen's analysis qualify rivers based on real data of the entrenchment ratio, width-depth ratio and sinuosity, slope, and main sediment sizes. Parker's classification assumes a causal relationship among the depth - width ratio (D/W), slope-Froude number ratio (S/Fn) and the channel pattern thus establishes the character of riverbed without actual knowledge of shape. The width-depth ratio is a determining factor in Rosgen's classification system, while its inverse; the depth-to-width ratio is the independent variable in Parker's method. The two methods can be used to control and verify each other. The embankment was not counted in the calculation of the incision (entrenchment) ratio. Sediment samples were taken with the piston sampler, at low water or wadeable circumstances, in the thalweg or near. The sampling was in the 20-30 centimeters of the sediment upper layer, at ten cross-sections. Sediment particle sizes and distribution were analyzed with a shaker sieve device, 0.05, 0.1, 1.0, 2.0 mm pore sizes, in air-dry condition. The viscosity of 20°C water was applied to estimate Reynolds number. The plant functional habitat types were identified by Harper and Smith (1995) and Raven et al (1998). The vegetation consisted of degraded, incomplete populations. The codes and descriptions of the studied plant habitats:

1) SI (Silt) - With a few, insignificant mosses and macroalgae
2) SA (Sand) - As described above
3) MP (Marginal plants) - Scirpo phragmitetum, Filipendulo-Petasition, Alopecurenion pratensis, Salicetum albae-fragilis, Salicetum triandrae
4) EM (Emergent-macrophytes) - Nymphaetum alba-lutae
5) SMF (Submerged, fine-leaved) - Potamion, Myriophylletum, Myriophyllo-Potametum etc.

6) SMB (Submerged, broad-leaved) - Potamogetonetum, Elodeetum etc.

The examination of the 25 rivermorphological and ecohydrological factors has been done by factor analysis, with the principal component analysis method. The results were interpreted and separated by varimax (orthogonal) rotation, thus uncorrelated factors were achieved. Performed for verification of non-orthogonal (PROMAX) rotation has created the same factor structure.

2.3 The hydrological model

The HEC-RAS is a one-dimensional hydraulic program for surface water courses. The program calculates the hydraulic characteristics of streams in permanent (steady) and non-permanent (unsteady) flow circumstances, using of geometric data and resistance of the riverbed. The program is widely used in the theory and practice of river research and management (Downs and Thorne, 2000, Moutona et al., 2007). The verification and validation of the model has been confirmed with paired comparative analysis of real-time and simulated data series of the water level. The strong linear regression relationships ($R^2 > 0.9$) indicate the reliability of the model. The cross sections were surveyed approximately 500 m. The X coordinates (of left and right endpoints of cross-sections), the longitudinal Z coordinates (distance from of cross-sections) were transformed WGS-84 reference system. The default value of Y coordinates (altitude) is the Baltic Sea level. The determination of banks of the main channel, and the assessment of riverbed roughness conditions, occurred during field surveys.

3 Results

3.1 The hydro-geomorphologic attributes

The examined sections included in the meandering (sinuous) zone on the basis of Parker (1976) categorization, a smaller part included in the adjacent transition zones (Figure

2). The method separates the braided, meandering and straight river pattern categories on the basis depth-to-width ratio (x-axis) and the Froude number-slope ratio (y-axis). Based on Rosgen's river classification the hydro-geomorphologic characteristics of the stream are as follows; according to the entrenchment ratio (primary level of classification), the width-depth ratio (secondary level), the sinuosity ratio (tertiary level), the water levels drop (fourth level) and the sediment grain size (fifth level): 1st: Entrenchment ratio: 98 cross-sections (65.5%) are slightly entrenched, 28 (18.9%) moderate incised, 23 (15.5%) are in the intermediate region between the two categories. 2nd: Width-depth ratio: 91 sections (61.5%) are low (W/D <12), 55 sectionds are medium (37%, 12 <W/D <40), and 2 sections are high (5.1%, W/D > 40). According to the data, the B (moderately convoluted), C (highly meandering), and E (transition) natural river categories can be considered. 3rd: Sinuosity: Due to the regulations, the stream pattern is predominantly straight (Sinuosity <1.2) 4th: Water surface slope: The slope for two-stages approach the value of 0.01, the all other 146 sections remain under 0001. This result excludes the moderately meandering (B) river type, because of this typical fall is between 2-4%. 5th: The main sediment grain sizes of the investigated sections belong to the sandy bottom type. Further prioritization is not required.

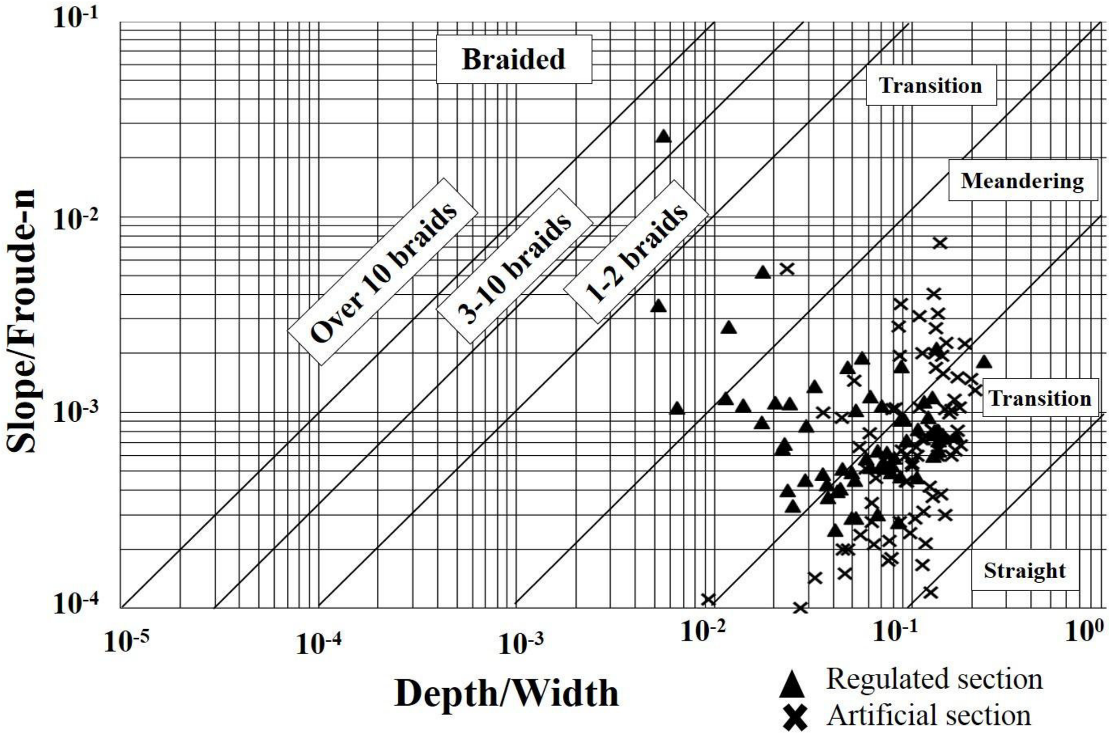


Figure 2: The morphological patterns of examined river sections based on the Parker's classification.

