Czech University of Life Sciences Prague

Faculty of Agrobiology, Food and Natural Resources

Department of Water Resources

Ecohydrological evaluation of a selected small stream and its catchment

Diploma Thesis

Author of Thesis: Bc. Katarina Trnovec

Thesis supervisor: Ing. František Doležal, CSc.

I declare that the Diploma Thesis “Ecohydrological evaluation of a selected small stream and its catchment” is my own work and all the sources I used are listed in the Bibliography.

Prague, 13.4.2017 Bc. Katarina Trnovec

Acknowledgement

I would like to thank my family, friends and especially my supervisor Ing. František Doležal, CSc. and my consultant Ing. Andrej Škrinár, PhD. for their patience, help and support during this period.

Summary

The Revúca River is a typical hilly and mountain river. It is located in the northern part of Slovakia called Liptov. It is surrounded by and flows through national nature parks. The whole region is a well-known touristic area. There are parts of the river that are totally undisturbed, while some others are significantly modified.

The aim of this work was to evaluate the proximity of this stream and its individual sections to nature and their suitability to maintain and develop life of already present water organisms, as well as their capacity to retain water in the area. This was done via two ecomorphological methods, named EcoRivHab and HEM, developed at the Charles University of Prague.

The river with its 33, 43 km length and 265, 73 km^2 catchment area represents a typical medium-sized stream of the Liptov region. For the purpose of evaluation, the stream was divided into seven homogeneous sections with different lengths. These sections were evaluated following the EcoRivHab and HEM ecomorphological methodologies. Overall, the Revúca River is rated as slightly modified (II. Ecomorphological Grade = EG) by both methods. Some stream section, however, were evaluated differently by EcoRivHab and HEM. This was due to different criteria used in the two methods. The EcoRivHab method was usually more generous and the resulting grades were close to nature (I. EG) along 46%, slightly modified (II. EG) along 29% and medium modified (III. EG) along 25% of the stream length.

The HEM methodology was harsher, evaluating only 27% of the stream length as close to nature (1. EG), 25% as slightly modified (2. EG), 43% as medium modified (3. EG) and 5% as strongly modified (4. EG).

The highest degree of man-made modifications of the stream was identified in the urbanized areas of Liptovské Revúce and Ružomberok towns. Some other minor modifications were found in Liptovská Osada and Biely Potok villages, but the biggest issues are two fish migration obstacles and the highly urbanized area of Ružomberok. Therefore, there are two revitalization actions proposed in this work. The first one is to create a migration path for the biota and the second one is to revitalize the river in the Ružomberok area.

Keywords

ecohydrology, hydromorphology, EcoRivHab, HEM, stream fortification, stream restoration, catchment, stream-bed, stream bank zone, flood plain, runoff, flow pattern, habitat, sediment

Index

1. Introduction

Rivers are an important part of the landscape and one of the essential conditions for life on Earth. The human kind has always been thought as the owner of the Earth. This could be true but only by listening to nature because it has been proved over history that nature is much stronger than mankind. Maybe therefore, there were many attempts to put nature under human subjection, which were also revealed in the relationship between people and water.

Unfortunately over the years, usefulness and expediency were the main aim when treating water management. This led to many modifications in rivers and water bodies that were pushing its natural state to very low. Flood protection often resulted in river channelization, water gates and dam construction and overall stream modifications. This had unfortunate consequences in the elimination of biota or its total extinction. The best known example is the almost extinction of beluga (European Sturgeon, *Husa Husa*) in the Danube river caused by the construction of Iron Gate.

The prevailing theory used to be that nature has to obey the mankind. This opinion is slowly decreasing when understanding the aftereffects of these actions. Nature can be much stronger and complex than what we sometimes think. Luckily, we have been realizing this everyday more and more and there are many scientists looking for the best solution and according to nature in different areas. As for the water bodies ecomorphology started to be one of the main heading indicative.

One of the main things when applying ecomorphology is to identify all the parts of the problem in order to revitalize the river the best way possible. In this work two different ecomorphological methods were applied. EcoRivHab and HEM were both created in Czech Republic and applied on Revúca River in the Lower Liptov Area in Slovakia.

Revúca River and its surroundings is an area that is strongly bounded to my memories as I have spent there many of my holiday times. Also, another reason why I chose this river is because I believe that the golden age of the region is still about to come due to its natural treasures, beautiful views, national nature parks and unique ambient.

2. Scientific hypothesis and work objectives

Hypothesis:

In order to design and implement adequate and viable measures aiming at the restoration of small streams and surrounding terrains, one can successfully employ a river evaluation methodology based on the quantitative assessment of the river bed morphology and vegetation and of the near-stream terrain surface and vegetation, relying on the criteria of:

1) Proximity to nature,

2) Suitability and diversity of living conditions for water organisms,

3) Capacity to retain water and retard its runoff.

To evaluate the actual state and previous history of a particular small stream and its catchment with special attention to their anthropogenic alterations. To propose, in general terms, the solutions of existing problems, taking into account the existing plans of the stakeholders involved.

3. Literature overview

3.1. Hydrologic cycle

Water is one of the most important components of this world and makes the life on the Earth possible. The hydrologic cycle defines the whole movement of water on the Earth (Trimble, 2008). There are some main pathways along which water on the Earth moves, one of them being the river flow.

Rivers are also important for the development of the human society. The first cultures that started to modify rivers arose in ancient Egypt, China, Mesopotamia, Greece and some other countries (Molle, 2009; Trimble, 2008). There are documents that prove their deep knowledge of the hydrologic cycle and its principles as well as recommendations for river modification so that benefits of freshwater could be extended to bigger territories (Molle, 2009). In Europe the golden age of rivers were the Middle Ages and the Early Modern Age, where scientist studied and drew maps of rivers and deepened their knowledge of the hydrologic cycle (Barrow, 1998; Molle, 2009). There are many reasons why the human kind intervenes in river channels. With the agricultural development, flood protection, land use, potable water and irrigation water needs, waste water treatment and other water demands, many rivers and water bodies were changed (Echeverria, 1989; Trimble, 2008). Another very important reason why many rivers were changed in the course of the history is the urbanization. Especially in the second half of 20th century, when the world population started to increase rapidly, many rivers were trained and modified so that cities and other inhabited areas could be safe from flooding or of simply in order to have more space for construction (Chin, 2006).

3.2. Nature conservation

Some of these many changes and interventions were not really good in the end and, therefore, reconstructions in different forms have to be done (EUR 20875, 2003;

Šlezingr, 2010). Arias (2015) names the non-compliance with nature as one of the worst illegal acts in the world.

Šlezingr (2010) in his book Revitalization of Streams defines the revitalization as a group of actions aiming to restore or to remedy natural functions of ecosystems, habitats or their groups that were harmed.

Over the history land use has changed substantially. From forests and pastures to agricultural ploughed fields and from small villages to multi-million cities. These changes had obviously profound impact on rivers and the riparian zones surrounding them. This development lead to floods as the water retention capacity of the landscape decreased. Therefore, the river restoration urges more and more (Wang et al, 1997).

In this context, a very important topic of science is to elaborate the methods that would allow us to know if the river status is good, close to nature, or not. An important group of river status indicators is the appearance, health and growth of its ecosystem. There are many ways how to measure or assess these indicators.

In highly urbanized areas it is very difficult to return the modified river channel to its original more natural state. One of the options to imitate the original flow regime of natural rivers with riffles and pools, even with artificial in-stream structures. Pretty et al (2003) confirmed that introducing these structures in the river channel is a very good practice for improving the pattern and diversity of the flow regime. It also has some positive impact on the fish habitat in the rivers.

Another topic in relation to the river restoration is its perception by the public. It can be very well done in engineering terms, but people that actually live in those areas does not need to be automatically conformed to the new project in their living environment. There may be necessity of removing agricultural areas. Junker and Buchecker (2007) showed in their study that people perceive better when the restoration gives them also more opportunity for leisure and free time activities. Very similar results were received also by McCormick and her team in their case study of the twin catchments in Auckland, New Zealand (McCormick et al., 2015). They arrived at the conclusion that public prefers natural state as it evokes health of the ecosystem.

3.3. Ecohydrology in use

As written above, well developed and healthy ecosystem is a very important quality marker of river restorations. This started to be one of the main topics after the UNESCO Vth International Hydrological Programme (IHP-V) saw the light of the world. Janauer (2002) makes it clear that with the help of ecohydrology it will be much easier for the authorities to make good decisions on changing, modelling or restoring the landscapes.

Besides, it is always positive, when more points of view are present at the instant of decision making. Batelaan and Witte (2008) finds it enriching when during a study on the wetlands of Zwarte Beek Valley many different connections between vegetation, geochemistry and groundwater were found. So the results of their study could be more objective as they proclaim.

3.4. Ecomorphology and ecohydromorphology

One of the main ecohydrological branches is ecomorphology or ecohydromorphology. Ecomorphology is combining quality of the water and biodiversity of the land as of the river and finding the optimal ecomorphological level of the water body (Matoušková, 2008). There are many methods all around the world that use ecohydromorphology as a tool and guideline for revitalization of different water bodies.

In 2000 European Union provided its countries with a directive regarding the water policy, valid for all member countries and the countries wanting to be members (European Union, 2000). The aim of the directive was mostly to protect all water bodies in Europe and prevent the worsening of their state from the consumption viewpoint as well as from the environmental viewpoint. Another reason for this directive was also to unify all hydrological programs, as the water bodies do not respect political borders. It was also intended to prevent any non-ecological use of any water body, emissions to them, floods and droughts (European Union, 2000). This led to a small revolution among hydrological and environmental scientists in the whole Europe. Many countries adopted this directive by their own legislation and added more points related to protection of land and water (Druga, 2014; Ilnicki et al., 2010b; Just, 2010; Šípek et al. 2009). Drawing on the framework directive, many new ecomorphological methods were developed or the older ones redesigned. Slovakia as a part of European Union since 1. 5. 2004 also has to follow the EU directives.

3.5. Legislation directives and ecomorphological methods

3.5.1. European Water Framework Directive 2000/60/EC

One of the main reasons of the Water Framework Directive is to unify and integrate the approach to water in the whole European Union (European Union, 2000). The member countries should maintain or develop a good state of all water bodies on their territory (European Union, 2000).

3.5.2. EN 14614

This Guidance standard for assessing the hydromorphological features of rivers was issued by the European Union in 2004 and was implemented individually by each member country. The main reason why this directive was created is to unify and put together all hydromorphological mapping methods, their evaluation and outlets (Langhammer, 2013; Matoušková, 2008)

3.5.3. EN 15843

Six years after the first Guidance EN 14614, the European Union published a new one. This guidance, in contrast to the previous one, is about determining degrees of river morphology modification (Langhammer, 2013).

3.5.4. LAWA

This group of method has its origin in Germany. The methods had been put into use before the European Water Framework Directive was published but later on were updated to comply with the new directives. There are many parameters being put under surveillance in this method, such as the flow type, erosion, river-bottom structure, flow variability and depth variability in the longitudinal and transversal profiles. The parameters of the river and riparian zone together were divided into 6 main groups (Lawa, 1999). Similarly as in other methods, the values of the parameters in each group were found via the field survey and evaluated in order to make a final appraisal (Lawa, 2000; Matoušková, 2008). Many elements of the LAWA methods served a base for preparation of the Water Framework Directive 2000/60/EC (Lawa, 1999).

3.5.5. RHS

River Habitat Survey (RHS) has been developed in the UK and Ireland. This method went through a lot of changes and updates since 1994, when it was introduced for the first time. One of the main goals of this methodology was to describe and determine the state of freshwater bodies (Environment Agency, 2003). The authors advice to look carefully for any channel modification that has occurred before the field study, as sometimes it is very hard to differentiate what is natural and what is modified. The method is based on pre-survey preparation, field survey and data analysis. This method is very complex and detailed. 500-meter channel sections are chosen, in which approximately 10 check spot-checks are at approximately 50 meter distance. Each check spot is 10 meter long. Main focus is on the bank material, bank modification, channel substrate, type of flow, channel features, bank vegetation etc. This method is used in many European and non-European countries. It is appreciated for its flexibility and applicability to different types of rivers and streams.

3.5.6. HEM

Hydroecological monitoring (HEM) method was developed by J. Langhammer in 2007. Till today the method went through two small actualizations, one in 2008 and the second one in 2013. They were not essential as the most thing that had changed were some comments from the Ministry of Environment of the Czech Republic and few other details (Langhammer, 2013). This method will be explained in a greater detail in the Materials and Methods section, as it was used in this thesis. This method was created after the European Water Framework with all the following normative acts were adopted by the Czech Republic. The HEM method looks for the hydromorphological quality of the stream by evaluating various parameters (Langhammer, 2008; Langhammer, 2013). One of the main aspects of the evaluation is to look at the modifications of the stream and its alluvial plain. There are seventeen main indicators that prove the stream bottom and stream banks quality together with the quality of the flow regime in the stream the way in which the stream and its surroundings manage flood flows.

