ACTA UNIVERSITATIS CAROLINAE
2001 GEOGRAPHICA, No. 2, PAG. 133–146

Ecomorphological evaluation of the stream habitat quality and its application on the model area of Rakovnický Stream Basin

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Abstract

The ecomorphological evaluation of stream habitat quality is one of the new, complex evaluation methods that monitors the level of anthropogenic influence on water ecosystems. The article presents the method "Ecomorphological evaluation of the habitat quality of small and middles sized watercourses in hilly country areas", and its application in the model area of Rakovnický Stream Basin.

Key words: ecomorphological condition, hydromelioration, revitalization, water quality

1. Introduction

Watercourses are a part of the landscape, and aside from this quality they fulfill a series of important functions such as transport, retention, infiltration, biological and even esthetic functions. The current ecological state of many of them isn't satisfactory, since they have been straightened and degraded to become a technical gully, mainly providing a transportation function. Today efforts are appearing for restoration of their natural functions – so-called revitalization. Knowledge and evaluation of the original condition of quality of the watercourse is a prerequisite for successful restoration.

2. Water quality evaluation methods

Standard evaluations of watercourses call for methods aimed at the problematic of the condition of surface water quality, i.e. methods of hydrochemical and hydrobiological analyses of surface water quality. Both are irreplaceable for measurement levels of pollution of surface waters. They concentrate heavily though on the quality of the water itself.

Hydrochemical and hydrobiological water quality indicators though also depend on hydromorphometric characteristics of stream basins, the degree of anthropogenic changes, runoff and sediment regime, the character of the vegetation

belts along watercourses, etc. Starting at the end of the 1990s new evaluation principles have been applied, reflecting the overall so-called ecological/ecomorphological condition of watercourses and are a suitable basis for their integrated protection.

Lampert and Sommer (1993 in Zumbroch et al. 1999) deal in possibilities of ecological evaluation of water courses. They put forth the question of whether it is possible to evaluate ecosystems on the basis of ecological principles, because in theory they have no value, or their value cannot be determined. Evaluation is possible only after anthropogenic changes in them that can be measured, classified and evaluated according to certain evaluation measures. They also point to the problematic of difficult differentiation of natural, near-natural and anthropogenically influenced conditions in the present cultural countryside. A. Otto (1991, 1993) covers ecomorphological approaches to evaluation of watercourses in detail. He is the author of the monitoring method of the ecomorphological condition of quality structures of small and middle-sized watercourses in the rural areas of mountainous country, hilly country and lowlands. Furthermore N. Niehoff compiled an ecological evaluation method of watercourses, which should serve as a basis for restoration of large watercourses (1996). The method "Gewässerstrukturgütekarte BRD" from the work group LAWA-AGO, Germany (Binder, W. et al. 1996) also solves this problematic. Its main goal is first enabling broad evaluation and mutual comparison of the ecological condition of large and middle sized stream basins.

A newly compiled guideline from the European Union – Water Framework Directive (Commission of the EC 2000) underlines the significance of ecological evaluation methods. This is founded on a complex ecological evaluation of watercourses, lakes, estuaries and coastal waters and their integrated protection. A basis for analysis of the quality of watercourses contained in this guideline is a so-called ecological statute, which is determined by the biological, hydromorphological and physical and chemical parameters.

In the Czech Republic, several studies have been elaborated, based on ecological principles. The methodologies mostly emerged as parts of individual research projects, carried out within the basins examined or within selected sections of watercourses. In cooperation of the VÚV T. G. M. (Tomáš G. Masaryk Water Research Institute) and the German institution BfG Koblenz, the research project "Unification of Methods of Hydroecological Evaluation of Watercourses and Flood Plains with Pilot Application on the Labe River Sections" was processed. (VÚV 2000, Fuksa 2000). A study concerned with a complex approach to evaluation of watercourses quality and multicriterial analysis of watercourses, elaborated by M. Šindlar. (Šindlar 1998)

For the reason of absence of suitable methodology for small streams within the researcch project GAUK (1997–99) "Water Quality in the Berounka River Basin ", the methodology of "Ecomorphological evaluation of habitat quality of small and middle sized streams in hilly country areas" was formed by Langhammer, Matoušková (2000), Matoušková (2001) and work on Ph.D Thesis "Ecohydrological monitoring as a basis for restoration of streams" Matoušková (2002).