3.2 The types of flows

The analysis of the average and bankfull discharge has similar results. The flows are subcritical for all cross sections. The current is laminar (Re<500) in 22 cross sections (~15%), 125 cross sections (~85%) are slightly turbulent (500<Re<2000). Empirical fact indicate that laminar flow does not occur in the real streams (or extremely rare). Probably the low velocities (~0.3 m/s), slopes (~0.0001) and Hydraulic Radiuses (~1.5) caused the low values of the Reynolds number. However, the lower artificial, and the upper regulated river sections are separated from each other in respect of the flow conditions. (Figure 3). The linear regression relationship between the Froude-n-velocity, and the Reynolds-n-velocity is much stronger (R^2=0.85 and R^2=0.58) on the regulated section than the artificial riverbed section (R^2=0.82 and R^2=0.30). The flow is moderately turbulent in four-fifths of the upper section (80%), in one- fifths laminar. This ratio is only 87-13% in the artificial, nearly straight lower reach. (The weakly turbulent flow is more favourable in terms of oxygen supply, BOD decay, etc. than laminar). The summary of the descriptive statistics found in Table 1.

Table 1. Descriptive Statistics of the Riverbed Filling Discharge of the Berettyó River (147 XS)

Ecohydrological parameter	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Variance**
Q	9.41	19.50	13.41	3.83	14.65
WSElev	82.62	98.02	90.11	4.20	17.66
EGElev	82.72	98.10	90.14	4.20	17.65
Slope	0.000002	0.026478	0.000434	0.002258	0.000000
Area	6.55	135.27	34.21	22.30	497.09
Vel	0.11	2.07	0.61	0.30	0.09
WP	9.06	89.97	25.23	15.08	227.35
Width	7.33	88.75	23.56	15.07	227.21
Shear	0.03	59.58	2.78	5.70	32.50
Power	0.00	90.85	2.77	9.02	81.43
Mann	0.01	0.07	0.02	0.01	0.00
HR	0.23	2.79	1.39	0.40	0.16
Fr	0.03	1.02	0.18	0.14	0.02
Re	164.00	1626.00	775.88	285.80	81683.42
FrctnLoss	0.00	0.72	0.09	0.10	0.01
Headloss	0.00	0.72	0.09	0.10	0.01
Depth	0.23	3.25	1.53	0.47	0.22
WD	4.36	192.74	20.43	27.71	767.79
DW	0.01	0.23	0.09	0.05	0.00
SlopeFr	0.000067	0.025959	0.001164	0.002312	0.000000
Sinuosity	1.00	1.68	1.04	0.09	0.01
EntrRat	1.00	2.00	1.27	0.40	0.16
Length	200.00	1011.99	511.06	114.99	13222.93
VelHr	0.05	6.61	0.58	0.79	0.62
FHabit	1.00	6.00	2.77	1.42	2.02
The return period of the riverbed filling discharge is 100%, the annual durability is 60-80% (220-290 days/year).					

3.3 Results of the multivariate analysis

The variables studied are suitable for factor analysis, as evidenced by the Kaiser-Meyer-Olkin criterion (KMO) Measure of Sampling Adequacy of (MSA), the significant correlations and a significant Bartlett test. The suitability of a set of variables includes the mediocre ($0.6 \leq \text{KMO} \leq 0.7$) category based on the KMO = 0.66, the spherical Bartlett test was significant (Sig. 0.00) in all cases. The MSA was in most cases between 0.5 and 0.8, in the case of the bed roughness, the imprinting ratio, longitudinal section and hydraulic radius slightly below the lower limit. An exception of these variables would not increase the KMO value, it would be one less number of factors, but the information content is significantly reduced, so it remained in the analysis.

Examination of the total section

The factor analysis calculated seven components by principal component analysis method. The number of factors was decided by the Kaiser Rule. (The Kaiser rule is to ignore all components with eigenvalue under 1.0.) The seven principal components explain 88% of the total variance (Figure 3). The ideal 95% variance explanation can be achieved by nine factors. (Variance explained criteria). In this case, changes in the factor structure are irrelevant. The first five components are not changed, and the 6th factor represents the Maximum Depth and the Depth-Width ratio, the 7th is the examined section Length, the 8th component symbolizes the Entrenchment Ratio, and in the ninth the Sinuosity appears with sufficient factor weight and 6-5% explained variance (in descending order). The more complex factor structures do not give significant additional information (including the Cattell scree test plot), so there is no point in avoiding the Kaiser rule.

The interpretation of the components: The 1st principal component includes: Velocity-Hydraulic Radius (Average Depth) Ratio; Total Stream Power; Energy Grade Line (Water Surface) Slope; Froude Number; Shear Total; Velocity Total. Relatively low, but evaluable weight (0.6) appears on the Slope-Froude Number Ratio As Well. The 2nd Component contains: Top Width; Wetted Perimeter; Hydraulic Radius; Reynolds Number; Flow Area; Width-Depth Ratio; Depth-Width Ratio. The 3rd component is a symbol of the gauge practically: this includes the Energy Grade Line Elevation (~Water Surface Elevation) and Total Flow (=Discharge). The 4th factor group indicates the relationship of bed roughness (Manning's-n) and the functional plant habitats. It should be noted that the aquatic, wetland and riverbank vegetation is highly degraded, incomplete, often only as a residual association can be found along the river. The factor weight of the Slope/Froude Number Ratio is greater (0.71) than in the first component (0.6). In the 5th group, the Total Energy Loss and Friction Loss are included with nearly equal values. The 6th component represents the Channel Length and Sinuosity (weight factors: 0.81 and 0.76). The 7th group contains the Entrenchment Ratio and the Maximum Depth. This component explains the least variance (~ 5%).

The analysis of the artificial and regulated river reaches

The analysis shows the difference between the ecohydrological characters of the investigated upper and lower reaches. The variables were grouped in six components, in both cases. The upper section factor structure is changing that the bed roughness, Slope/Froude Number Ratio and Functional Plant Habitats were transferred from the fourth component into the first component, and their factor weights have increased. The number of components is reduced by one, the sixth factor that explains the 6% of variances contains the Entrenchment Ratio and Sinuosity. The significance of Riverbed