3.5.7. EcoRivHab

This method will be also described in a greater detail in the section on Methods and Materials as this thesis is based on this method also. Basically, EcoRivHab is based on collecting all available information about the stream and the terrain mapping of the riverine area (Matoušková, 2008). The evaluation relates to the present state of the stream but also looks for a potential reference section which is also being mapped. The method as well as its outputs are consistent with the European Water Framework Directive.

3.5.8. IFIM

The instream flow incremental methodology (IFIM) was developed in the United States by various scientist on the request from the Government in the 80s of 20th century (Stalnaker et al. 1995). This methodology, although not fully aligned with the European Water Framework Directive for Water 2000/60/EC, is used in many European countries and then, of course, worldwide. This is mostly because the biota is a very good river health indicator from many points of view. The main issue of this method is to measure the environmental impact (Stalnaker et al. 1995). The main topics that IFIM is studying are the river bottom and river-bed, the stream network, the macro, meso and micro-scale patterns of climate, geology, land use and vegetation, runoff, floods, water temperature and composition, channel geometry and other factors. The output of this method is the habitat suitability curve (HSC), for which many of the above mentioned indicators need to be quantified, as they may have a large influence on the curve (Macura et al., 2012). There are some critics to this method as many scientist say that there is no proven correlation between the actual fish presence and their potential presence, especially in waters which have different temperatures (Mathur et al., 1985; Scott and Shirvell, 1987).

3.5.9. MHR

Methodology for hydromorphological river survey (MHR method) was developed in Poland by Piotr Ilnicki and his collaborators. The method is mostly applicable for artificial (modified) rivers but also for other water bodies (Ilnicki et al., 2011). This method uses five different classes to evaluate the status of the water body and four ecological potential classes where the most ecological status is defined as the status that had most probably occurred in the first half of the 20th century (Ilnicki et al., 2010a; Ilnicki et al. 2010b). These four ecological classes break down into nineteen subclasses and other thirty four branches (Ilnicki et al., 2011). The mean features that MHR methodology is focused on are the water flow and its characteristics, its connection to groundwater, the presence of dams, the longitudinal profile, the cross section, the river-bottom structure, the riparian zone vegetation, the alluvial plain, the land use and flood control features (Ilnicki et al., 2010a).

3.6. River Revitalizations

Once the river was already assessed and the main ecohydrological issues identified there should be created a health program for the water body. There are many attitudes on the river restorations topic, as well as many opinions about what and how is the best way to revitalize the river. This is understandable as each geographical region has its exact specifications and requirements. Macura and Halaj (2013) confirm that it is important for each country to have more or less its own way to approach the optimal river revitalization as each country depends on its own geographical and geomorphological properties. There are similar properties for many countries, but they are never entirely the same. Therefore there can be a common understanding, but the final reach is very specific. Additionally, Macura and Izakovičová (2000) set the example in which for Slovakian rivers it is good to take inspiration from the revitalization methods done in alpine region but it is essential to apply them correctly to Slovak real properties. Also, there are many issues complicating the process of river revitalization. One of them is the relative distance between ecology and hydrology and sometimes it is hard for scientists to find a common word (Macura and Izakovičová, 2000).

In Slovakia region the main issue why the rivers needs revitalization is that in the past the rivers were well technically modified but the ecological aspects were highly omitted. Also, the practical realization was many times blurry and till nowadays there is still missing the ultimate goal on what we want to reach when modifying or revitalizing a water body (Macura and Halaj, 2013).

Macura and Izakovičová (2000) defines the revitalization as escalating the quality of the stream by maintaining its function. This is a very long process as the revitalization takes years and the consolidation comes at least after one or two years (Macura and Izakovičová, 2000). Even though in Slovakia some revitalization processes started to be carried out, it used to happen that the physical properties were prioritized over the biological, obtaining results that were not always so optimal. As Macura and Halaj says

(2013), the ecological stability correlates with the biological species diversity of the environments but this one correlates with the abiotic factors as well. Another very important aim that should be followed is that a good and successful revitalization should achieve a higher total moisture regime of the soil during the flood season (Macura Izakovičová, 2000). In fact, there are many criterions that are very important to take in count for the stream to be in equilibrium with its surroundings (Neruda et al., 2012).

The main topics when thinking about revitalizing a water body are the stream-bottom depth, the curved trajectory, rugged river-bottom, protection of the river-banks against erosion, lowering of water over-heat and increasing the riparian belt vegetation presence (Hughes and Rood, 2003; Just, 2010; Lusk et al., 2003; Neruda et al., 2012; Macura and Halaj, 2013; Macura and Izakovičová, 2000). One of the things that Just (2010) recommends is to make the stream more open and free from the previous purely technical flood protection adjustments.

4. Materials and Methods

4.1. EcoRivHab

This method was created by RNDr. Milada Matoušková PhD at the Faculty of Science, Charles University in Prague. The method follows the principles of the European Water Framework Directive 2000/60/EC-. It is applicable to a relatively broad selection of streams and relief types (Matoušková, 2008). The main purpose of this method is to ascertain to which extent a particular stream is in a "good ecological state" and also to find the best way for the stream to keep its natural state even in urbanized areas. The way of doing this is to define a "reference state" to which particular reaches of a stream could be compared and which could provide inspiration for restoration of these streams. The main features to be taken into consideration are hydromorphological characteristics, human modifications, diversity of flow, habitats and vegetation in the river bed zone, the riparian belt and the alluvial plain, the land use in the latter and other ecohydrological characteristics of the area (Matoušková, 2008).

The stream evaluation procedure according to the EcoRivHab method is divided into particular stages- Each of these stages are equally important for obtaining optimal results of the survey. The first stage is preparatory, when all kinds of accessible documents about the area need to be collected and the area is described based on this documentation. The second stage is to survey the stream in the field. Next stage, the third one, aims to process all the information obtained and to carefully check the results of the mapping. The last phase is to synthesize the results and to present the outcomes in the form of texts, maps and geodatabases.

4.1.1. Preparatory phase

In this phase all the available documents needs to be collected, especially all kinds of maps of the command area and its surroundings. If possible, it is recommended to combine topographic maps, water management maps, geologic, pedologic, vegetational and cadastral maps together as GIS layers (Matoušková, 2008). The author of the method also recommends to collect photos and all other documents regarding the modifications of the stream during the history, as well as the information regarding the climate, water quality, pollution of the area, industry and other factors.

4.1.2. Mapping phase

In the second part of the work, which is the field survey, there are many variables to be taken into consideration. The riverine landscape to be surveyed breaks down into the river-bed zone, both the part which lies under water and the other part which is normally above water, i.e. the river-bank, then the riparian belt, which is a belt about 10 to 15 meter wide, and the alluvial plain zone that sometimes it is very difficult to identify but should reach to around 100 meter distance from the stream (Matoušková, 2008).

The mapping itself should be done along the whole stream length, starting from the spring and proceeding towards the river mouth or confluence with another stream. The total stream length is to be divided into smaller, relative homogeneous sections, ideally about 200 to 1000 meter long. Each section must well described and marked on the supporting maps and in the mapping form in a clear and understandable way, to prevent mistakes and errors.

The mapping form is crucial in this phase as it reminds the surveyor which information should be noted down. There are three main groups of parameters comprising seventeen different aspects and together thirty one parameters. The parameters are evaluated in two diverse ways, first verbally and then as a score from 1 to 5, numerically or symbolically.

EcoRivHab: Ecomorphological monitoring of water streams sheet	
Data characteristics	Data evaluation
1. Streambed morphology and river path	
1.1 Valley type	Verbal
1.2 River curvature	Verbally & score

1.3 River bed shape	Score
1.4 River bed depth	Score
1.5 Erosion and accumulation features present	Score
2. Longitudinal profile	
2.1 Weir presence	Score
2.2 Pipes presence	Score
2.3 Flow characteristics	Score
2.4 Riffles and pools	Score
2.5 Runoff characteristics	Score
3. Transversal profile	
3.1 Profile type	Score
3.2 Average depth	Numerical
3.3 Width variability	Score
3.4 Technical adjustment of the profile	Score
4. River-bottom structures	
4.1 Substrate	Verbal
4.2 Technical adjustment of the bottom	Score
4.3 Microhabitats	Score
5. River-bank structures	
5.1 Vegetation	Score
5.2 Structure of vegetation	Score
5.3 Technical adjustment of the banks	Score
5.4 Bank stability	Score
6. Water quality	
6.1 Hydrochemical	Score
6.2 Hydrobiological	Score
6.3 Waste water outlets	Numerical

7. Riparian belt	
7.1 Presence (within 10m width)	Score
7.2 Vegetation	Score
7.3 Land use	Score
8. Alluvial plane	
8.1 Dominant land use type	Score
8.2 Presence of flood control measures	Score
8.3 Water retention potential	Score

Table 1. EcoRivHab: Ecomorphological monitoring of water streams sheet (Matoušková, personal communication; adapted by the author of the thesis)

4.1.3. Processing phase

The parameters are evaluated in two diverse ways, verbally and numerically. Some parameters are included for providing a background qualitative information. The scoring of some parameters is based on the worst situation found, in other case the dominant situation or the average level of the parameter decides.

4.1.4. Evaluation phase

All the information obtained needs to be interpreted in a correct and comprehensible way. A verbal evaluation of each section and each zone of the section has to be formulated. Another output is graphical, in the form of maps for each section and for the whole stream. Five ecomorphological grades (EG) are possible, namely: Ith EG – the natural state, IIth EG - slight anthropogenic modification, IIIth EG - medium anthropogenic modification, IVth EG - strong anthropogenic modification, and Vth EG - very strong anthropogenic modification (Matoušková, 2008).

4.2. HEM

The HEM method was created by Assoc. Prof. Jakub Langhammer, Ph.D., at the Faculty of Science, Charles University in Prague. This method is also based on the European Water Framework Directive ES 2000/60/ES. Its main objective is to evaluate the stream according to its hydromorphological characteristics with due regard to the requirements of Czech legislative (Langhammer, 2013).

The procedure is similar to that followed by EcoRivHab. It is based on scoring of different parameters of ecomorphological quality of the stream. There are seventeen different parameters divided into three main groups, namely, the river bed, the riverbanks and the flood zone.

4.2.1. Preparatory phase

For the preparatory phase it is essential to identify the water body, both the stream and its alluvial plain. The author recommends to collect all possible data from historical maps, army maps and cadaster maps but also the data on hydraulic properties of the stream, the land use and the existing structures in the alluvial plain, the river bank modifications and other circumstances (Langhammer, 2013).

4.2.2. Mapping phase

The stream is divided into smaller homogeneous sections. The main point of view on which one can base the division of the stream into sections are the horizontal projection of the stream (i.e., the plan view), the riparian belt and alluvial plain land use and the anthropogenic modifications of the stream. Regarding the lengths of the sections, the author of the method recommends to use common sense. A rough rule is that the sections of small streams not wider than 10 meters should be about 100 meter long, the sections of middle sized streams with the width up to 30 meters should be about 500 meter long and the large streams, the width of which is more than 30 meters, have a recommended section length 1000 meters. This is, of course, only a recommendation. The decisive factors are the relief of the valley and human modifications of the alluvial plain. The actual sections can be longer or shorter, depending on the current situation. The mapping should be done when the stream discharge allows to see and describe all properties of the river-banks and river-bed and when the access to the stream is not obstructed by vegetation. All observations and measurements needs to be put in the mapping sheet immediately together with the borders of the section. For the field mapping survey, it is recommended to use GPS, a range-finder and a camera to be able to document all properties of the stream sections properly.

HEM - Hydromorphological monitoring - mapping sheet			
Name of the river			
ID			
Length (m)			
Geometrical characteristics of the section			
Section borders	river km	coordinates X	coordinates Y
Valley type			
1. Stream path modification			
Stream type	marks of straightening	marks of revitalization	historical state
2. River-bed width variability			
2.1. River-bed width			
2.2. Water level width			
2.3. Alluvial plain width (L)			
2.4. Alluvial plain width (P)			
3. Depth variability along the longitudinal profile			
4. Depth variability in the transversal profile			
5. River-bottom substrate			
6. River-bottom modification			
7. Dead wood in the river-bed			
8. River-bottom structures			

9. Flow character			
10. Hydrological regime modification			
11. River-bed longitudinal throughput			
12. River-bank modification			
13. River-bank vegetation			
14. Riparian belt use			
15. Alluvial plane use			
16. Flood plain throughput			
17. River-bank stability and lateral river-bed movement			

Table 2. HEM: Hydromorphological monitoring of water streams arch (Langhammer, 2013; adjusted by the author of the thesis)

4.2.3. Evaluation phase

The evaluation is based on the score assessment of all the above mentioned parameters. First of all, each section is evaluated and then its score among other sections is calculated, from which the total score of the stream is obtained.