This is a method consisting of individual partial goals and several independent evaluation elements interconnected in the conclusion. It includes an analysis of hydromorphological characteristics of the watercourse, of the state of anthropogenous modifications performed on the watercourses, degree of dynamics and character of the flow, quality of surface water, state of the bank vegetation, land use of areas situated along the watercourses, and other characteristics of individual model basins. The basis for the evaluation is the so called "potential natural state" which does not represent the original, "historical" state of the watercourse in an untouched natural landscape but a condition of the watercourse which would be formed based on the given physically geographic development of the area investigated without marked negative anthropogenous impact performed to the landscape.

The methodology is not related only to the watercourse itself. The water ecosystem is understood here as a wider area formed by individual zones, mutually interconnected. The spatial unit of the highest rank is the *basin*, other eco-morphological zones are the *flood plain, riparian belt*, and the *watercourse bed.*

The main goal of the methodology is representation of ecomorphologically problematic sections of watercourses and parts of the basin which should be revitalized. Individual group parameters are provided in Fig. 1.

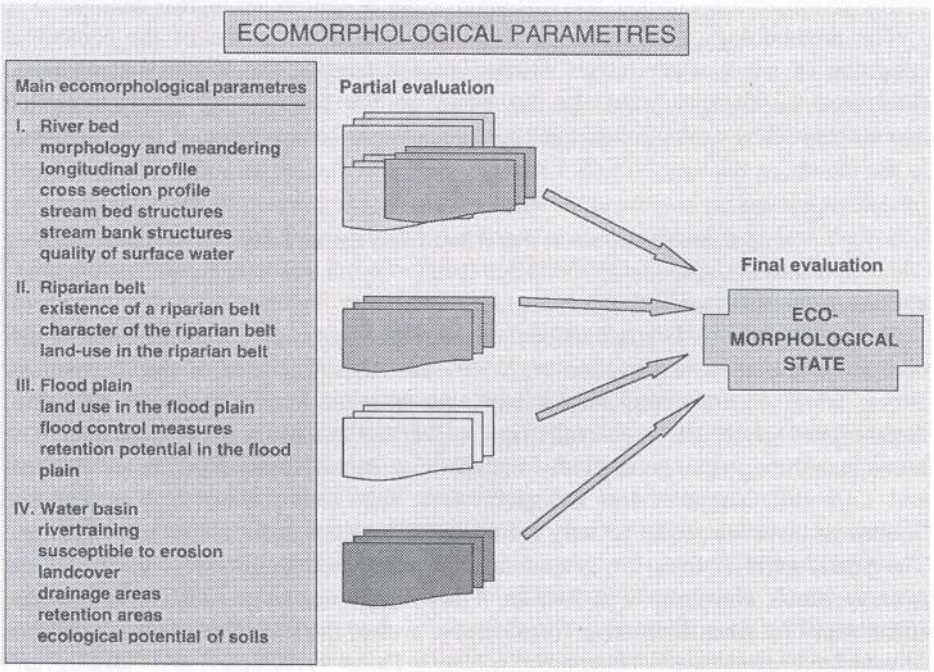

Fig. 1 Review of ecomorphological parametres

Ecomorphological mapping is performed in firmly defined sections of the watercourse. In the case of small watercourses (main watercourse length ML < 20 km, basin area BA < 100 km^2), it is suitable to perform the mapping in sections homogenous from the length point of view. The recommended section length is 100 m or 200 m depending on the accuracy, requirements, and purpose of the mapping. In the case of middle sized basins (500 km^2 > BA > 100 km^2), it is suitable to perform the ecomorphological mapping in sections heterogenous from the length point of view, with the emphasis laid on their qualitative homogeneity. Length of individual sections lies within the range of 500–1500 m. Every section of the watercourse is delimited exactly on the map and marked numerically. Their mutual non-overlapping must be guaranteed. For the terrain mapping, spring and autumn periods are favourable. Investigation of hydromorphological structures of the bed should be performed when the discharge is low. Mapping results are recorded in a working blanket form, in maps, and subsequently processed to obtain their digital form, and finally evaluated using a spreadsheet editor and represented in thematic layers of GIS.

Individual indicators are evaluated according to a point system (0–5). Values of partial parameters are calculated on the basis of the maximum principle, i.e. the worst values recorded, or prevailing, the so called dominant values, or possibly on the basis of the arithmetic average. Values of group parameters as well as the quality of the resulting ecomorphological condition of quality of the given section, are calculated on the basis of the arithmetic average of the previous order category. At the end, verbal evaluation is added to the numeric result obtained, according to classification into firmly delimited and defined intervals into 5 class of ecomorphological quality.