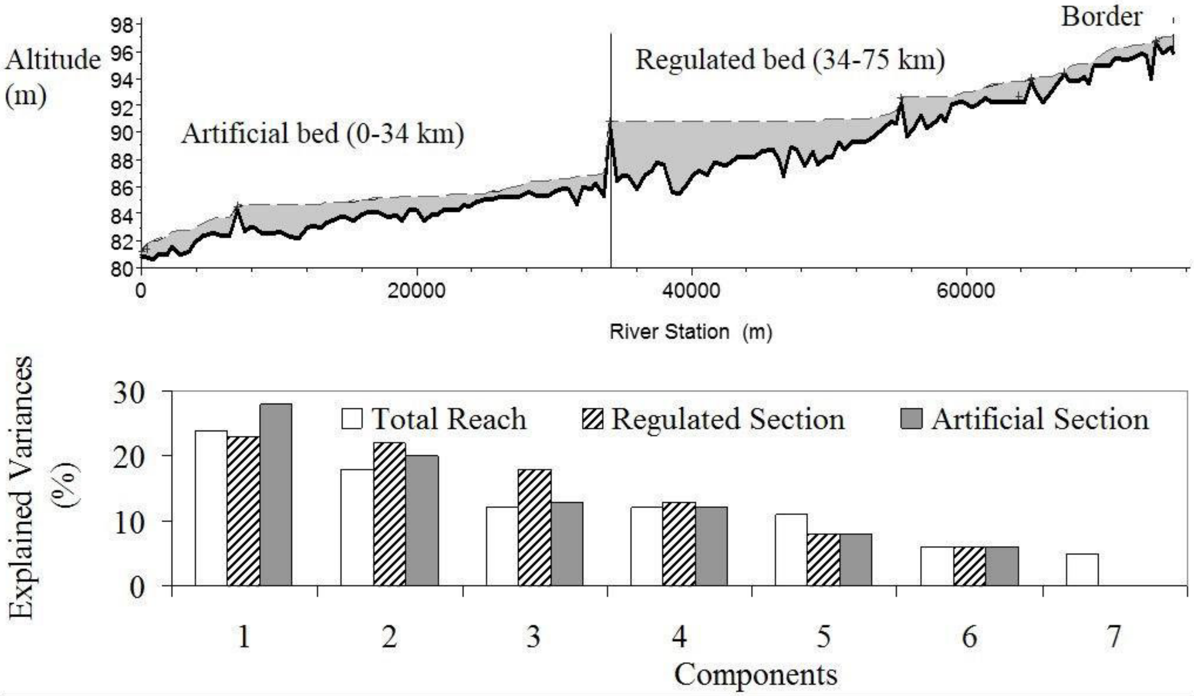
Roughness and the Functional Plant Habitat decrease in the artificial downstream section, they form the fifth component together, which is responsible for 8% of the total explained variance. However, in the upper section the Froude number is transferred to the first component from the second, and the Reynolds number is transferred into the second component from of the third, with increased factor weights. There is a significant change in factor structure, that the importance of Total and Friction Energy Losses significantly increases and they move to the third component from the fifth. The importance of Entrenchment Ratio falls below the assessable threshold, the value is shown for illustration only (Figure 3).

4 Discussion & Conclusions

4.1 Hydro-geomorphology

The initial step in the rehabilitation of watercourses is the determination of the necessary and sufficient parameters that define the stream's ecological, hydrological and morphological characteristics of both qualitative and quantitative terms. The winding river valley, meandering and U-shaped riverbed is the typical geographical pattern on alluvial plains (Sinuosity>1.2). Under the Rosgen's classification system, the type of the river is meandering, based on the Entrenchment Ratio and Width-Depth Ratio, on the basis of the Water Level Slope and Energy Grade Line Slope belongs to the Moderate to High Sinuosity (C-type) and High Sinuosity (E-type) river patterns. The Sinuosity of such streams is more than 1.5.

The realistic, measured values of the stream's sinuosity contradict to the above mentioned conclusions: the river belongs to the straightened category (Sinuosity<1.2) because the average value of sinuosity is 1.04. The river essentially belongs to the meandering category, according to Parker's method. This method distinguishes three categories (braided, meandering and straight) in a rectangular coordinate system where the independent variable is the Depth-Width ratio, and the dependent variable is the Slope-Froude-Number Ratio (dimensionless variables). The Depth-Width Ratio represents the cohesivity of the bank, this is a geometric factor. The Slope is the water level difference per unit river section, and describes the change in potential energy per unit stage, and the Froude Number represents the relationship of inertial and acceleration forces. Therefore the Slope-Froude-Number ratio describes the relationship among the energetic and kinematic factors which cause and influence the stream flow.



Total River Reach							
Comp. & Exp. Var. (Total 88%)	1 (24)	2 (18)	3 (12)	4 (12)	5 (11)	6 (6)	7 (5)
Factors & weights	VelHR 0.94 Power 0.93 Slope 0.93 Fr 0.92 Shear 0.82 Vel 0.79 SlopeFr 0.60	Width 0.90 WP 0.89 WD 0.88 Re -0.78 DW -0.73 HR -0.66 Area 0.48	WSElev 0.92 EGElev 0.92 Q -0.85	Mann 0.90 FHabit 0.81 SlopeFr 0.71	FrctnLoss 0.91 Headloss 0.90	Length -0.81 Sinuosity 0.76	EntrRat -0.84 Depth 0.58
Upper Reach, Regulated Stream Corridor							
Comp. & Exp. Var. (Total 89%)	1 (23)	2 (22)	3 (18)	4 (13)	5 (8)	6 (6)	
Factors & weights	SlopeFr 0.95 Mann 0.92 Shear 0.92 Slope 0.90 Power 0.86 FHabit 0.79	VelHR 0.94 Fr 0.91 HR -0.86 Vel 0.82 Area -0.72 Depth -0.66	WD -0.94 DW 0.88 Width -0.84 Re 0.81 WP -0.76	WSElev 0.93 EGElev 0.93 Q -0.72	Length 0.80 FrctnLoss 0.74 Headloss 0.73	EntrRat 0.82 Sinuosity 0.77	
Lower Reach, Artificial Stream Corridor							
Comp. & Exp. Var. (Total 88%)	1 (28)	2 (20)	3 (13)	4 (12)	5 (8)	6 (6)	
Factors & weights	Slope 0.98 Power 0.97 Shear 0.97 VelHR 0.93 SlopeFr 0.93 Fr 0.91 Vel 0.75 Depth -0.63	WP -0.91 Width -0.90 WD -0.89 Re 0.86 HR 0.79 DW 0.75	FrctnLoss 0.94 Headloss 0.93 EntrRat -0.24	Q 0.90 EGElev -0.81 WSElev -0.81 Area 0.53	Mann 0.94 FHabit 0.90	Length 0.86 Sinuosity -0.73	

Figure 3: The factor-structure, factor weights and explained variance of the results of principal component analysis on the studied river reach

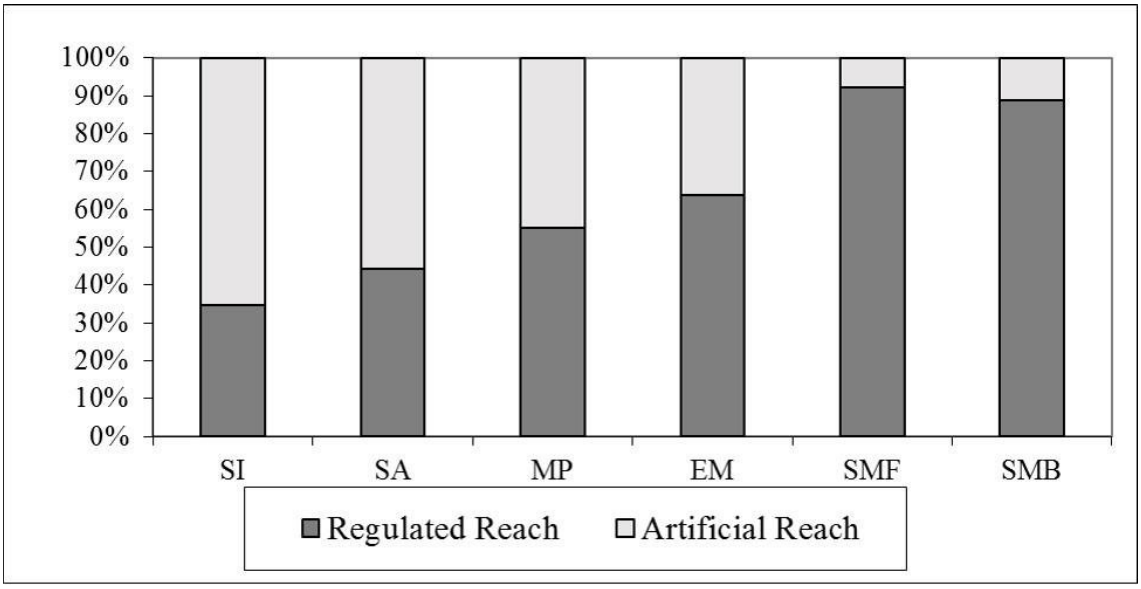
The results of the morphological classification and factor analysis verify that these background variables belong to the most important attributes of the streams.