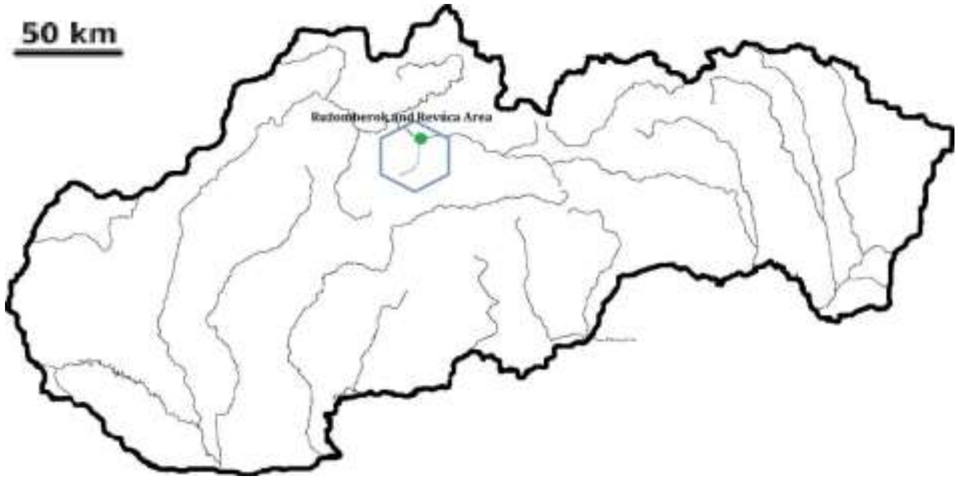
HEM Scoring System	weight
River-bed and stream path	2.6
1. Stream path modification	1
2. River-bed width variability (rate max/min)	0.1
3. Depth variability along the longitudinal profile	0.1
4. Depth variability in the transversal profile	0.1
5. River-bed substrate	0.1

6. River-bed modification	0.25
7. Dead wood in river-bed	0.1
8. River-bed structures	0.15
9. Flow character	0.1
10. Hydrological regime modification	0.1
11. River-bed longitudinal throughput	0.5
River-bank and riparian belt	0.8
12. River-bank modification	0.25
13. River-bank vegetation	0.15
14. Riparian belt use	0.4
Alluvial plain and floodplain	0.6
15. Alluvial plain use	0.3
16. Flood plain throughput	0.15
17. River-bank stability and lateral river-bed movement	0.15

Table 3. HEM scoring weights for highland rivers (Langhammer, 2013; processed by the author)

The total score allows to evaluate the stream as a whole, acquiring values from 1 (the best) to 5 (the worst).

4.3. The Revúca River characteristics



Picture 1. Ružomberok and Revúca River within Slovakia (Open Street Map, processed by the author)

The Revúca is a relatively small river located in the northern Slovakia in the Liptov region. It creates a natural border between two different natural parks. The catchment area of the Revúca River is 265, 73 km^2. For this river it is very typical to carry gravel, which contributes to dynamic stability of its bed. Forest covers 60% of the catchment area. The official length of the river in the hydrological database is 32, 33 km. The total length of the river that has been used for the purpose of this work is 33, 34 km. There are some structures on the river which locally change its discharge and water temperature. These are three hydro-power stations and one fishery. There are also several waste water treatment plants that may deliver pollution into the river. The average annual precipitation in the catchment is 711mm but it strongly varies with altitude. The catchment area belongs to humid, slightly-cold to slightly warm climatic zone. Snowpack is present for 140 to 200 days in a year.

Catchment area	265.73 km^2
Shape coefficients (area/length squared)	0.22
Stream spring altitude	1590 m

Stream end altitude in the Váh River	472.9 m
Average stream slope	7.60%
Catchment order	4-21-02
Q_a (mean annual discharge)	5.5 m^3/s
Q_5 (5-year peak discharge)	53 m^3/s
Q_{100} (100-year peak discharge)	110 m^3/s

Table 4. Basic hydrological characteristics of the Revúca River

The discharges Q_a, Q_5 and Q_{100} relate to the whole catchment area of 265.73 km^2.

The average annual temperature of water in the last five years was 7, 1°C with the maximum of 15, 6 °C in July 2012 and minimum 0, 0°C in winter 2011/ 2012.These values were obtained at the hydrological station in Podsuchá, where the mean annual discharge in the last five years was 4, 02 m^3/s. The minimal discharge in the last five years in Podsuchá was 1, 07 m3/s in winter months of 2012 (January and February) and the maximum discharge 22, 51 m3/s was measured in April 2013.

4.3.1. Tributaries

There are more than 40 tributaries of different size to the Revúca River. The main ones are listed in the table below.

The Revúca river kilometer	from the side	Tributary name
26.315	Left	Zelený potok
26.18	Right	Šturec
25.46	Left	Pilná
25.255	Right	Koleso
24.63	left	Malá Turecká
23.395	left	Veľká Turecká

22.735	left	Veľká Rakytová
22.005	left	Malá Rakytová
21.43	right	Veľký Hričkov
20.51	right	Malý Hričkov
19.68	right	Špatná Dolina
19.155	left	Teplá dolina
18.19	left	Skalné
16.675	right	Korytnica
16.515	right	Lužnianka
15.615	left	Hlinová
14.49	left	Šafárka
14.3	right	Hlaváčsky potok
13.08	right	Vyšné Tiché
12.61	left	Sojkovo
11.8	left	Zajačka
11.35	left	Matejkovo
10.95	right	Vyšný Brankov
10.9	right	Nižný Brankov
6.85	left	Trlenský

Table 5. Main tributaries to the Revúca River

The main 25 tributaries contributes with their different discharges that depend on the actual weather and hydrological conditions. The largest tributaries are mineral spring rich in Fe^{2+} Korytnica and Lužianka.

4.3.2. Water quality

The Revúca River, lying between two national nature parks which are highly protected is considered to be a very clean and well maintained water body. A recent water quality study investigated water samples taken from Revúca River close to the fishery at

Podsuchá. The samples were taken on 6th February 2017. The water quality class was I as for enterococcus and inorganic micro pollutants (arsenic, cadmium, lead and mercury). The water quality class was II as for coliform bacteria and thermotolerant coliform bacteria and class III as for psychrophilic bacteria. The quality obviously changes with the season and over the years. When a similar was done in 2016, the overall water quality class I.

4.3.3. Historical approach

The traces of first pre-historical settlements of the *Homo sapiens neanderthalensis* along the Revúca River date back to 130 000-90 000 B.C. Archaeologic excavations also discover later settlements of *Homo sapiens sapiens* from around 40 000B.C. (Struhár, 2009). The area was densely populated as there was a lot of thermal water springs there and the average air temperature during the glacial periods was around 0°C to 3°C (Struhár, 2009). There are many archeological founds in the area, as it is rich in caves. There are many written documents witnessing about the settlement of the Ružomberok area starting around the twelfth and thirteenth century (Struhár, 2009). Revúca River was used to transport wood and different other goods. In historic maps we can see that there was an extensive construction activity along the downstream reaches of the Revúca River around 1946, right after the Second World War (Slezáková, 1989). As there had been many floods over the history. A new channel was built to conduct the river water close to its end into the River Váh. This big construction changed the river channel substantially. Before it used to be more branched and rugged.

Another factor that changed the river flow and morphology over the history was the land use in the catchment. In the past, the most of the land was used as pastures or natural meadows for goats, cows and sheep. Recently, large areas have been turned to ploughed fields where different crops, including potatoes and corn (maize), are grown. Thereby the water retention capacity of the landscape has been reduced and the runoff during the high flow periods has become quicker, as the water is rapidly drained down to the

River Váh (Slezáková, 1989). This effect was further enhanced by deforestation. Old trees over 80 years have been cut down on a large scale, sometimes unfortunately also younger trees have been cut together with them. Hence, the root system of the forest is not yet well developed because of lack of time for growth. Water retention of the forest is therefore reduced decreases as well. Some mountain slopes that used to be well covered by the forests are now turned to meadows or small forest nurseries for the fast growing forestry business. The long-term average runoff has decreased over the years of the twentieth and the twenty-first century (Slezáková, 1989).

The ecosystem protection in the Revúca River catchment is also an important issue. The natural pattern of wild animal species that live in this area was and is being changed over the last two centuries. Disproportions are evident and increasing. For example, some of the animals are protected by law on the pretext that they are disappearing, but there is no evidence of their disappearance. Their real numbers in the area are not known and their actual influence on the whole nature and the biota composition is overlooked. Regarding the Revúca River, in particular, there is an overpopulation of otter which plunders the fish population in water bodies. The otter can be a good marker of a healthy ecosystem, but this does not apply in this case, as in the Revúca River the fish population is being replenished artificially.

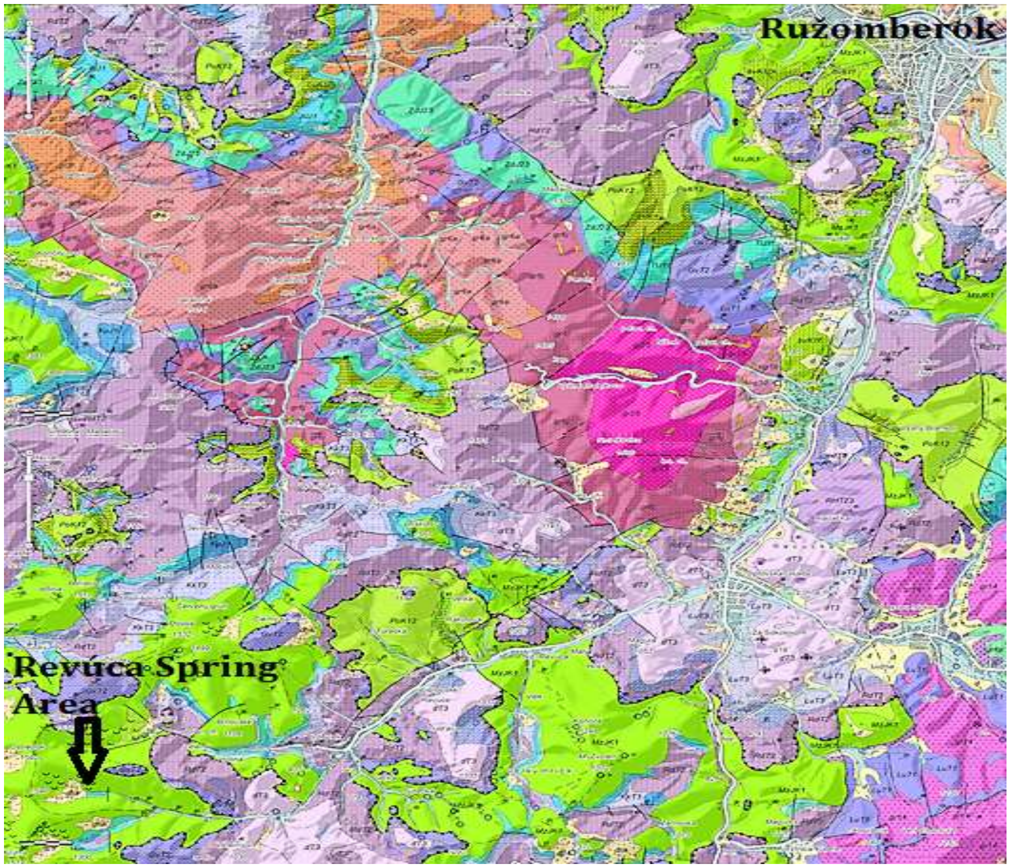
4.3.4. Fauna and Flora

The fauna living in the stream are mostly salmonid species (*Salmonidae*) as Rainbow trout (*Oncorhynchus mykiss*), Brown trout (*Salmo trutta*) and Grayling (*Thymallus thymallus*). Another common fish species is Alpine Bullhead (*Cottus poecilopus*) from the sculpins group (*Cottidae*). From bird species, the most common are Ardea (*Ardeinae*), Lesser Spotted Eagle (*Clanga pomarina*), Black Stork (*Ciconia nigra*), Owl (Bubo bubo), Eurasian Jay (*Garrulus glandarius*) and Common Kingfisher (*Alcedo atthis*). From mammal species, there are the biggest European beast Brown Bear (*Ursus arctos*), Grey Wolf (*Canis lupus*), Lynx (*Lynx lynx*), Red Deer (*Cervus elaphus*), Otter (*Lutra lutra*), European Hare (*Lepus europaeus)*, Common Viper (*Vipera berus*), fire salamander (*Salamandra salamandra), Carpathian Newt (Triturus montandoni*) and many kinds of butterflies, spiders and other insects.