The methodology introduced has been verified in evaluation of the ecological condition of small watercourses situated on the land of the Křivoklátsko CHKO (Protected Landscape Area). In the basin of the Rakovnický Brook, detailed ecomorphological evaluation of quality structures has been performed from its spring to the mouth, in the length of 48.4 km.

4. Application on the model area of Rakovnický Stream Basin

4.1 Characteristic of the Rakovnický Stream Basin

Rakovnický Brook is a left affluent of the river "Berounka", which it enters in its 63.3 river kilometer at elevation of 235 meters ASL. The area of the Rakovnický Brook water basin spans 368.14 km^2, the brook's lenght measures 48.4 km. Geomorphologicaly the brook falls into a river system of the river Berounka. The brook cuts through two geologically distinct units. In the Northwest there are Permian and Carboniferous sediments (conglomerates, sandstones, claystones) and in the Southwest there are predominantly proteozoic formations (shales, spillites, phyllites). The yearly rainfall over the subject area averages 500 millimeters (mm) and the average runoff elavation of is 74 mm. The average discharge is 0.7 m^3/s (station: Rakovník; 17.8 river kilometer). Considerable area of the subject water basin consists of protected nature areas. There are two Nature Parks: "Jesenicko" and "Džbán" and Protected Landscape Area "Křivoklátsko".

The area carries a population of 32,000. The majority of which is concetrated in the Rakovník City (pop. 17,000). Industry of the region is concetrated in the Rakovník City and its immediate vicinity. The greatest share is taken by chemical industry, then by building materials industry and by machinery industry. The majority of the industrial plants in the Rakovník City are connected into the sewerage system which drains both the domestic and industrial waste into one common sewage treatment plant. Other industrial plants in the basin have an own sewage plant and drain industrial waste water directly into streams.

Agriculture is also an important economic activity in the Rakovnický Stream Basin. 45% of the basin is made up of arable land. Here, farmers mainly grow cereals and feeder grains. A important crop grown in the basin is hop. It's mostly grown in the northeast and northern part of the basin, where clay, red-colored heavy soils with a good supply of nutrients are prevalent. Due to the low forestation in this part of the basin, there occurs a serious loss of materials due to the influence of heavy rains mainly during the summer. This can be seen in the color and turbidity of watercourses. Animal production is aimed mainly at pig and cattle. They undoubtedly take part in polluting surface waters with organic materials. When using the population equivalent of pollution (PEP) it was found that animal production significantly increases organic burden produced by the human population living within the basin.

The largest areas from the aspect of land cover are taken up by farmlands (48%), of which 45% is arable land, and forested bodies (48%). Continuous urban areas make up 2%, industrial and commercial units make up 0.3%. Natural grassland make up 0.14% of the entire area of the basin.

4.2 Hydrographic network and its anthropogenic transformation

The drainage pattern of the Rakovnický Stream Basin may be indicated as an dendritic type network that is slightly disrupted by the asymetry of the basin to the benefit of tributaries on the left side.

The Rakovnický Stream, just like the majority of its tributaries, has a significantly straightened bed in the Permian and Carboniferous region, with a low degree of meandering. This is given by the geological and geomorphological conditions and also by significant anthropogennic interferences in this area. In the proterrozoic territory we can see higher degree of meandering, which is mainly given by the geological and geomorphological factors, but also the lower part of the watercourse runs through protected areas, where the courses haven't been altered significantly.

In the study area changes occurred in the hydrographic network mainly due to meliorative actions, flood protection, outflow of drainage systems, sewage systems, roadway overpasses, urbanization of the territory and strip mining.

The first serious alterations occurred in the hydrographic network in the 17th century, due to the construction of fishponds on the upper course (Jesenice fishponds system). The cadastral map of the city of Rakovník from 1841 documents the existence of a system of fishponds, mill races and a flooded moat on the southern foreground of the city. The original bed of the Rakovnický Stream was found roughly 100 m further to the north than its present course. Extensive changes occurred at the

beginning of the 20th century in the streambed around the city of Rakovník and its surroundings. This was spurned on by the catostrophic flood of 1872. In 1902 there was a movement of the bed from the historic center of the city and its release into a deep channel, where the mill race had been. In later stages from 1902 to 1930 alterations of the bed above and below the city occurred. Similar regulation, mainly due to flood protection, occurred in practically all communities lying in the upper and middle stream.