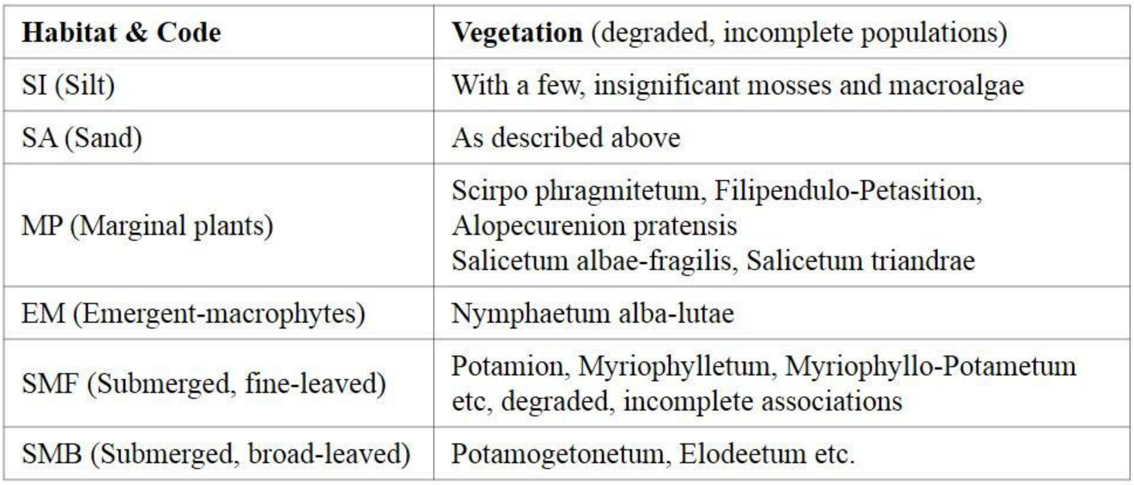
In summary, the three dominant factors of the Rosgen geomorphic, descriptive system – the Entrenchment Ratio, the Width-Depth Ratio and Slope – presume sinuous pattern, but because of the bed-hydraulic interventions the river is straightened. The causal Parker's method also presupposes that the Berettyó River belongs to the meandering class.

4.2 The factor-structure of the principal component analysis

Total studied section: The first factor represents the typical stream dynamic, energetic and kinetic factors. The Slope-Froude Number Ratio belongs to the first factor also, confirming the assumption that it indicates a fundamental attribute of the river (Parker, 1976). It should be noted that the factor weight of the Slope/Froude Number Ratio is greater in the fourth component (0.71) than in the first component (0.6).The Power, Shear, the Water Surface Slope, Velocity, etc. are the hydrodynamic factors that accelerate or slow down the stream flow. These mostly dependent variables are defined by the potential energy difference and water level differences between adjacent cross-sections, i.e. these are hydraulic status indicators of the longitudinal dimension of the river. The second component basically summarizes the transversal dimensions of the river, i.e. displays the basic and derived geometry data of the wetted cross section. It can be seen that the width and depth, namely the horizontal and vertical dimensions were not separated from each other. The Froude number (the ratio of inertial to acceleration forces) belongs to the first or longitudinal, the Reynolds numbers (the descriptor of the ratio of inertial to viscous forces) to the second or transversal component.

The comparisons of artificial and regulated section: The variance explanation of the first component significantly increases in the case of lower, artificial section, indicating the dominance of the longitudinal dimension, and the straightened line of the riverbed. The factor structure of the more natural upper section is more rearranged, the importance of the first component is reduced, and the third is increased. The vertical and horizontal geometric characteristics of the second (transversal) component are separated from each other, and develop a vertical dimensional second component (containing the Hydraulic Radius and Depth) and a third horizontal component (with the Wetted Perimeter, Top Width etc.). The Water Velocity and the Froude Number relate to the vertical geometrical factors, the Reynolds number belongs to the horizontal factors. The functional habitats and the bed-roughness are strongly correlated with each other. These two features move together, indicating a strong effect of vegetation conditions on the bed roughness (et vice versa). They are in the first factor on section of the river which remained more natural, their weight is also considerable. The Manning's n and functional plant communities can be found in the fourth component in the case of the total-longitudinal profile (explained variances: 12%), but decrease to fifth group of the analysis of the artificial channel (explained variances: 8%). In practice, they are separated from all other variables in the latter two cases. This result shows that the vegetation plays a role in the development and determination of hydraulic conditions, not only in the biological and chemical indication. The direction of causality cannot be established unambiguously in each case (Figure 4).





Habitat & Code	**Vegetation** (degraded, incomplete populations)
SI (Silt)	With a few, insignificant mosses and macroalgae
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SMB (Submerged, broad-leaved)	Potamogetonetum, Elodeetum etc.

Figure 4: Composition and proportions of main plant associations of Functional Aquatic Habitats (Percentage occurrence of habitats).

The close relationship of Friction loss and Headloss indicates that the longitudinal friction losses are a significant part of the total energy loss, the importance of the local losses is insignificant. The designation of the measured cross-sections occurred more or less at regular intervals (approx. 500-1000 m). The application of this factor is only appropriate that supports the importance of longitudinal energy losses. The importance of the entrenchment (incised) ratio and sinuosity is small, the factor weights and explained variances are low in the factor structures (they are involved in the 6. or 7.

components). However, these are among the most important status indicators of the current classification systems. It can be concluded that these are the hydro-geomorphological parameters that have gone through the most significant modifications during the river regulations. The results of the factor analysis also show the contradiction and discordance because the Measure of Sample Adequacy (MSA) calculates the lowest values for these factors. The riverbed incision can cause a lot of poor ecohydrological conditions. The more appropriate sediment and nutrient transport, biomass production, hydraulic conditions and habitat quality indicate the better environmental condition of less regulated and non-incised streams (Shields et al., 2010). The reduced sinuosity, flood levees and disconnected wetlands cause the degraded environmental condition of the river, in addition to chemical pollution.

Summary: The alluvial streams are open ecohydrological systems that adapt to the continuous dynamic changes of the energy and material inputs and outputs. The geomorphologically based static classification systems ignore these fundamental elements and processes. The most important attribute groups sorted by the river: 1. The longitudinal kinematic and energetic factors, 2. The vertical dimension of the geometric factors that tend to move in the flow descriptor Froude number, 3. The horizontal dimension data, and the turbulent flow conditions characterized by Reynolds number. The first three components include fifty to sixty percent of the background information. The adequate characterization of the stream requires additional ecohydrological factors (aquatic vegetation, bed roughness, loss of energy, sinuosity, incision, etc.). During the Factor Analysis (Principal Component Analysis Method) the number of factors was significantly reduced (from twenty five to six), but retained ninety percent of the original information content (explained variances). The question arises why the vertical dimension is more significant than the horizontal~~?~~ The simple explanation is that the lateral effects along the river are less functional, because it is enclosed between embankments. In the case of natural and semi-natural lowland, rivers the horizontal dimension is more dominant than vertical. The Sinuosity and the Entrenchment Ratio can be used in the planning only carefully, because they are not causal factors, but the effects and consequences of the misguided regulations and other hydro-technical interventions, e.g. artificial meander cutoffs, dyke constructions, etc.