Flora is also very rich. The main species are Daisy (*Bellis*), Cowslip (*Primula Veris*), Crocus (*Crocus heuffelianus*), Calamint (*Calamintha Alpina*), Slovak Pasque Flower (*Pulsatilla slavica*) and many others. The forests are mostly coniferous (65%), mixed (25%) and leafy (10%). As per species, the most occurring are spruce and pine, beech, oak, whitethorn, rowanberry, blueberry and blackthorn (*Prunus spinosa*).

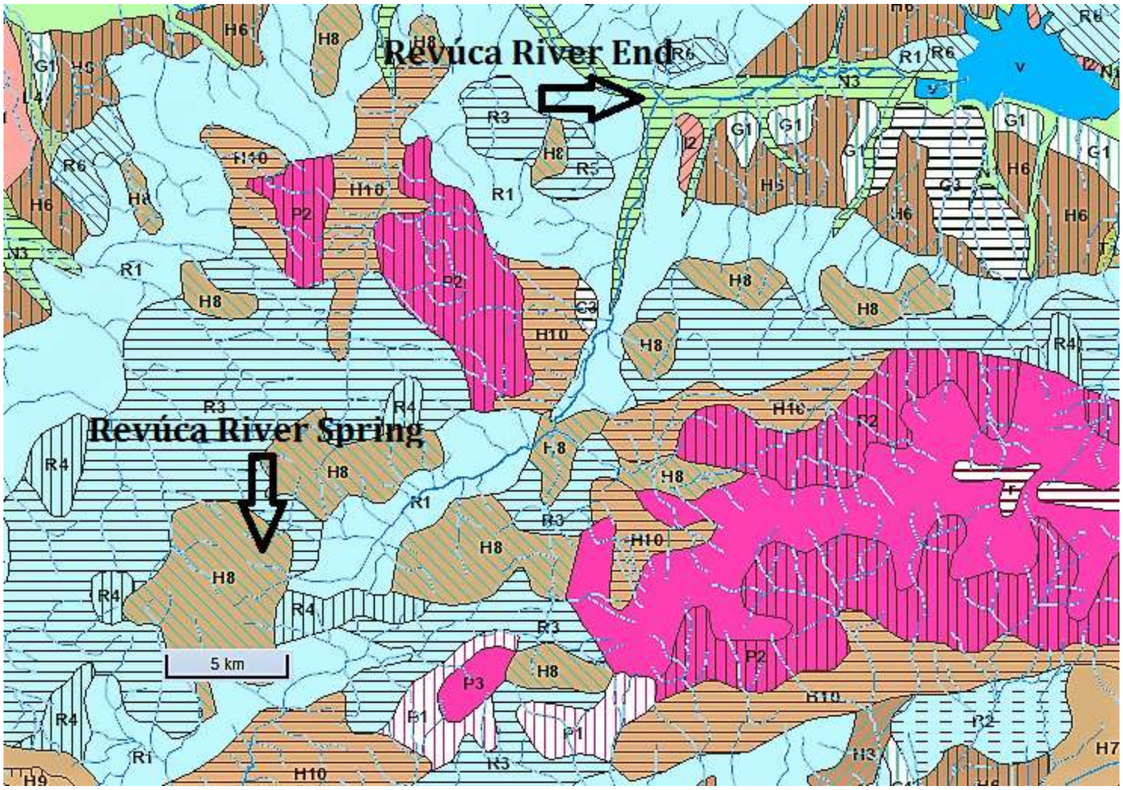
4.3.5. Geology and pedology

Revúca River area is formed by central Carpathian Paleogene sediments that are covered by quaternary sediments (Novodomec, 2006). The composition is therefore by paleogeneous sandstones and flysch shales covered by mesozoic dolomites and limestones (Hók et al., 2001). The area is also neotectonic with some distinctive cracks with infiltration areas and mineral springs that are typical for crystalline complex (Novodomec, 2006). The whole area is underlain by limestone and sandstone geological group. There is a very rich composition in the kinds of lime stone that can be found in the area. The main groups of geological underlier as shown in the map are shale, different kinds of schists, dolomites, keuper limestone, binary granites, orthogneiss chemical-organogeneous sediments, guttenstein limestone, marlyslate, marlstone, piedmont deposits and deluvial sediments. A very interesting and beautiful part of the Revúcke Valley is approximately 10 km travertine area. This unique place is one of the biggest travertine area in Slovakia. Unfortunately this zone was highly destructed by human activities during the last century (Novodomec, 2006).



Picture 2. Geology of the Revúca River area (geology.sk, processed by the author)

Among soils as showed on the picture below there are mostly cambisols (the H group), rendzic soils (group R), podzols (group P), luvisols (group I), chernozems (group C), fluvisols (group N), mollic fluvisols (group L) and luvisolic planosols (group G). These soils have a relative small production capacity of Tatra – Fatra zone (Slezaková, 1989). The average amount of hummus in medium quality is 100-200 t/ha.



Picture 3. Pedologic map of the Revúca River area (Geoportal SK, processed by the author)

The National Agriculture and Food Centre with its Soil Science and Conservation Research Institute published on their web page the soil composition of agricultural soils. For Ružomberok area there is steep hill with 18, 32% that is not counted and then 38, 13% cambisols, 31% rendzic soils, 9, 41% fluvisols, 1, 32% albic luvisols and less than 1% per each planosols, histosols, leptosols, gley soils, arenosols and podzols (Soil Science and Conservation Research Institute, podnemapy.sk).

4.4. AutoCAD and Infraworks 360

The author of this thesis used the AutoCAD Civil 3D 2017 in a free student version. It has been used especially for modelling of the final revitalization project.

4.5. GIS

The author used the QGIS 2.18.2 Las Palmas available free from the internet. It has been used for processing various maps as base documentation and for this work.

5. Results

Picture 4. Water management map of the Revúca River with the location of the spring marked (Slovak Water Management Office, processed by the author)

5.1. EcoRivHab

The field survey of the Revúca River ecomorphology, based on the EcoRivHab method by Matoušková 2008), was done from August to December 2016 with the aim to assess the selected reaches of the Revúca River. The field survey period was relatively long, as the discharge was changing and the author of this thesis wanted to make a more comprehensive survey comprising both the high flow and low flow situations. The river was divided into seven relatively homogenous sections. The division of the stream into sections was done before the field survey mapping and its correctness was confirmed during the actual mapping.

Name of the stream	Total length (km)	Number of sections	Average section length (m)	Maximum section length (m)	Minimum section length (m)
Revúca	33.43	7	4775.71	7820 (RE06)	1780 (RE07)

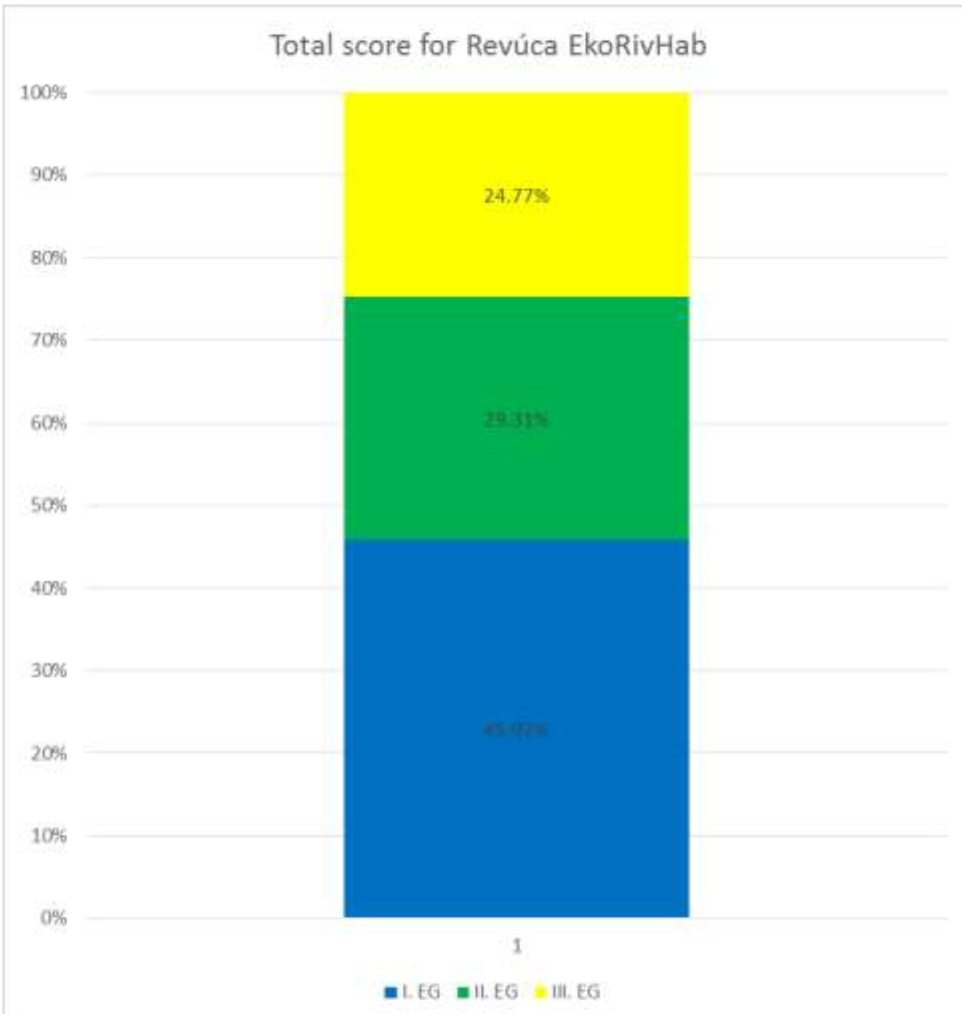
Table 6. Overview of the EcoRivHab sections

The sections were labeled as advised by the author of the method. Each section's name is composed of two parts. One is alphabetical, containing two capital letters taken from the name of the water body (in this case RE stands for Revúca), while the other part is numerical, representing the section location order, starting from the river spring and ending with the stream section joining the River Váh, so from 01 till 07.

Section	Downstream end (river km)	Upstream end (river km)	Section length (m)	Cartographic coordinates			
				X (DE)	Y (DE)	X (UE)	Y (UB)
RE01	27.1	33.43	6330	-415436	-1210276	-420894	-1210856
RE02	20.6	27.1	6500	-410804	-1206892	-415436	-1210276
RE03	17.73	20.6	2870	-408374	-1205629	-410804	-1206892
RE04	15.84	17.73	1890	-407234	-1204381	-408374	-1205629
RE05	9.6	15.84	6240	-405327	-1199365	-407234	-1204381
RE06	1.78	9.6	7820	-403565	-1192551	-405327	-1199365
RE07	0	1.78	1780	-403165	-1190843	-403565	-1192551

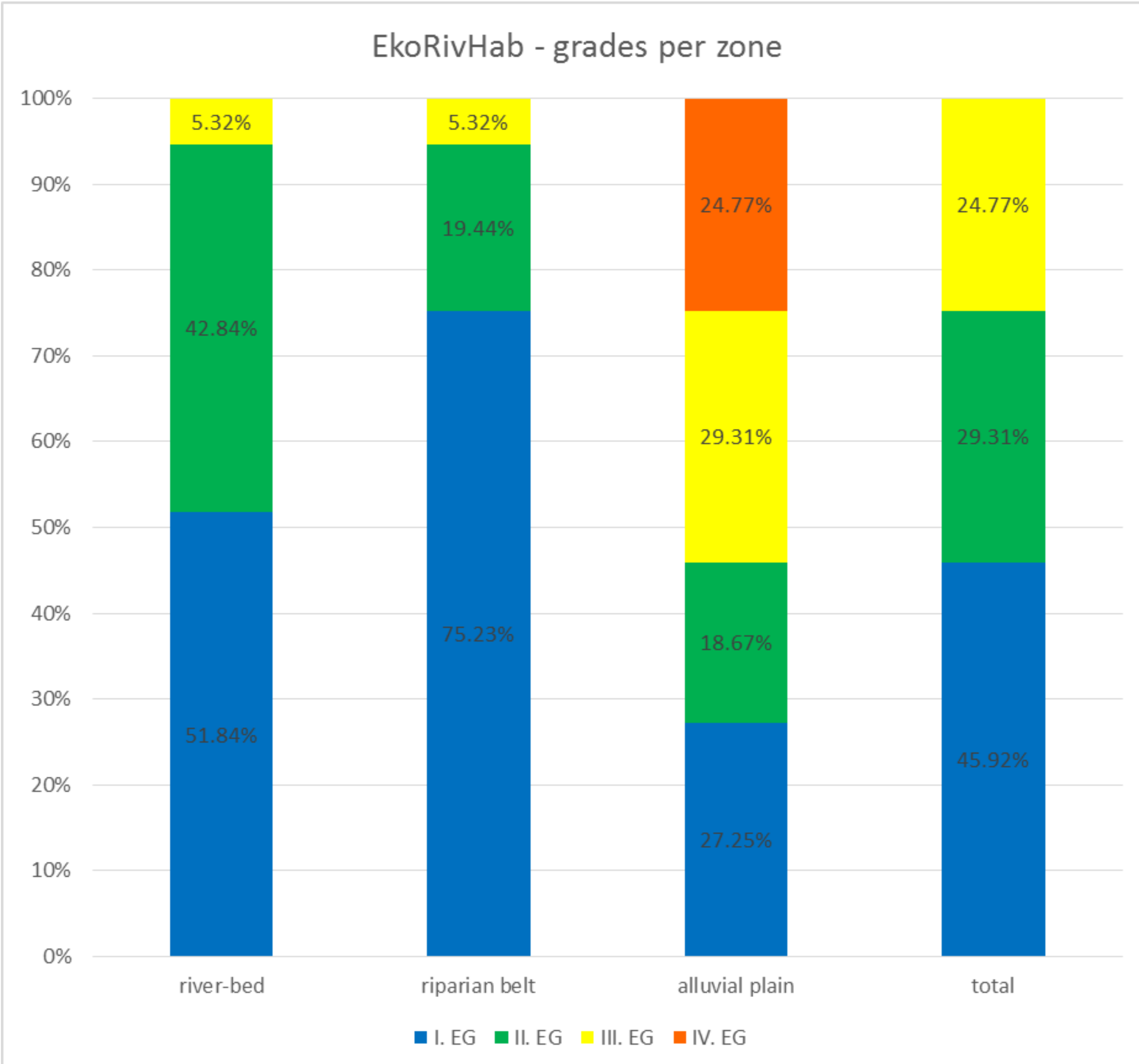
Table 7. Positions of the REcoRivHab sections in terms of river kilometers and coordinates of their ends