The most intensive changes in the hydrographic network in the stream basin occured in the 1970s and 1990s, in order to perform large river training. The entire extent of altered territory amounted to 150.48 km^2. The beds of the Rakovnický, Kosobodský, Soseňský, Klečetná, Řeřišský, Kolešovický, Petrovický a Jalový streams were all transformed in a total length of 70.24 meters. Transformation of the stream network in the basin is illustrated on Fig. 2. From it we can see that the main part of the courses is anthropogennically influenced. In the territory occurred shortening of the length of streams, their straightening, deepening, reinforcing the beds and con-sequent quickening of the runoff from the basin. The original project of melioration included at least building accumulation dams, but they were never built (Hydroprojekt 1970).

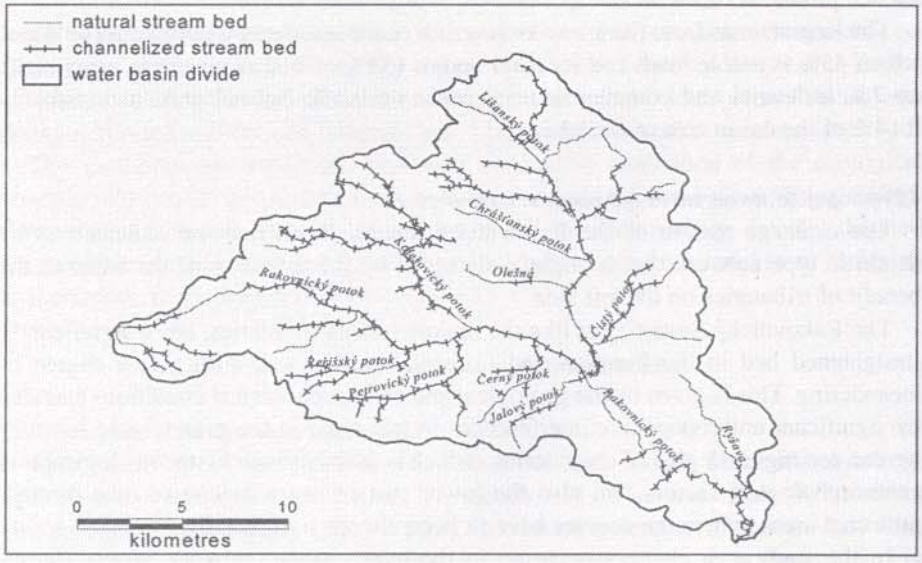

Fig. 2 Transformation of the river network in the water basin Rakovník Brook

4.3 Quality of surface waters

The quality of surface waters was evaluated separately from the analysis of ecomorphological quality structures of the Rakovnický Stream. The reason was mainly insufficient quantity of profiles, sufficiently characterizing the longitudinal profile of the course.

As a fundamental information source was used data compiled by a water basin agency „Povodí Vltavy" and ČHMÚ (Czech Hydrometeorological Institut). This data was collected in periond beween 1965 and 1999 and it was grouped into three basic profiles: „Rakovník nad" (21.2 r. km), „Dolní Chlum" (14.5 r. km) and „Křivoklát" (0.3 r. km).

The highest degree of pollution can be seen on the middle course (4th quality class for parameters BOD_5, COD_{Cr}, $N\text{-}NH_4$, 5th quality class for $N\text{-}NO_3$, P_{tot}). The cause of such a condition is the outlet of communal and industrial wastewater from the city of Rakovník. The vast majority of the volume of wastewater is led into and treated in the Rakovník sewage treatment plant, which has been under gradual reconstruction since 1995, increasing its effectiveness. A certain improvement in the condition of quality can be recorded from the analysis of long-term development of individual parameters, ex. the slight drop in concentrations of the parameters BOD_5, COD_{Cr}, and a more significant decrease in the concentrations of $P\text{-}PO_4$ a P_{total} (Fig. 3). Nevertheless a large difference still exists between the quantity and burden of wastewater and the capacity of the recipient. The upper course of the Rakovnický Stream shows a lower level of organic pollution (3rd quality class for parameters BOD_5, COD_{Cr}, $N\text{-}NH_4$, but 5th quality class for the parameter $N\text{-}NO_3$). The source of organic pollution here are small settlements and animal production. It is definitely seen from the dependent analysis that diffuse sources also take part in $N\text{-}NO_3$ pollution.