These results will help to plan the steps of the stream corridor restoration, e.g. the artificial, partial re-creation of the meandering channel, the restoration of natural hydraulic and flow conditions, the corridor widening with the relocation of levees, increasing the species richness of habitats.

5 Glossary: Explanation and abbreviations of the studied variables

Channel Lenght: Downstream reach length of the main channel (ChLenght)

Depth-Width ratio: Average channel depth divided by the surface width for Parker methods (DWRatP)

Energy Grade Line Elevation: Energy gradeline for calculating water surface elevation, baseline the surface of the Baltic Sea (EGElev)

Energy Grade Line Slope: Slope of the energy grade line or slope of the water surface (EGSlope)

Entrenchment Ratio: The incision of the river bed. The channel width at two times the bankfull depth (Flood Prone Width) divided by the channel bankfull width (EntrRat)

Flow Area or Wetted Area: Total area of cross section active flow (Area)

Friction Loss: Energy loss or head loss due to viscous effects between two cross sections (Frctnloss)

Froude number: The ratio of inertial forces to acceleration forces for the main (wetted) channel (Fr)

Head loss: Total energy loss between two cross sections (Headloss)

Hydraulic radius: Wetted area divided by the wetted perimeter of cross section (HR)

Manning coefficient: Represents the conveyance weighted river bed roughness or friction for the main channel (Manning’s-n)

Maximum Depth: Maximum main channel depth in the thalweg

Plant Habitat: Ecohydrological perspective classification of functional aquatic plant habitats habitat-Harper and Smith, modified (PlantHabit)

Reynolds number: The ratio of inertial forces to viscous forces (Re).

Shear Total: Shear stress in total wetted cross section (ShearTot)

Sinuosity: The ratio of the channel length to the center line (Thalweg) and the downwalley length of the river reach unit (Sin)

Slope-Fr Ratio: The ratio of the slope of water surface or energy gradeline and the Froude number for Parker stream classification method (SlopeFrRat)

Thalweg: Longitudinal outline of a deepest part of bed, or line of steepest descent along the stream.

Top Width: Top width of the water surface in wetted cross section (TopWidth)

Total Flow (Discharge): The volume rate of water flow in cross section. (QTot)

Total Stream Power: Total cross section shear stress times total cross section average velocity (PowerTot).

Velocity-Hydraulic Radius Ratio: Indicates the relation of the average flow rate and the average depth (VelHR)

Velocity Total: Average velocity of flow in total cross section (VelTot)

Water Surface Elevation: Calculated water surface from energy equation. (WSElev)

Wetted perimeter: The circumference of the wetted cross-section except top width (WPTot)

Width-depth Ratio: Surface width divided by the average channel depth for Rosgen classification (WDRat)

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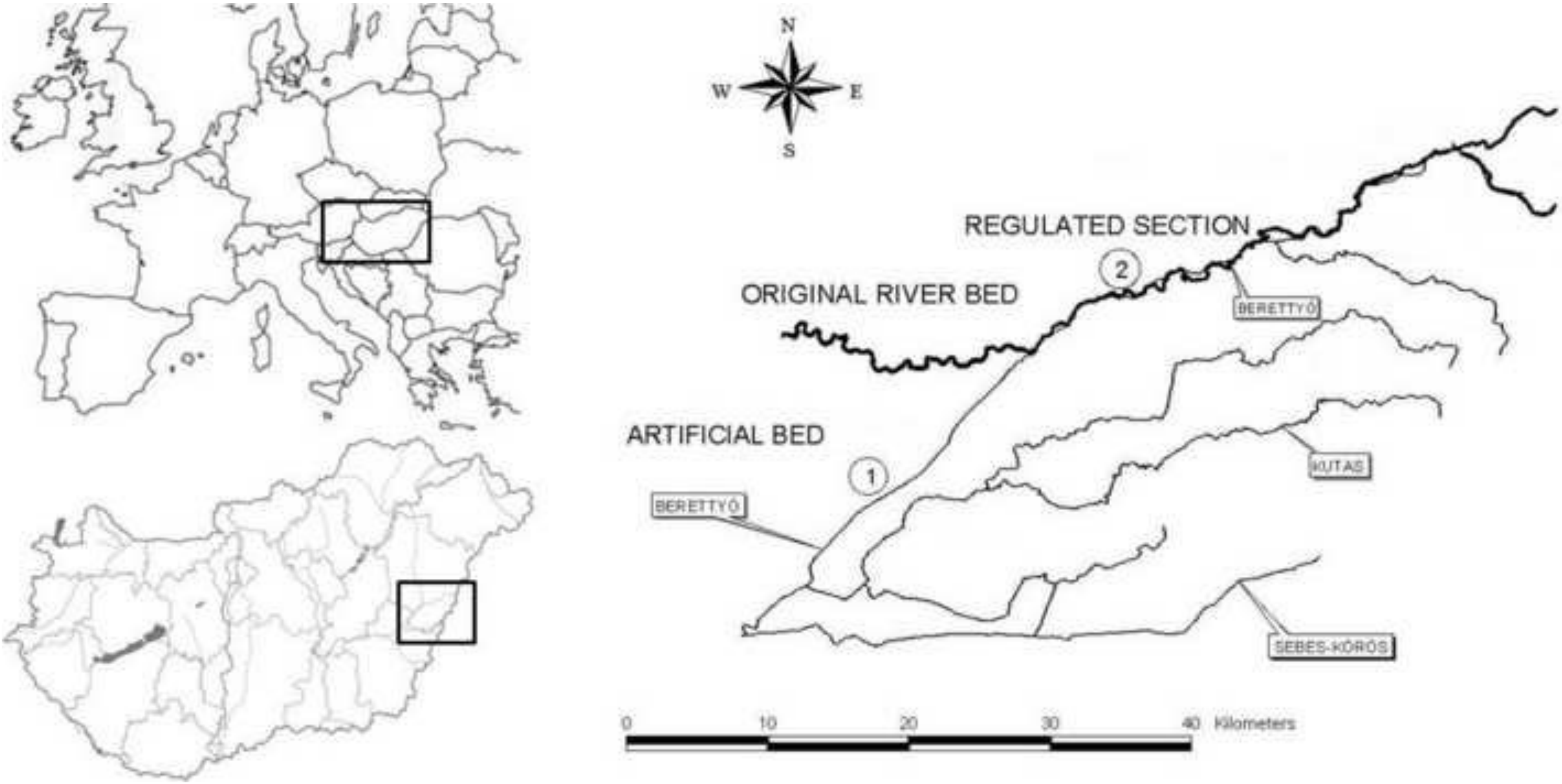
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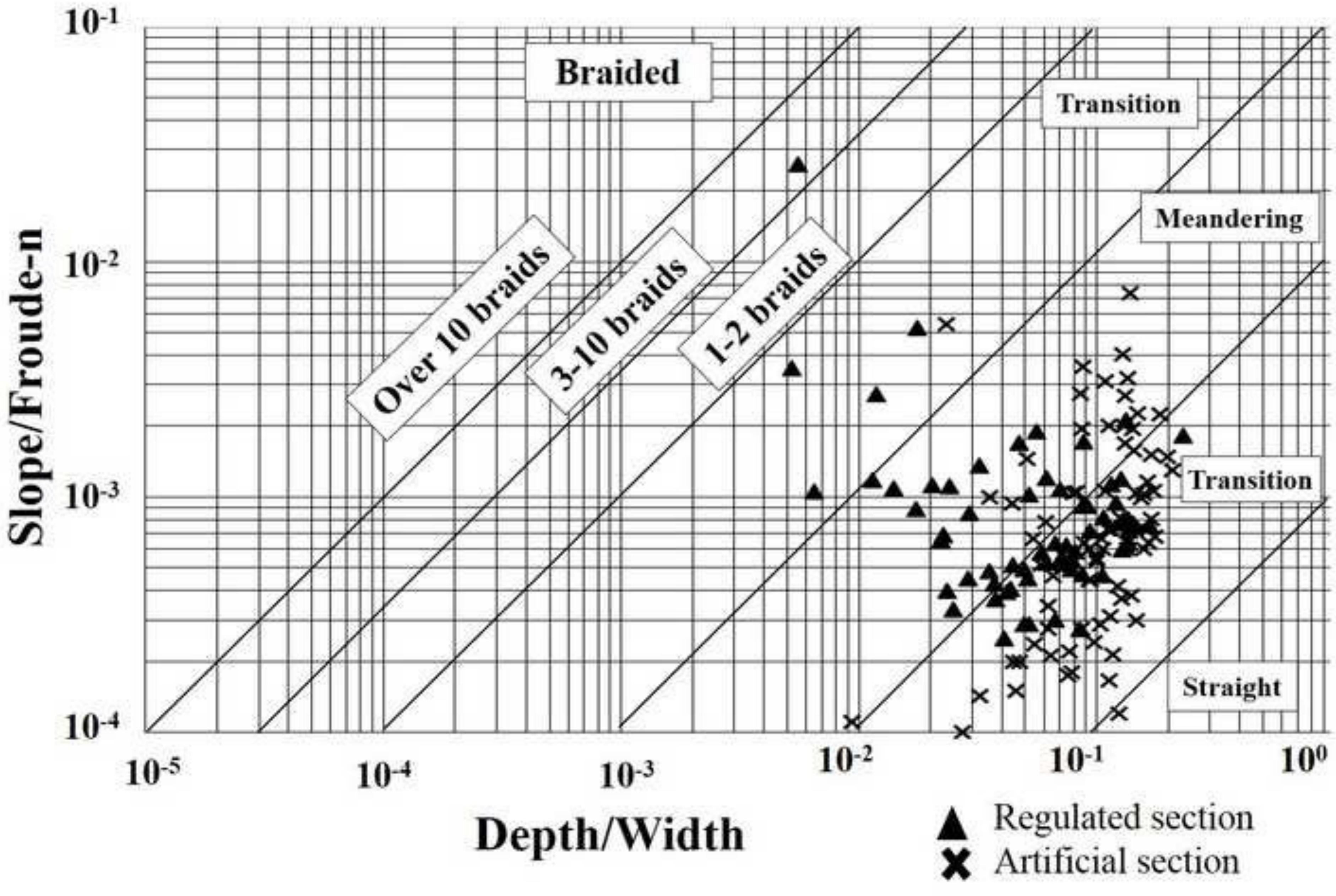
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Figure