The number of sections is not high, and therefore their length is relatively large, because the river morphology is little differentiated. The average section length is 4775, 71 m. Althought the sections are long, they were chosen based on the criterion of their homogeneity and risk of systematic error is minimal.



Graph 1. The overall EcoRivHab ecomorphological score for the Revúca River

The total EcoRivHab ecomorphological grade of the Revúca River is II. About one half of the river length is in very good ecomorphological conditions. This means that, although there are some parts where the river needs to be restored or revitalized, the overall condition is very good and the Revúca River can be called as being only slightly anthropogenically modified, in mostly natural conditions.



Graph 2. Ecomorphological EcoRivHab grades per zones

Looking at particular zones of the landscape around the river gives somewhat different and more heterogeneous results. The riparian belt of Revúca River is the best valued one, followed by the river-bed zone. The worst rating has the alluvial plain. This was awaited as the river flows thru highly urbanized areas.

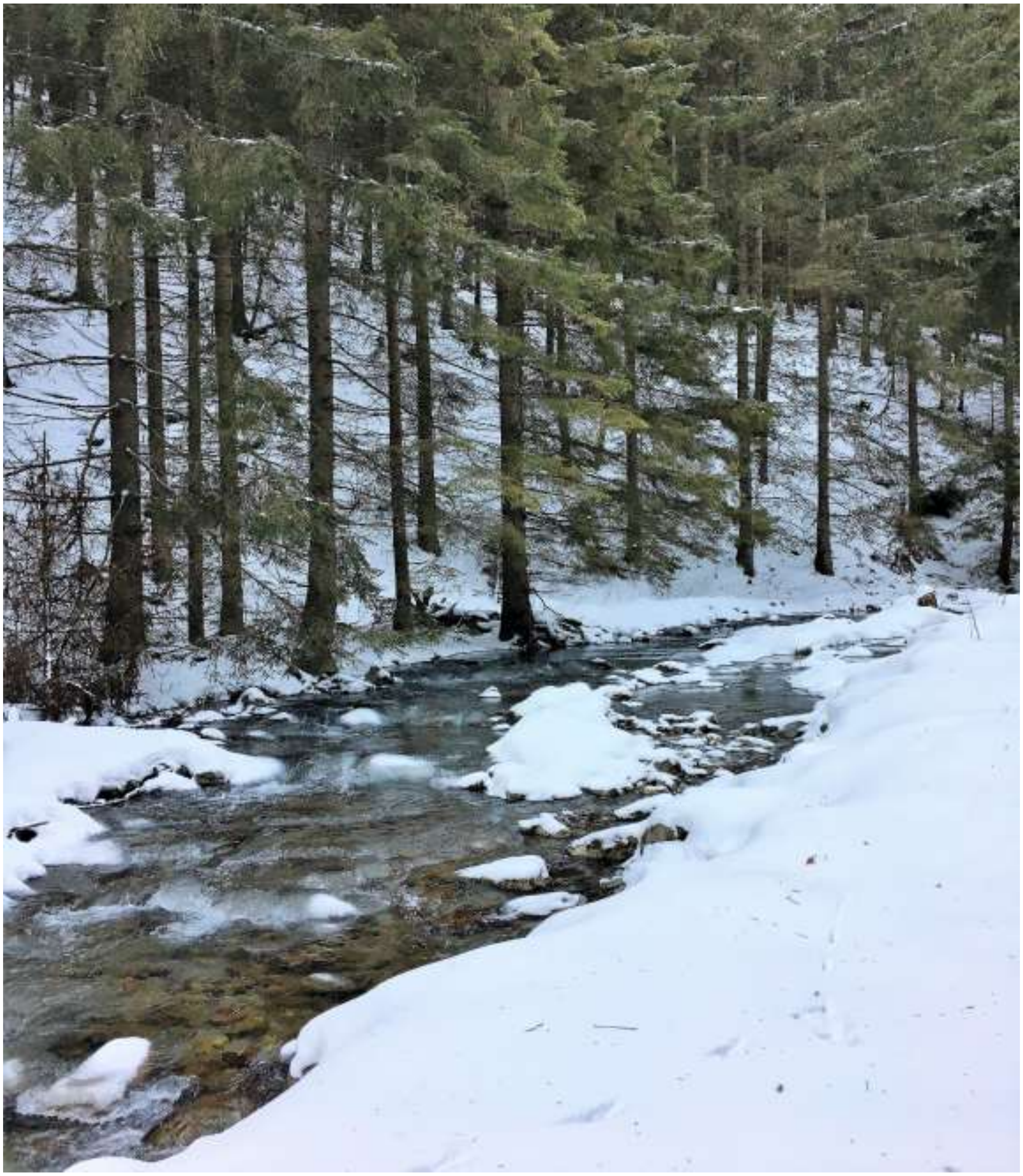
section	length (m)	river-bed	riparian belt	alluvial plain	total
RE01	6240	I.	I.	I.	I.

RE02	6500	II.	II.	IV.	III.
RE03	2870	I.	I.	I.	I.
RE04	1980	I.	I.	III.	II.
RE05	6240	I.	I.	II.	I.
RE06	7820	II.	I.	III.	II.
RE07	1780	III.	III.	IV.	III.

Table 8. Overview of the EcoRivHab ecomorphological grades per sections and zones

In this table, it is clearly visible that the main cause of worse ecomorphological assessment of the river as a whole is the alluvial plain. The river bed of the last section (RE07) with a two-meter high weir and two other smaller is assessed as not in good state. The riparian belt in this section is also receiving a worse grade. The land use around this section is highly urbanized, which affects the alluvial plain but also touches the riparian belt. The alluvial plain in the section RE02 receives IVth ecomorphological grade, as the situation there is the same as in RE07. Two sections, RE04 and RE06, also have poor graded alluvial plains (III. EG), because of their lower water retention potential (limited by flood control structures).

5.1.1. Reference section



Picture 5. RE03 Reference section

The section RE03 with an overall ecomorphological grade I was chosen as a reference section. This section finds itself in the area where the river discharge increases due to some small creeks joining the Revúca. The river is passing here through a partially urbanized area along a major communication route. However, the river-bed zone is not modified by any structures. The stream-bed is natural with gravel, cobbles and stones. There is high variability of flow along the alternating riffles and pools. The riparian belt is composed of meadows, pastures and forest. Regarding the whole alluvial plain, even though there is a road, this never comes close to the river, so that the flow is not modified. The whole valley is very nature-friendly and idyllic for its scenic views.

5.1.2. Ecomorphological evaluation per sections

Picture 6. RE01 section where cobbles sustains river-banks underneath one of the bridges

The first section RE01 starts at the very beginning of the Revúca River at its spring on the south-east hillslope of Ostredok (1592 m) as a torrent creek made out of three small streams. It quickly comes to a valley surrounded by forest, composed mostly of spruce (*Picea abies*). Rock outcrops are present both in the forest and near the stream creating natural curves. The valley has very wide bottom overgrown with small trees, fern, burdock, wild grass and other vegetation for mountain streams. The river bed width is variable. There are places where the stream looks wilder, being very narrow, and places where the river bed is wider and creates small pools. In the valley there is a mountain trail and, therefore, there are several wooden bridges crossing the creek, where the river bank is stabilized by stones and concrete. This stone fortification is partly destroyed on some places because of the stream water impact. There is a side creek there joining the Revúca stream. The tributary creek is conducted through a tube underneath a culvert over which the trail is lead. In winter, this tube becomes partly blocked by accumulated ice, broken tree branches and leaves. What happens in this case is that their lateral creek overflows the banks next to the trial and creates a small pool. On both sides of the valley there is a compact forest with some rock formations. The overall ecomorphological grade is I and is the same value for the river-bed, the riparian belt and the alluvial plain.

Picture 7. A typical concrete river-bank fortification around a bridge in the E02 section

The second section RE02 starts in Liptovské Revúce, a small but very long town alongside the still quite small Revúca River. The town layout is “Y”-shaped, where the long side lies next to the Revúca River and the other, branching part surrounds the Suchý Vrch Mountain (1550 m). The town has 3 parts called the Upper, Middle and Lower Revúce. The river, as well as the town, are located on the bottom of a valley. A part of the valley bottom is used as pastures and small fields. The Revúca River is mostly on the left side of the town. The other river bank is accompanied by forest that continues upslope in the south-east direction. The river has been partly modified by humans, mostly due to artificial river bank fortification and the stream narrowing. The river bank fortification is made of stones bound by cement mortar, so that the final look is as if it were made of concrete blocks. On some places, the water stream broke the concrete and the disintegrated stones fell inside the river, but otherwise the river-bed is not modified.

This river-bank fortification was done partly by public institutions and partly by people from the village. The fortification mostly affects the river-banks only and not the bottom of the river. Therefore the river-bed ecomorphological grade was taken as II, as well as the riparian belt. The alluvial plain consists of urbanized areas mixed with forest and meadows. Its ecomorphological grade is IV. The total ecomorphological grade for this section is therefore lower, compared to RE001, namely, grade III, as there are only small parts of the stream where the natural state is visible.

Picture 8. Typical RE03 section area in winter

In the third section RE03, which is also the reference section, the Revúca River follows the valley that has relatively wide bottom (20 – 150 m). The river is surrounded from both sides by forest, in some parts there are tree alleys. The ecomorphological grade for the riparian belt as well as for the alluvial plain is I. There is a road connecting Liptovské Revúce and Liptovská Osada with some crossings of the river via bridges, but mostly the road is placed at higher elevation, compared with the river, which flows on the bottom of the valley. In the parts, where the river is surrounded by tree alleys, the riparian belt is used as pastures with solitary trees. The river-bed is in its natural unmodified state and is rated as the Ith EG. After reaching Liptovská Osada, the river changes its direction from north-west to north. Even though there are some small river bank modification in this section, the total ecomorphological grade is I.

Picture 9. RE04 after Liptovská Osada

The fourth section RE04 lies near the Liptovská Osada village. The Revúca River does not flow through the village but along its left end. Right at the beginning of this section there is a small hydro-electric power plant. The river divides into two channels of which one conducts water to the hydro-electric station. The water flowing out of the station has a higher temperature than the rest of the river water. In here, many other small streams contribute to the river so that its discharge increases. The natural water balance of this area is disturbed as there is a ski area there with an official permission to take water directly from the river for the artificial snowing. Gladly to say, it never happened so far as the ski center is mostly closed because of the lack of visitors. At one point the river flows through a small defile where, after riffles, a small pool arose. Many people from the village enjoy jumping from the defile rocks to that pool. There is a cycling trail next to the stream as well. In the past, there used to be single-track railway leading from Ružomberok to Korytnica spas. Because of this railway, there are some parts where the river bank is created by the railway embankments, overgrown with grass. The river flows towards north now and leads straight to Ružomberok direction. There is a more frequented road next to the river. Both the road and the river follow the bottom of the Revúcke valley. This is one of the reasons why the alluvial plain ecomorphological grade was taken lower, namely III. Neither the river bed nor the river banks are much modified. Therefore, both were given the grading I. The riparian belt in this part is partly forested and partly tree alleys. There are many meadows around, pastures and small fields (where people mostly plant corn and potatoes). The overall ecomorphological grade of the section is II.