The lower course of the Rakovnický Stream can also be deemed as very polluted, as the parameters BOD_5, COD_{Cr} indicated the 3rd quality class, $N\text{-}NH_4$ the 4th class and $N\text{-}NO_3$, $P\text{-}PO_4$ the 5th class. Here the source of pollution is still the city of Rakovník and communities lying in the valley of the Rakovnický Stream. This pollution is dissatisfactory, since the lower course runs into the Protected Landscape Area (PLA) Křivoklátsko.

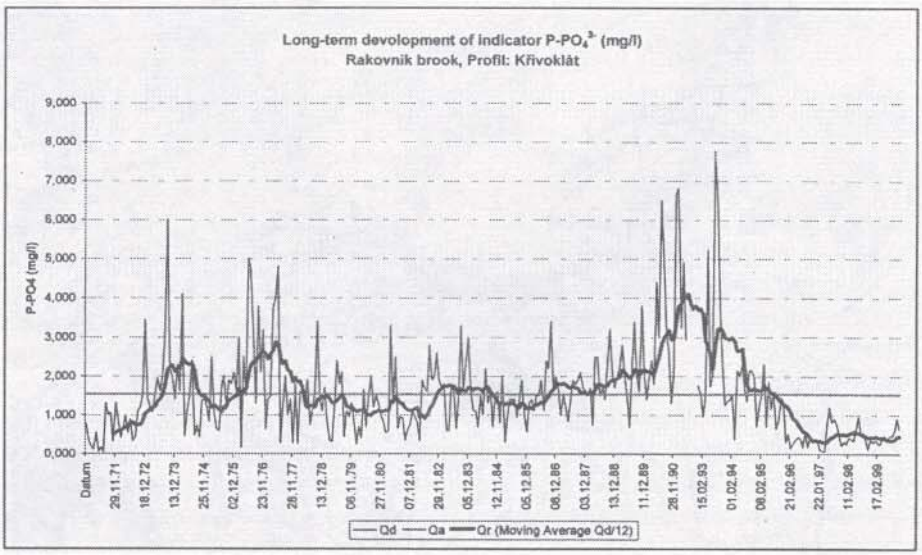

Fig. 3 Long-term development of concentration $P\text{-}PO_4^{3-}$

4.4 Ecomorphological condition of the Rakovnický Stream

Ecomorphological evaluation of the habitat of the Rakovnický Stream was performed along its entire length from the source to the mouth, i.e. 48.4 km. Terrain mapping took place in three basic zones, i.e. the watercourse bed, riparian belt and the flood plain. A total of 46 sections of equal length were determined. Localization of individual sections is indicated on Fig 4, 5. In the **zone** of the streambed of the watercourse, the parameters of *morphology meandering, longitudinal profile, cross section profile, streambed structures and stream bank structures* were evaluated. According to the results gained it's possible to divide the watercourse into several areas. Already the point of the upper stream (sections 1,2,3) is anthropogenically influenced to a great degree (4th quality class) from the aspect of the aforementioned parameters (Fig 5). This is because hydromelioration and alterations of the streambed occurred. Here are mostly straightened, artificially reinforced sections with quarry stone or concrete prefabricate with medium diversified stream flow and a low diversity of substrate. On the upper stream in the territory of the Jesenicko Nature Park there appear mainly slightly anthropogenically-influenced structures. Sections 4–6 under the Krtský fishponds are classified as natural and near-natural. The streambed here is found in its original course, it is natural with unfortified, irregular cross-section profile, with middle variability of depths and widths.

On the other hand significant anthropogenic influence of the hydromorphological quality structures (4th and 5th quality classes) can be seen on the middle course, where related alteration and stabilization of the streambed was performed (sections 13–14,