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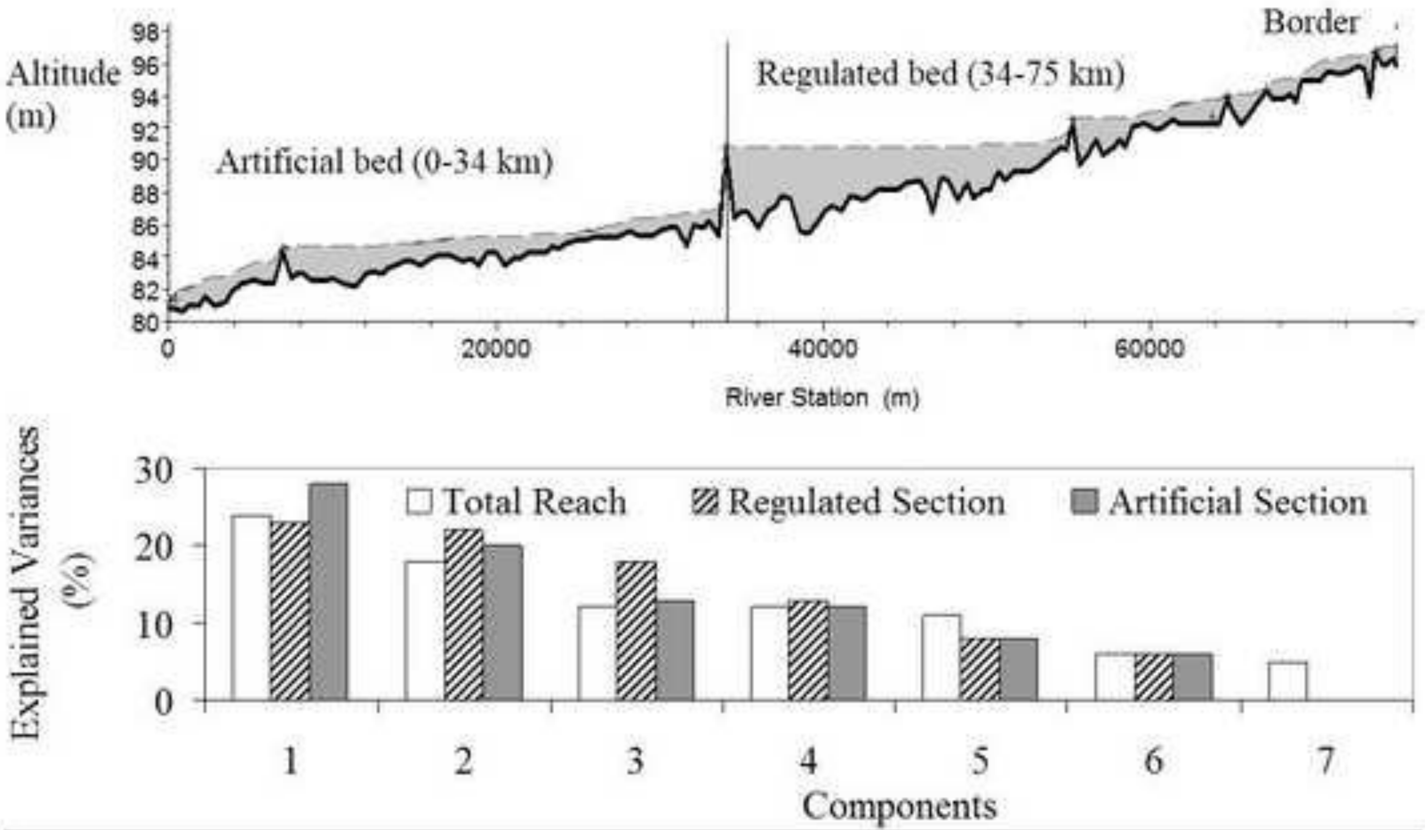
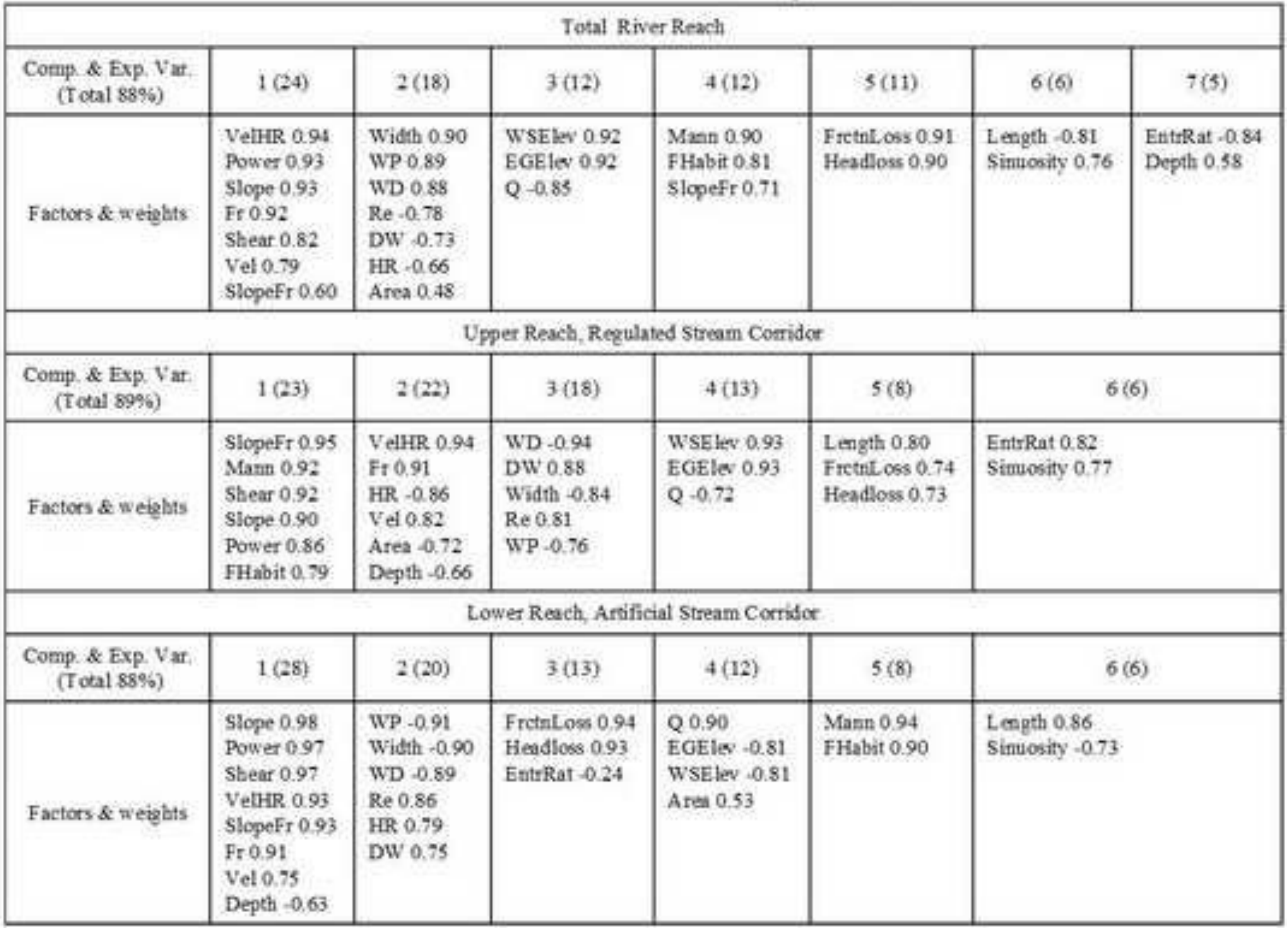
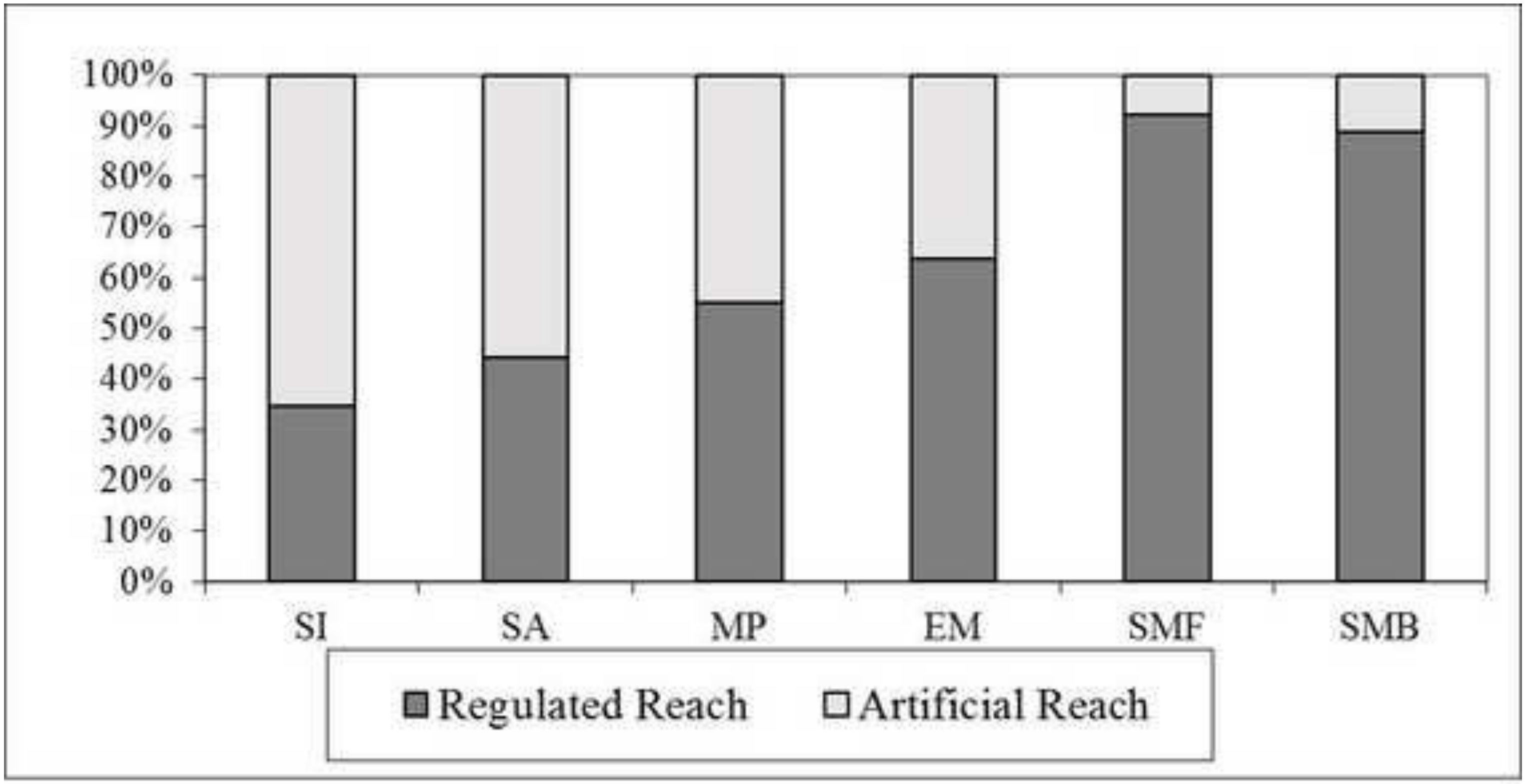