Picture 10. Section RE05 with bicycle road Cyklokorytnička

In the section RE05, the Revúca River flows in a wavy way and creates a natural border between two nature reserves, Nízke Tatry (Ďumbier, 2043 m) on the left (east) side and Veľká Fatra (Ostredok, 1596 m) on the right (west) side.. As the valley is wide, the road is not always located directly next to the river. The stream bed is not modified and flows in small curves. Its ecomorphological grade is I. In the part of Podsuchá there is small fortification of the river bank done. There is also an inlet to the gauging station for measuring the river discharge and the physical and chemical properties of water. Further downstream there is a fish company having an inlet channel from the river. This company also provides the whole river with young fish for increasing the fish populations. Depending on the stream discharge and the month, they can take in up to 1.5 m^3/s of water. As for the riparian belt, the most frequent arrangement here are tree alleys that have gone a bit wild over the years and nowadays create an almost total protecting cover of the stream. The alluvial plain is composed of some urbanized areas and a motor-highway leading toward Ružomberok. The ecomorphological grades for the riparian belt is I and for alluvial plain it is I. The total ecomorphological grade is I.

Picture 11. Historical water gate (weir) viewed from the upstream side at the beginning of the RE06 section

Next section, RE06 begins in a historical water gate (weir) with another hydro-electric power station. On the left side of the water gate, there is a water inlet for the power station. The water gate, when open, does not present a migration block. However, when the discharge is low, the gate has to be closed, so that the owner of the power station can take enough water through the turbines. There is a project in preparation for a regular fish migration path on the right side of the historical water gate. The construction should be realized in forthcoming years. Downstream of the water gate, the streambed is wider and shallower. After entering Biely Potok village, the stream becomes slightly modified, but the modified parts are not so many and the river mostly follows its natural the wavy path, the same as in previous sections. The riparian belt is typically grown over with trees or meadows, although there are parts where the river flows next to houses of Biely Potok village. Its ecomorphological rating is I. The river banks are partially fortified with stones. This fortification was done 30-40 years ago and is rarely recognizable today, as the grass, small trees and water flow remodeled the area. The river-bed as a whole is given the Ith EG. The section ends with a recently modified riparian belt, where a new playground and bicycle path have been established. The alluvial plain has a worse grade (IIIth EG), as it is a mixture of urbanized areas, gardens, highways, alleys and other similar land use types. The total ecomorphological grade of the section is II.

The last section of the Revúca River RE07 is fully modified by man, as it flows through a highly urbanized area. From historical maps it is clearly visible that the river used to be divided into more channels. Several meters after this section begins, there is another water gate (weir) with 2-meter high step. Next to the main river channel, there is a small hydrological center, where previously a hydro-electric power station was run by Slovak Water Management Office. At this point, there is also a lateral channel that ends about 50m downstream on the right side of the Revúca River. There is no fish pass at this water gate. About 200 meters downstream of the big weir there are two smaller steps built in the early 1980's. They are now naturally destroyed and flown through. No fish pass is present there, either. Streambanks are mostly fortified by big stones bound united with cement mortar, as in Liptovské Revúce. Although the river-bottom is not fortified, the stream-banks are and that is why the ecomorphological grade for this zone is III. The riparian belt quality varies; there are parts there with tree alleys and other parts fully urbanized. Its overall grade is also III. There are many small sediment bars in the river, some of them overgrown with grass and small bushes. The alluvial plain is occupied by highly urbanized areas, industrial zones and roads. This makes the grade of the alluvial pain one of the worst ones along the whole river (IV. EG). The river has stable stone-made banks but they are occasionally interrupted by staircases so that you can go to water. These were mainly made for sporting fisherman. The Revúca River joins the Váh River from the left side in a very smooth way. The overall ecomorphological grade for the section RE07 is III.

Picture 12. Two-meter high weir shortly after the beginning of RE07 section

5.2. HEM

Similarly as the EcoRivHab survey, also the HEM field survey took place from August to December 2016. The HEM and EcoRivHab mapping was done at the same time, but of course using the proper mapping sheets. The sections are marked as the author of the HEM method recommends, using with three capital letters inducing the stream name and three numbers inducing the number of the section. The first section begins at the point where the river ends by joining the recipient, in this case the River Váh. The mapping field survey description progresses against the stream flow direction. Seven river sections were evaluated, starting with REV_001 and ending with REV_007. The section lengths and boundaries were identical for both methods used. The relatively homogeneous natural conditions of the Revúca River made it possible to choose the same, relatively long, physical reaches of the river without breaching the rules of the two ecomorphological methodologies.

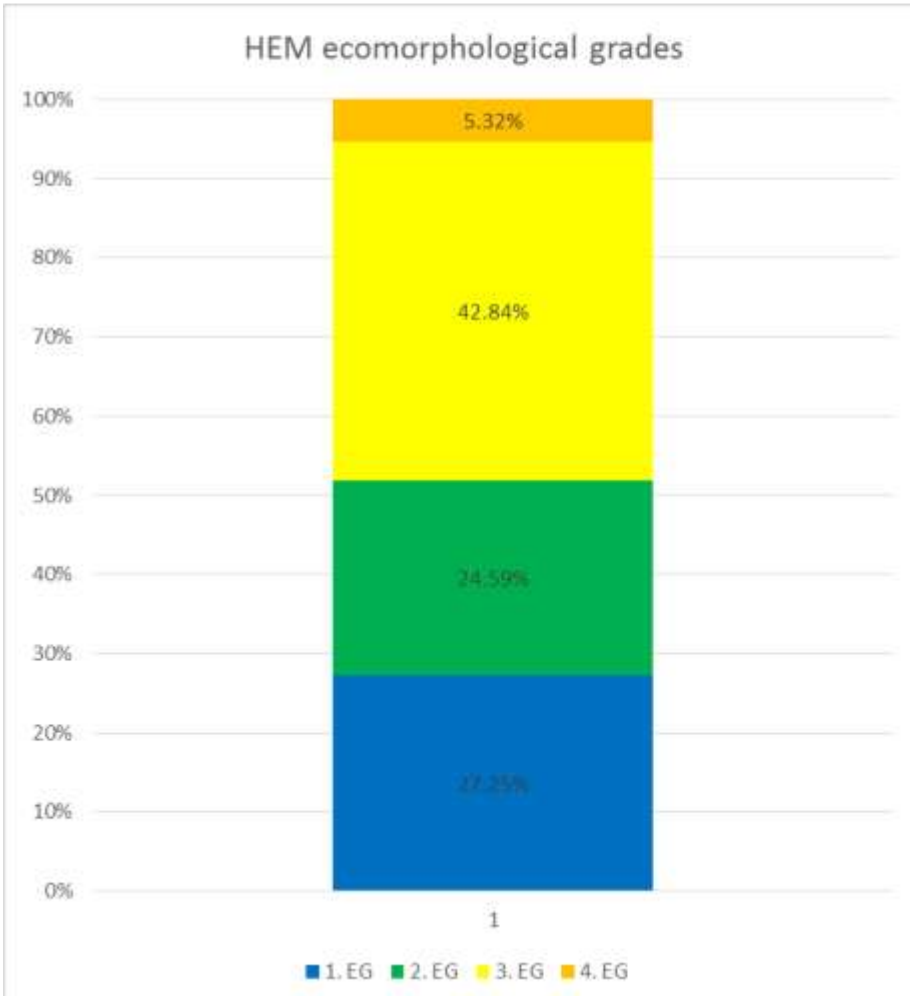
Name of the stream	Total length (km)	Number of sections	Average section length (m)	Maximum section length (m)	Minimum section length (m)
Revúca	33.43	7	4775.71	7820 (REV_002)	1780 (REV_001)

Table 9. Overview of the HEM sections

Section	Downstream end (river km)	Upstream end (river km)	Section length (m)	Cartographical coordinates			
				X (DE)	Y (DE)	X (UE)	Y (UE)
REV_001	0	1.78	1780	-403165	-1190843	-403565	-1192551
REV_002	1.78	9.6	7820	-403565	-1192551	-405327	-1199365
REV_003	9.6	15.84	6240	-405327	-1199365	-407234	-1204381
REV_004	15.84	17.73	1890	-407234	-1204381	-408374	-1205629
REV_005	17.73	20.6	2870	-408374	-1205629	-410804	-1206892

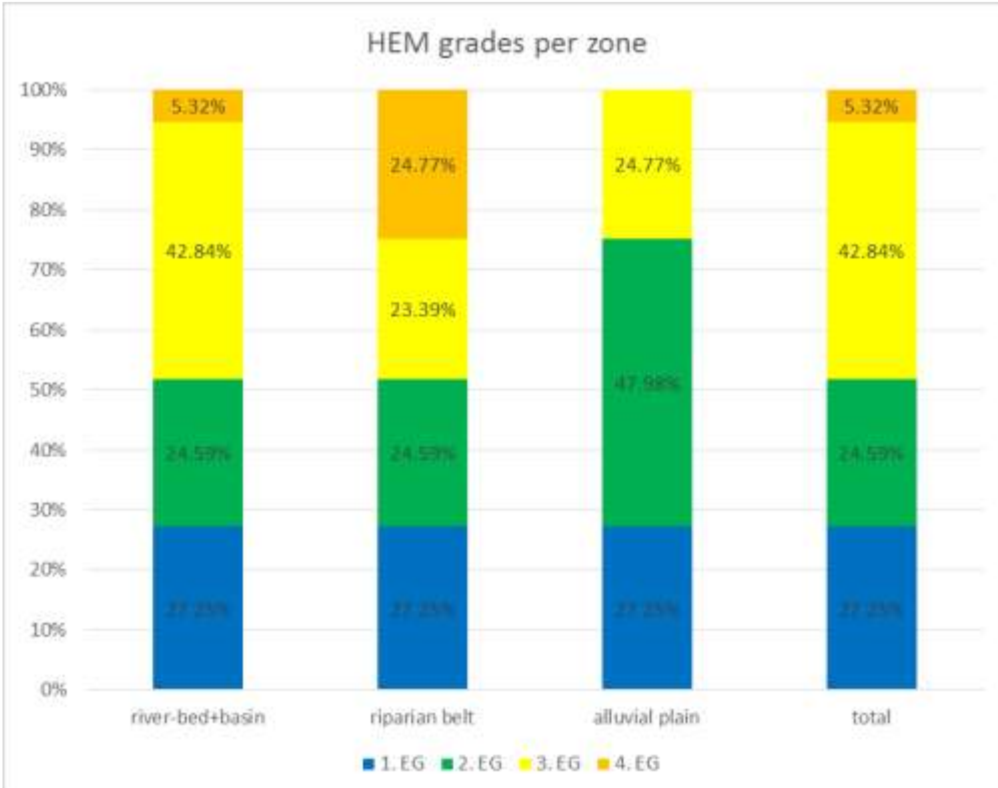
REV_006	20.6	27.1	6500	-410804	-1206892	-415436	-1210276
REV_007	27.1	33.43	6330	-415436	-1210276	-420894	-1210856

Table 10. HEM section overview with river kilometers and coordinates



Graph 3. Total score for the Revúca River using the HEM method

The total ecomorphological score using the HEM methodology is 2. EG, which is interpreted as a slightly modified river. The evaluation shows that something more than a half (51, 84%) of the Revúca River is close to nature close or in slightly modified conditions, while the rest (48, 16%) is medium or largely modified. It is a positive outcome that the largely modified part makes only 5, 32% of the total river length and not more.



Graph 4. HEM Ecomorphological grading per zones

As per particular zones the ecomorphological grades vary more. The best graded zone according to the HEM methodology is the alluvial plain. Its grading is obtained from the alluvial plain land use, the flood plain throughput and the river bank stability and its ability to move. The second best zone is the riverbed zone. Although there is some diversity in the grades of this zone, as the fourth ecomorphological grade also appears in this zone, the majority of the sections is evaluated as nature close or slightly modified grade. The riparian belt of the Revúca River is the more heterogeneous. This is also because HEM evaluates the river-bank modification as part of this zone and there are some forms of the river-bank fortification present in many sections of the Revúca River.