Fig. 4 Delimitation of ecomorphological segments

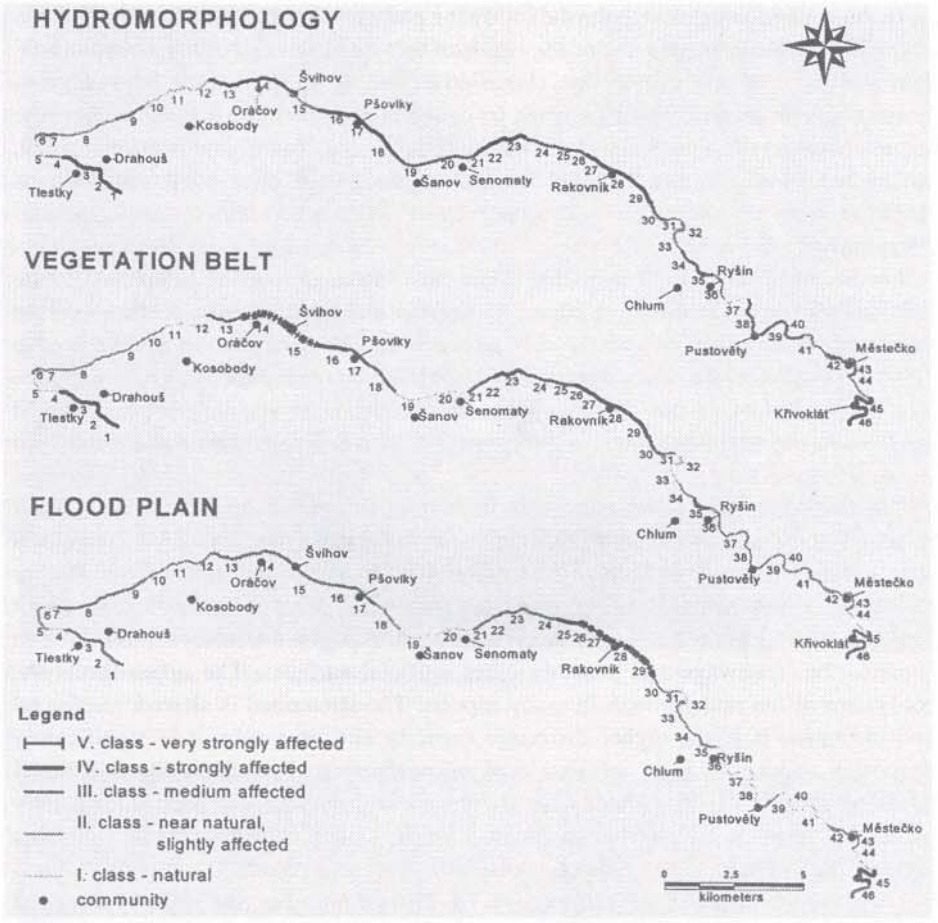

Fig. 5 Evaluation of separate ecomorphological zones

16–18, and 26–29, i.e. Oráčov – Šanov, Senomaty – Rakovník). In these parts alterations of the streambed occurred mainly due to flood protection, housing settlements and hydromelioration. The character of the streambed is mainly artificial, reinforced with quarry stone, with little variability in depth and width. The water flow has medium diversification, and the presence of accumulation and special structures of the bottom is low.

Within the territory of the PLA Křivoklátsko, i.e. at the down stream, there were also found sections with natural or near-natural streambed characteristics (sections 31–33, 36, 37, 41, 44), where it is possible to record natural erosion processes of the streambed. Here however there also appear locations with heavy anthropogenic influence (sections 45–56), characterized by trapezoid, artificially reinforced cross-section profile, and low variability of depth and width. The migration permeability of the course here is limited by the construction of weirs.

In the zone of vegetative belts the following parameters were monitored: existence of the *riparian belt, character of the riparian belt and land use in the riparian belt.* The head area of the course was classified in the 4th quality class. Riparian belt doesn't appear here, or doesn't attain a so-called minimum width, i.e. 10 m. Also the section between the communities of Oráčov and Pšovlky (14–16) and sections 26–29, which are found within the territory of the Rakovník city, were indicated as dissatisfactory. In the urban areas, vegetative belts aren't fully developed and functioning.

On the other hand, sections on the upper flow in the area of the Jesenicko Nature Park (4–12) were classified as a natural or near-natural territory with existing riparian belts and their optimum land cover. The same can be said for the middle course (19–20, 31–34) and the down stream (36–44). Mainly in the area of PLA Křivoklátsko, where the watercourse runs through down stream have belts that are wide enough and are fully functional. The so-called overgrowth has maintained a functional bond with the watercourse (Fig 5).

The flood plain was evaluated with the help of the parameters: *land cover, flood control measures and retention potential in the flood plain.* Sections 25–29, found in the territory of the city of Rakovník and section 45 by the community Křivoklát were classified as very heavily anthropogenically influenced. This is logical because right here the alluvial plain has experienced heavy anthropogenic transformation through construction, roadways and possibly other artificial surfaces. The urban limits the ecosystem of the undergrowth in many aspects. The streambed is altered, reinforced and insulated. It has a higher discharge capacity and as a rule, it is significantly deepened under the level of the local alluvial plain, by which the functional hydrological bond is disturbed. Also the vegetative element has been significantly eliminated here. It is possible to indicate in the upper course sections 4–7 (area between Krtský and Velký fishponds) as natural or near-natural flood plain. This is also true for the middle course at sections 18–21 (communities Šanov-Senomaty) and the down stream running through PLA Křivoklátsko with the exception of the last sections 45 and 46 (Fig 5).