Total River Reach							
Comp. & Exp. Var. (Total 88%)	1 (24)	2 (18)	3 (12)	4 (12)	5 (11)	6 (6)	7 (5)
Factors & weights	VelHR 0.94 Power 0.93 Slope 0.93 Fr 0.92 Shear 0.82 Vel 0.79 SlopeFr 0.60	Width 0.90 WP 0.89 WD 0.88 Re -0.78 DW -0.73 HR -0.66 Area 0.48	WSElev 0.92 EGElev 0.92 Q -0.85	Mann 0.90 FHabit 0.81 SlopeFr 0.71	FrctnLoss 0.91 Headloss 0.90	Length -0.81 Sinuosity 0.76	EntrRat -0.84 Depth 0.58
Upper Reach, Regulated Stream Corridor							
Comp. & Exp. Var. (Total 89%)	1 (23)	2 (22)	3 (18)	4 (13)	5 (8)	6 (6)	
Factors & weights	SlopeFr 0.95 Mann 0.92 Shear 0.92 Slope 0.90 Power 0.86 FHabit 0.79	VelHR 0.94 Fr 0.91 HR -0.86 Vel 0.82 Area -0.72 Depth -0.66	WD -0.94 DW 0.88 Width -0.84 Re 0.81 WP -0.76	WSElev 0.93 EGElev 0.93 Q -0.72	Length 0.80 FrctnLoss 0.74 Headloss 0.73	EntrRat 0.82 Sinuosity 0.77	
Lower Reach, Artificial Stream Corridor							
Comp. & Exp. Var. (Total 88%)	1 (28)	2 (20)	3 (13)	4 (12)	5 (8)	6 (6)	
Factors & weights	Slope 0.98 Power 0.97 Shear 0.97 VelHR 0.93 SlopeFr 0.93 Fr 0.91 Vel 0.75 Depth -0.63	WP -0.91 Width -0.90 WD -0.89 Re 0.86 HR 0.79 DW 0.75	FrctnLoss 0.94 Headloss 0.93 EntrRat -0.24	Q 0.90 EGElev -0.81 WSElev -0.81 Area 0.53	Mann 0.94 FHabit 0.90	Length 0.86 Sinuosity -0.73	