Section	Length (m)	river-bed + basin-basin	riparian belt	alluvial plain	total

REV_001	1780	4. EG	4. EG	3. EG	4. EG
REV_002	7820	3. EG	3. EG	2. EG	3. EG
REV_003	6240	2. EG	2. EG	2. EG	2. EG
REV_004	1980	2. EG	2. EG	2. EG	2. EG
REV_005	2870	1. EG	1. EG	1. EG	1. EG
REV_006	6500	3. EG	4. EG	3. EG	3. EG
REV_007	6240	1. EG	1. EG	1. EG	1. EG

Table 11. Overview of the HEM ecomorphological grades per sections and zones

The first section, REV_001, has an overall evaluation of 4th EG, which in verbal description means a largely modified stream. This could be expected as the Revúca River flows in this section through the city with residential houses and industrial buildings lying in high proximity to the stream. The river as a whole and especially the alluvial plain gets better in the following REV_002 section. In here all the three zones are one ecomorphological grade better than in REV_001. The river bed and river basin in REV_002, together with the riparian belt, were modified in the 1980's, but nowadays the modifications are not that visible anymore, although they are still present. The alluvial plain has better ecomorphological grade also due to the end of the city. There is a village of Biely Potok and some scattered urbanized zones in this section, but the total degree of urbanization is not as high as in REV_001. The third section, REV_003, is one of the longest sections, stretching over six kilometers. This section has the same ecomorphological grade for all zones, being classified as slightly modified. The next section is REV_004 where the Revúca River flows next and through Liptovská Osada. There are some slight modifications of the natural conditions, but they do not interfere with the river so much. The total evaluation of the section is "slightly modified", the same as in the previous section REV_003. After that, the section REV_005 follows, with its overall almost three kilometers of nature-close state and very beautiful scenic views. The section REV_006 is located in Liptovské Revúce and with its six and a half kilometer is the second longest section. There is a small step, some river-bank fortification, urbanized and industrial zones in both the riparian belt and the alluvial plain. This all leads to the 3th EG, that is, medium modified. The last section, marked as REV_007, is more than six kilometers long. This section is very similar to REV_005 as the Revúca River flows there in its natural way. The ecomorphological grade for this last section is also “nature-close”. The water in the stream comes from the forests and meadows on the Ostredok hillslope.

Picture 13. A typical view of the REV_007 section with 1th EG value according to the HEM methodology

5.3. Comparison between EcoRivHab and HEM methodologies

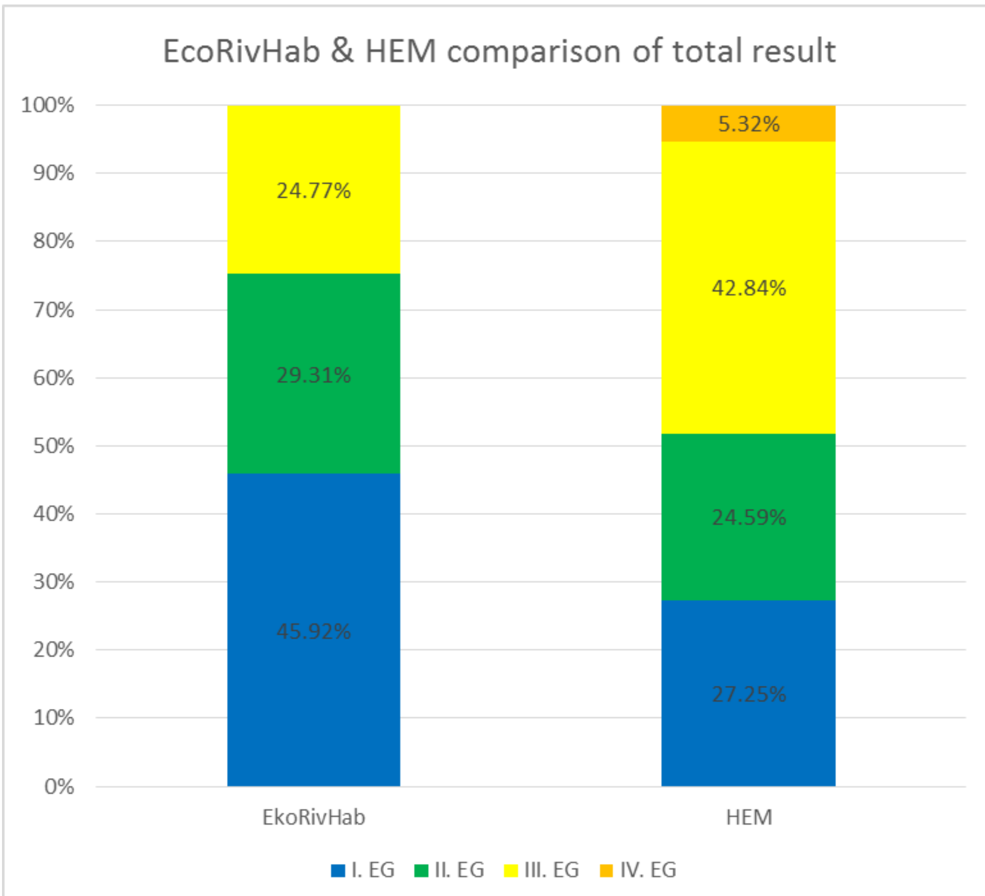
Picture 14. Revúca River (flowing underneath the bridge) joining River Váh in Ružomberok

The two methods come from the Czech Republic and have been used mostly for minor streams. There are many similarities between them, consisting especially in the fact that they are both based on the terrain mapping and field survey. However, they remain two different methodologies that differ from each other in many aspects. One of the basic differences is that the EcoRivHab progresses from the spring to the end of the stream that means walking along with its flow direction. The HEM methodology is exactly opposite in this respect as the mapping survey is done from the end of the stream up to its spring, against the water flow direction. Also the amount of parameters that are being investigated and evaluated is different in the two methods, where EcoRivHab has thirty-one and HEM seventeen parameters. Another big difference lies in the nature of the parameters chosen and the way of their evaluation. In EcoRivHab, there are three basic zones that are being evaluated. These, as already mentioned in the Methodology chapter, are the river-bed, the riparian belt and the alluvial plain. In the HEM methodology, as also already mentioned in the Methodology chapter, there are four basic zones to be evaluated, namely. The river-bed, the river-bank and the inundation zone, supplemented by the topic of water flow and hydraulic regime of the water body studied. For the grading purpose, the river-bed and the river-bottom are calculated together, so that in the end there are three zones separately evaluated. This difference makes the two methodologies to some extent incomparable, as they basically investigate similar or the same issues but from different viewpoints, evaluating different parameters and variables. The evaluation part is also specific to each of the methods. In EcoRivHab, there is a very simple calculation done based on the points that each variable has obtained during the field survey. From these points, an arithmetic mean is calculated from which it is easy to assess the final ecomorphological grades. In the HEM methodology the way of evaluation is based on the calculation per section, depending on each variable's weight multiplied by special variables that are different for different types of the stream. Having arrived at a result for particular section, the final grade can be obtained from the arithmetic mean for all four parts.

6. Discussion

6.1. Overall results

The two methods, although they are different and use diverse approaches, aim at measuring the ecomorphological status of water bodies and may give similar results. This has confirmed in the case of the Revúca River.



Graph 5. Comparison of results between the EcoRivHab and HEM methodologies

On the above graph, it is very easy to see that the results of both methodologies are different to some extent. This is mostly caused by different approaches and also by different parameters recorded. However, the final summary result of the ecomorphological grading is the same for both methods, being IIth EG.

Šmerousová and Matoušková (2011), when evaluating the River Slubice in the Czech Republic, mentioned that different ways of stream division into sections could generate differences in the final ecomorphological grades. In this thesis, this factor was eliminated by choosing the same section lengths and locations in both evaluation methods. Despite this provision, the total ecomorphological grade obtained by two different methodologies was slightly different, namely, the total grade is the same, but the percentual division varies between the two methods. These total ecomorphological grades are quite favorable, which means that the Revúca River is only slightly modified and close to nature. However, there are some parts of the river which received worse grades.

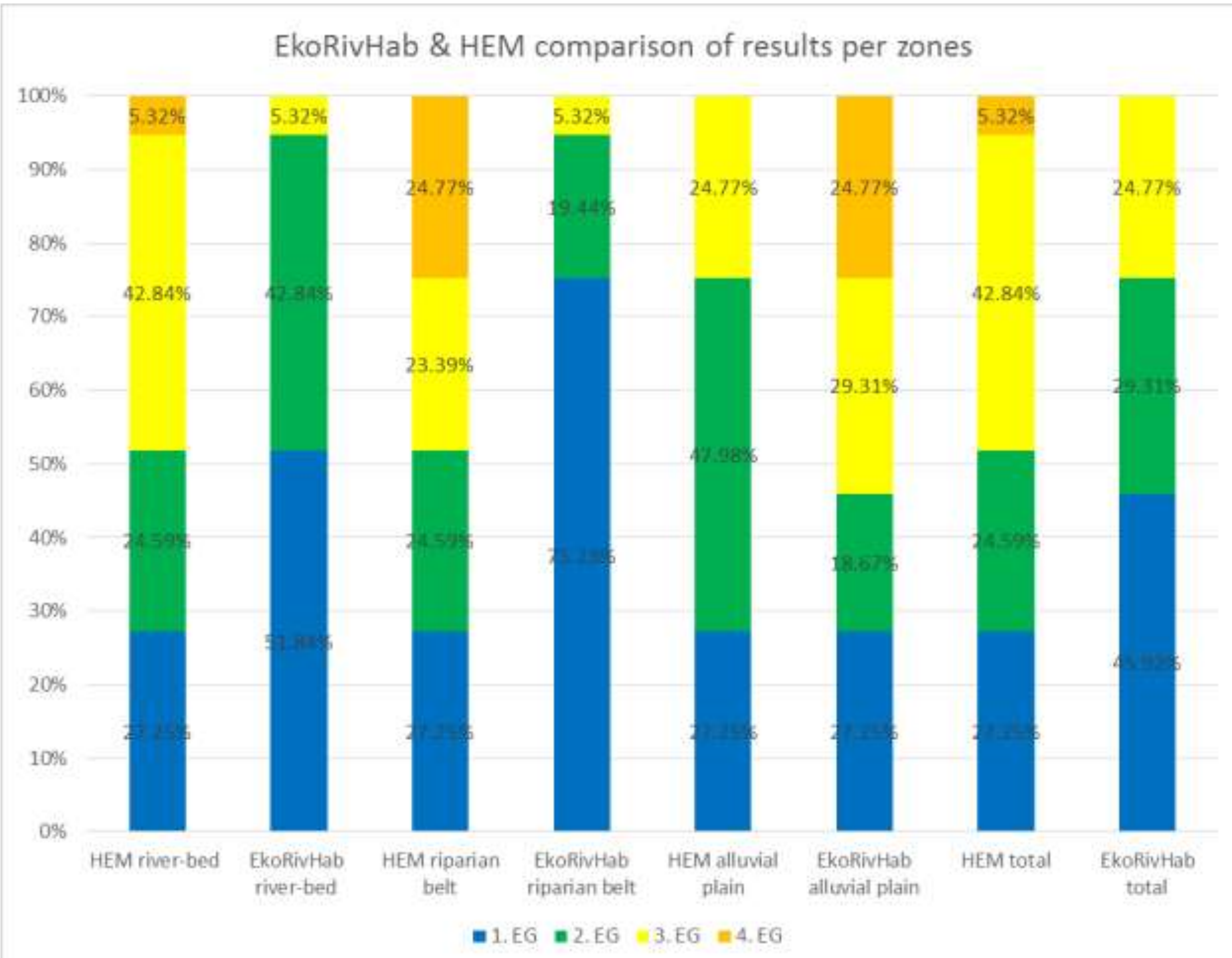
Šmerousová and Matoušková (2011) also mention other differences between the two methods. In particular, these authors say that HEM is focused on the actual state of the river and its parameters, while EcoRivHab sets forth a reference section as a model for the other sections and their future restoration. This is true, but it is very hard to follow the model of the reference section when one has to restore the sections that have been significantly modified. As for this thesis, the reference section is RE03/REV_005, which is very nature close and its ecomorphological grade is I (1). The sections RE02/REV_006 or RE07/REV_001 are impossible to revitalize to the extent that they would become like the reference RE03/REV_005 section. The alluvial plain is highly urbanized in both of the two sections and the reverse modification to its natural state is nearly or totally impossible. What could be improved in future are some riparian- zone and river-bank structures If we focus on the lower stream sections only, then we can find some parts of the section RE06/REV_002 that could be used as a good example for the RE07/REV_001 restoration. This is for example the last part of the section RE06/REV_002, where a nice riparian zone revitalization project took place. The situation is showed on the picture below.

Picture 15. Example of a partly revitalized riparian zone in RE06/REV_002 section

The difference between total HEM grade and the total EcoRivHab grade can also be due to different ways of counting and calculation of the results. The HEM methodology does not calculate the total grades as simple arithmetic means but as weighted means, depending on particular weights ascribed to particular zones and factors. Another factor that may have come into play is the internal heterogeneity of the long sections. However, the sections were quite homogenous and this effect does not seem to be relevant in our case.