The overall ecomorphological condition of the Rakovnický Stream, evaluated on the basis of an analysis of the three aforementioned zones can be characterized in summary as dissatisfactory. Strongly anthropogenically influenced sections make up 23.5 % of the total watercourse length. This state is extremely dissatisfactory starting at the source (sections 1, 2, 3, i.e. 45.7–48.4 km.), where the streambed is straightened and reinforced, vegetative belts are not sufficiently developed here and intensive agricultural use of lands along the watercourse has occurred. Also sections 14–16 along the middle course between the communities of Oráčov and Pšovky are heavily anthropogenically influenced areas. This is the same for section 23 and sections 26–29 found within the territory of the city of Rakovník (Photo 1).

Natural sections make up only 7.7% of the total stream length. As natural were indicated sections 4 and 5 in the upper flow, and sections 37 and 44 on the lower course (Photo 2), which should be the subject of special protection. Ecohydrologicaly important are also near natural sections, which are slightly atropogenically influenced.

Photo 1 Section (no. 6) river training of the Rakovnický Stream

Photo 2 Natural section (no. 5) of the Rakovnický Stream

These territories took 42.4 % of the total stream length. The complete overview of the ecomorphological condition of the Rakovnický Stream is indicated on *Fig 6* and Tab. 1.

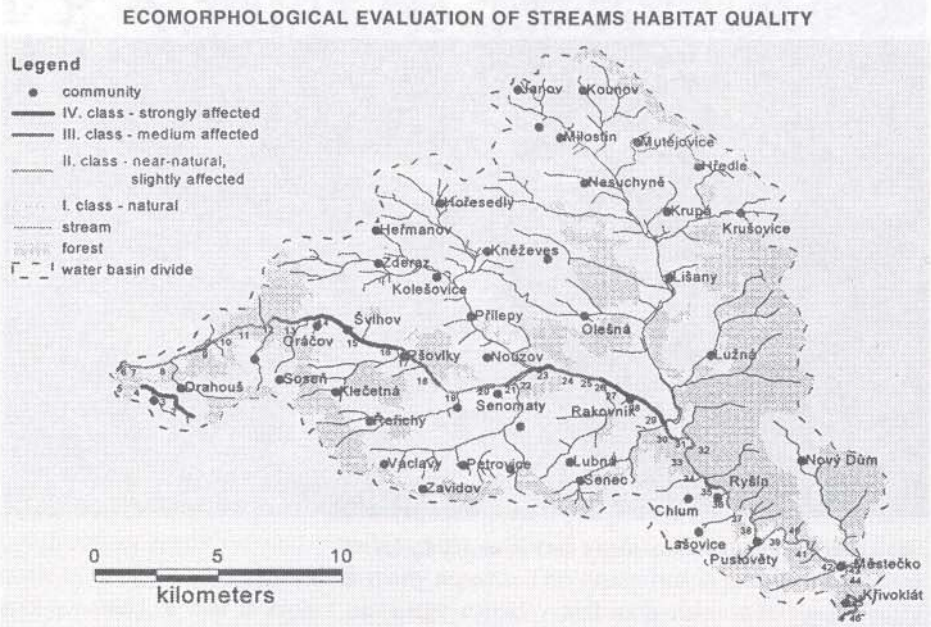

Fig. 6 Ecomorphological evaluation of Rakovník Stream

Tab. 1 Overview of the ecomorphological condition of the Rakovnicky Stream

Class of ecomorphological quality	*Interval*	*Evaluation*	*Number of sections*	*Total length (km)*	*% rate*
1.	<0; 1>	natural	4, 5, 37, 44	3.7	7.7
2.	(1; 2>	slightly affected, near natural	7, 8, 10, 11, 12, 19, 20, 21, 31, 32, 33, 34, 36, 38, 39, 40, 41, 42, 43	20.4	42.4
3.	(2; 3.5>	medium affected	6, 9, 13, 17, 18, 21, 22, 24, 25, 30, 35, 45, 46	12.7	26.4
4.	(3.5; 4.5>	strongly affected	1, 2, 3, 14, 15, 16, 23, 26, 27, 28, 29	11.3	23.5
5.	(4.5; 5>	very strongly affected	–	0.0	0.0

Revitalization of the water basin must first be directed into the uppert stream. Here so-called complete revitalization should be performed. First and foremost it's necessary to gain areas for creating functional riparian belts. Further it's necessary to free the course of technical reinforcement and leave it to develope natural fluvial morphological structures. Also appropriate would be planting of trees and bank

vegetation, or allow growth of vegetative belts by succession. Full restoration should also occur in sections 14–16 between the communities of Oráčov and Pšovky.