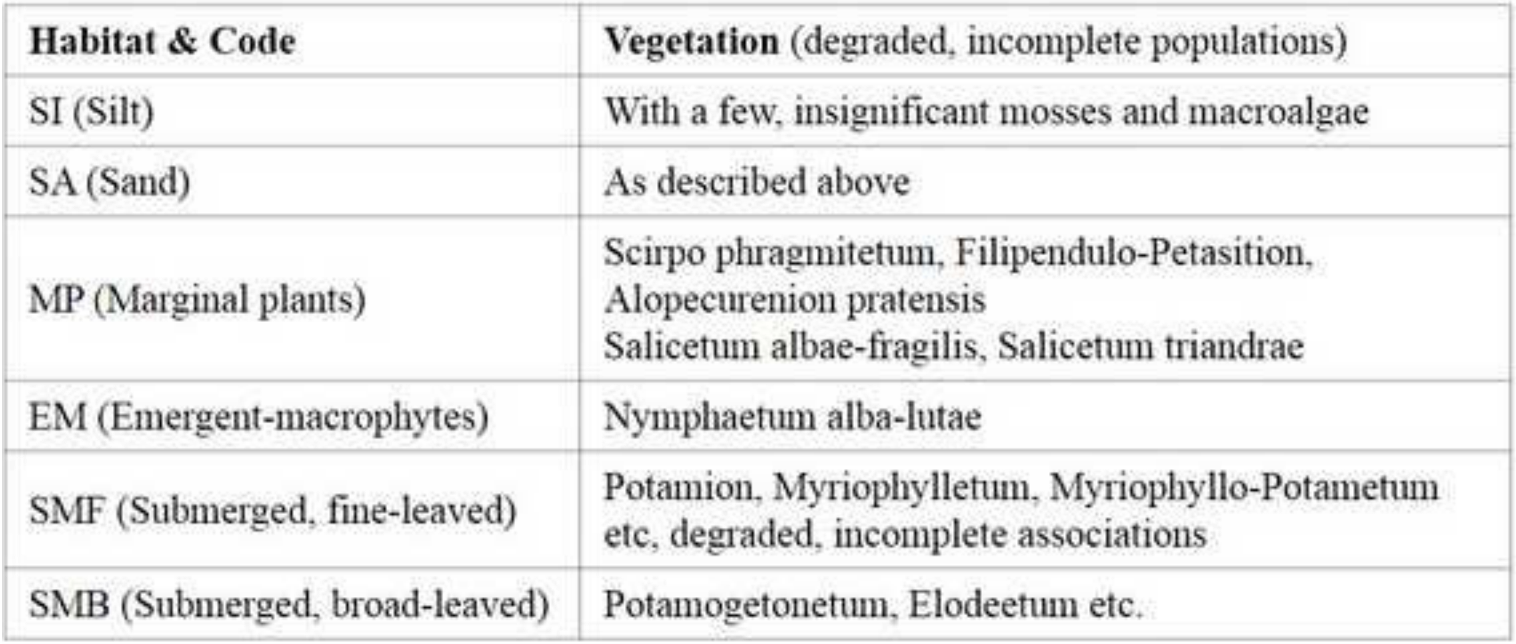


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Table

Table 1. Descriptive Statistics of the Riverbed Filling Discharge of the Berettyó River (147 XS)

Ecohydrological parameter	Min.	Max.	Mean	Std. Dev.	Variance
Q	9.41	19.50	13.41	3.83	14.65
WSElev	82.62	98.02	90.11	4.20	17.66
EGElev	82.72	98.10	90.14	4.20	17.65
Slope	0.000002	0.026478	0.000434	0.002258	0.000000
Area	6.55	135.27	34.21	22.30	497.09
Vel	0.11	2.07	0.61	0.30	0.09
WP	9.06	89.97	25.23	15.08	227.35
Width	7.33	88.75	23.56	15.07	227.21
Shear	0.03	59.58	2.78	5.70	32.50
Power	0.00	90.85	2.77	9.02	81.43
Mann	0.01	0.07	0.02	0.01	0.00
HR	0.23	2.79	1.39	0.40	0.16
Fr	0.03	1.02	0.18	0.14	0.02
Re	164.00	1626.00	775.88	285.80	81683.42
FrctnLoss	0.00	0.72	0.09	0.10	0.01
Headloss	0.00	0.72	0.09	0.10	0.01
Depth	0.23	3.25	1.53	0.47	0.22
WD	4.36	192.74	20.43	27.71	767.79
DW	0.01	0.23	0.09	0.05	0.00
SlopeFr	0.000067	0.025959	0.001164	0.002312	0.000000
Sinuosity	1.00	1.68	1.04	0.09	0.01
EntrRat	1.00	2.00	1.27	0.40	0.16
Length	200.00	1011.99	511.06	114.99	13222.93
VelHr	0.05	6.61	0.58	0.79	0.62
FHabit	1.00	6.00	2.77	1.42	2.02

The return period of the riverbed filling discharge is 100%, the annual durability is 60-80% (220-290 days/year).