In the urban areas of individual communities and in the territory of the city Rakovník it's not possible to perform complete revitalization, since it's not possible here to provide the course with a sufficient amount of area for natural formation. Rather it is certain that here it is possible to perform so-called partial revitalization. This means limiting high levels of pollution of the watercourse, increasing the variability of depths and widths with the help of structures made from natural materials, planting sections that lack potentially natural vegetation.

5. Conclusion

New approaches in the evaluation allow for gaining a broader view at the watercourses, that means that the stream quality is not affected only by pollution of water in its bed, but also by ecomorphological parameters of riparian belt, flood plain and whole water basin.

These methods give a continual view of the watercourse from its spring to its mouth. An indelible part of them should be a geographic characteristic of the water basin, which helps to understand ascertained facts. Results of the monitoring performed can be applied in practice, for they are related with protection of watercourses and their possible restoration.

Negative features of these methods include the generalization of individual characteristics of watercourses, subjectivity of evaluation of ecomorphological structures when performing the terrain mapping and high time demands. Objectivity can be ensured by clearly defined evaluation parameters, their statistical evaluation, exactness and reproducibility of the results obtained.

Within the framework of research of the ecological condition of watercourses, the method "Evaluation of the Ecomorphological Condition of Small and Middle Sized Watercourses in Hilly Country Areas" was formulated. Its applicability in practice was proven on the model area of Rakovnický Stream Basin. Evaluation was performed of the intensity of anthropogenic influence of the course and its stream zones from the source to its outflow to the Berounka River in a length of 48.4 km. Three ecomorphological zones were evaluated: the streambed, the vegetative belt and flood plain. Also performed were a geographic characteristic of the study basin and an analysis of the anthropogenic transformation of the stream network.

The attained results proved the significant anthropogenic influence on ecomorphological structures of the Rakovnický Stream. The most significant burden was found in upper and middle stream in sections, 1–3, 14–16, 23 and 26–29, where watercourses were altered, and technical alterations to the streambed occurred mainly due to hydromelioration, flood protection and the building of housing settlements. On the other hand the natural structures were maintained within the territory of Jesenicko Nature Park and in PLA Křivoklátsko. For improvement of the entire ecological stability of the water ecosystem, it would be appropriate to apply

complex revitalization of the Rakovnický Stream Basin and limitation of high pollution of surface waters.

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EKOMORFOLOGICKÉ HODNOCENÍ JAKOSTNÍCH STRUKTUR VODNÍCH TOKŮ A JEHO APLIKACE NA MODELOVÉM POVODÍ RAKOVNICKÉHO POTOKA

Résumé

Ekomorfologické hodnocení jakostních struktur vodních toků je založeno na monitoringu míry antropogenního ovlivnění vodního toku. Nevztahuje se pouze na samotné koryto vodního toku. Zohledněn je rovněž stav doprovodných vegetačních pásů, údolní nivy a celého zájmového území. Konkrétní výsledky této metody jsou uplatnitelné ve vodohospodářské praxi, především při revitalizaci vodních ekosystémů.

V článku je představena metodika „Ekomorfologické hodnocení jakostních struktur vodních toků v pahorkatinném reliéfu" a její aplikace na modelové povodí Rakovnického potoka.

Dosažené výsledky prokázaly značné antropogenní ovlivnění ekomorfologických struktur Rakovnického potoka. Nejvýraznější zatížení bylo zjištěno v pramenné a střední části toku (úseky 1–3, 14–16, 23 a 26–29, tzn. celkově 23,5 % délky toku). Došlo zde k překladům toku, technickým úpravám koryta a transformaci vegetačních pásů a údolní nivy především z důvodů melioračních opatření, protipovodňové ochrany a výstavby lidských sídel. Naopak přírodní struktury jsou zachovány pouze v 7,7 % celkové délky toku a to na území Přírodního parku Jesenicko (úseky 4, 5) a v CHKO Křivoklátsko (úseky 37, 44). Pro zlepšení celkové ekologické stability vodního ekosystému byla doporučena revitalizační opatření a nutnost zamezení nadměrného znečišťování povrchových vod.