Having two similar but different methodologies at hand can be regarded as an advantage, because similar results obtained by both methods indicate objectivity of evaluation. The results per zone obtained by the two methods differed more, but this may be a consequence of looking at the same river from two different angles of view and it does not speak in favor of one of the method against the other one. It is like asking two experts about the same thing; they answers are never absolutely the same. EcoRivHab and HEM complement each other and, when used together, deliver a more comprehensive information about the water body studied.

The main issues influencing the ecomorphological status of Revúca River are the absence of fish migration paths and the modifications (fortifications) of river-banks by stone and concrete, which results in the lack of river-bank mobility. As for the riparian zone, it is its total absence in some section, caused by high level of urbanization of the area or the presence of motorways near the stream. The main problems in the alluvial plain zone are urbanization, as in riparian belt and industrial buildings.



Graph 6. Comparison per zones of the two used methods

As per zones, the results vary much more than per the summary evaluation. There is especially a huge difference in terms of the riverbed and the riparian belt evaluation. It is probably due to different questions being raised by the evaluation forms and different definition of the ranks.

The seven sections of the Revúca River were chosen depending on the homogeneity of the stream and reflect the reality of the stream. The fact that the sections were chosen equal in length and location for both methods made the comparison of the results easier. In spite of this, it is very unlikely to obtain the same grading for particular section, as the two methods look at the same water-body from different points of view, and the scientific meaning of their results is therefore diverse. However, we obtained very similar results summary grade of the Revúca River (2^{th} EG).

This is a very positive overall result that means that the Revúca River, although modified in some parts, is mostly in very good or excellent conditions and after Implementation of some revitalization projects could become an example of an ecomorphologically well maintained river.

6.2. River-bottom and river-banks

The river-bottom and the river-banks of the Revúca River are ranked differently by EcoRivHab and HEM. The main difference comes from the fact that the river bottom was not modified but the river-banks sometimes were. Moreover the evaluation of scores in HEM is based on special weights which can influence the rating. There is more weight given by HEM to the river-bottom modification (the weight is 0, 25 for the rivers of the Revúca kind) than for example for the presence of dead wood in the stream, where the weight is 0, 1 (Langhammer, 2014). EcoRivHab counts the river-bank vegetation (Matoušková, 2008), while HEM takes it as part of the riparian zone (Langhammer, 2013).

6.3. Riparian belt

The riparian belt zone is the one where the differences between EcoRivHab and HEM are the most obvious. The two methodologies put different stress on the presence of vegetation in this zone. Also, another contrast between the two methods is the land use in this zone. This difference can be reduced if more trees are planted during revitalization in the riparian belt, as recommended by Just (2010). This is applicable especially for the RE07/REV_001 section, where the riparian zone obtained worse qualification by both methods. In addition to this, in the chapter revitalization projects is more detailed proposal.

6.4. Alluvial plain

The alluvial plain is also being differently evaluated by the two methods used. For example, EcoRivHab evaluates the river-bank stability as part of the river bed zone, but HEM takes it as a parameter of the flood (alluvial) plain zone. EcoRivHab put the same weight on all factors are the same, which means that urbanized areas in the alluvial plane have a larger negative impact on the total grade than in HEM, which ascribes low weight to the alluvial plain. The effect of the small flood retention capacity of highly urbanized areas in the sections RE07/REV_001 and RE02/REV_006 is then probably understated by HEM.

6.5. Revitalization projects

Even though the overall ecomorphological grade from both methods is very good, there are always some things that can be improved. In specific the migration paths that are artificially disturbed by some steps or water gates.

Slovakia as a member of the European Union needs to follow and accomplish its directives. With the Water Framework Directive 200/60/EC there are some obligatory implications that every member country needs to follow. Free migration path for the biota in the water body is one of them. There are two big crucial steps that make possible the migration of the biota through the whole Revúca River. One of them is in the section RE06/REV_002 in form of a water gate, were a small water hydraulic power station is also located. The other one is in the section RE07/REV_001 where a two meter high step is present. In this section there are another two small thirty-centimeter high steps but they are being naturally destroyed by the erosion and water discharge strength.

Slovak Water Management Office is preparing a project of a new migration path for the water gate in RE06/REV002 section. The project is now in engineering development process, as there are many complications. One of them, but a very crucial one, is the water discharge as there are two companies allowed to extract water from the stream. Therefore, the expected realization of the project is so far unknown.

The other big obstacle on the Revúca River is the previously mentioned two-meter step in section RE07/REV_001. There is a very positive fact that in the past the river was much more channeled and luckily there is still a blind cutoff present. As a part of this work there is a proposal design for the revitalization and migration path.

Picture 16. Migration path proposal using blind cutoff

Also, as the section RE07/REV_001 river-bank modification has been dimensioned taking a Q100 discharge. However, this one hundred years discharge has never been fulfilled as the already 70 years of presence have shown that the flood discharge has not been so high. Likewise, in a project created in 1988 for a possible reconstruction of the whole river, it is mentioned that this was over dimensioned. Therefore it could be a nice opportunity to bring this strongly modified section to a revitalized river that flows in the urbanized area closer to its natural state.

Picture 17. Revitalization proposal for RE07/REV_001 section

The design was done along with the nature close state idea. So that the river will be higher in natural quality without losing the function of technical adjustments done in the past. As Pretty et al (2003) recommends, there was put a high emphasis on the flow variability creation. There were put various representatives guaranteeing the flow variability in the revitalization design. The main ones are the whole stream direction change to more curves, differently sized stones and wooden particles inside of the stream that helps to increase the river-bottom broken relief. Also the river-bank structure is designed so it can retain more water and maintain the usual water temperature without giving it a chance to overheat as Just (2010) advises. Juncker and

Buchecker (2007) together with McCormick et al (2015) elaborate the topic of revitalization by its aesthetical and useful for recreation point. This was also put into consideration when designing the last section of Revúca River flowing through Ružomberok. There are paths for walking or bicycling, water plays for kids, rest areas etc. Another very important topic in revitalization as Macura and Izakovičová (2000) and Macura and Halaj (2013) mentions is the biota revival. In both cited publications they suggest to entry fish shelters so the biota can develop. This was also introduced in the design.

7. Conclusion

There are three main topics in the hypothesis, which they have been all reviewed in this work. The overall ecomorphological grade for Revúca River using EcoRivHab method is II. EG. When applying HEM methodology the overall ecomorphological grade is also 2. EG. The river is in slightly modified condition. The grading differs in the different sections and also when applying the two different methods. Another big difference between the two methods comes from grading of the separate zones, which was also expected as the methods are not the same and they have a different approach to the river health.

The worst graded sections in both methods were in the medium to highly urbanized areas of Liptovské Revúce and Ružomberok. Both of this sections have been evaluated by both methods as medium modified also with IIIth (3.) ecomorphological grade. In Ružomberok two revitalization projects were proposed in this work. One is to banish a migration obstacle in a part where two meter high step is present. This can be done by employing a blind cutoff that is already present and so making possible the fish migration. The second revitalization proposal is to insert some revitalization subjects in the very last part of Revúca River. This section RE07/REV_001 is just before the ending in River Váh inside the city of Ružomberok. This part has been strongly modified during the second half of last century with the construction of a new river-bank and straightening of the channel. As it has been shown over the years, this construction was designed for much higher discharges than the river reaches in reality. There is no possibility to change the river path and the river-bank construction, but there could be a place for another revitalization method. There is enough space to place fish shelters and some other small alternations to make the stream flow more diverse. In consequence, the suitability and diversity of the biota would be much easier to maintain as well as the capacity to retain water. As for the second worse section RE02/REV_006 in Liptovské Revúce, a very similar revitalization project could be implemented. The situation in this section is also particular as some of the river-bank modifications were done by the inhabitants of this village. A complex project should be proposed for the whole section that could be the most nature close state possible in the same way as preventing high loses on the urbanized area.

Another revitalization project is under construction by the Slovak Water Management Office. The aim of this project is to remove another migration obstacle in the RE02/REV_006 section. So far there is no time set when this project will be ready as there are some technical issues. Nevertheless, it should be done in the following years, as Slovakia needs to comply with the European Water Framework Directive 2000/60/EC.

All the other sections are in nature close or slightly modified ecomorphological conditions when employing EcoRivHab and HEM methods.

In conclusion, the objective of this work was fulfilled and the hypothesis has been confirmed. The two applied methods are very complex and if they are used together they can evaluate the studied water body very profoundly and objectively.

8. Bibliography

Arias, A. 2015. Understanding and managing compliance in the nature conservation context. Journal of Environmental Management. 153. 134–143.

Barrow, Ch. J. 1998. River Basin Development Planning and Management: a Critical Review. World Development. 171-186.

Batelaan, O., Witte, J. P. M. 2008. Ecohydrology & groundwater dependent terrestrial ecosystems. Proceedings of the 28th Annual Conference of the International Association of Hydrogeologists (Irish Group), Tullamore, Ireland, 22-23 April. 01-08.

Chin, A. 2006. Urban transformation of river landscapes in a global context, Geomorphology. 79. 460–87.

D'Odorico, P., Laio, F., Porporato, A., Ridolfi, L., Rinaldo, A., Rodriguez-Iturbe, I. 2010. Ecohydrology of Terrestrial Ecosystems. BioScience. 60. 898–907.

Druga, V. 2014. Spriechodňovanie bariér na tokoch. Štátna ochrana prírody Slovenskej republiky. p. 74. ISBN 978-80-89310-76-0.

Echeverria, J. D., Barrow, P., Roos-Collins, R. 1989. Rivers at risk: the concerned citizen's guide to hydropower. Island Press. USA. p. 217. ISBN 0-933280-82-3.

Environment Agency, 2003. River Habitat Survey in Britain and Ireland: River Habitat Survey Manual: 2003 version, p. 136. ISBN 0-85538-375-5.

EUR 20875, 2003. Aqualibrium – European Water Management between Regulation and Competition. European Communities. Luxembourg. p. 352. ISBN 92-894-6428-3.

European Union, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal L 327. 1 -73.

Geologic map of Slovakia M 1:50 000 [online]. Bratislava: Štátny geologický ústav Dionýza Štúra, 2013. Available from: http://mapserver.geology.sk/gm50js

Hannah, D. M., Wood, P. J., Sadler, J. P. 2004. Ecohydrology and hydroecology: A 'new paradigm'?. Hydrological Processes. 18. 3439–3445.

Hók, J., Kahan, Š., Aubrecht, R. 2001. Geológia Slovenska. Bratislava. Univerzita Komenského. p. 47. ISBN 80-223-1592-3.

Hughes, F. M. R., Rood, S. B. 2003. Allocation of River Flows for Restoration of Floodplain Forest Ecosystems: A Review of Approaches and Their Applicability in Europe. Environmental Management. Vol. 32. No. 1. 12–33.

Ilnicki, P., Górecki, K., Grzybowski, M., Krzemińska, A., Lewandowski, P., Sojka, M. 2010a. Principles of hydromorphological surveys of Polish rivers. Journal of water and land development. 14. 3–13.

Ilnicki, P., Górecki, K., Grzybowski, M., Krzemińska, A., Lewandowski, P., Sojka, M. 2010b. Ecological quality classes of river hydromorphology in Poland. Journal of water and land development. 14. 15-27.

Ilnicki, P., Górecki, K., Lewandowski, P., Sojka, M., Grzybowski, M., Krzemińska, A. 2011. Charakterystyka elementów hydromorfologicznych cieków sztucznych przy użyciu metody MHR. Acta Scientinarum Polonorum. Formatio Circumiectus 10 (1). 17–32.

Janauer, G. A. 2000. Ecohydrology: fusing concepts and scales. Ecological Engineering. 16. 9–16.

Junker, B., Buchecker, M. 2007. Aesthetic preferences versus ecological objectives in river restorations. Landscape and Urban Planning. 85. 141–154.

Just, T. 2010. Přírodě blízké úpravy vodních toků v intravilánech a jejich význam v ochraně před povodněmi. Revitalizace sídelního prostředí vodními prvky. 1. vydání. Praha. Agentura ochrany přírody a krajiny ČR. p. 213. ISBN 978-80-87457-03-0.

Kundzewicz, Z. W. 2002. Ecohydrology-seeking consensus on interpretation of the notion. Hydrological Sciences Journal. 47:5. 799-804.

Kundzewicz, Z. W. 2003. Ecohydrology for Sustainable Wetlands under Global Change – Data, Models, Management. Warsaw Agricultural University Press. 25–35.

Langhammer, J. 2008. HEM–Hodnocení ukazatelů–Metodika pro monitoring hydromorfologických ukazatelů ekologické kvality vodních toků. Univerzita Karlova v Praze. Přírodovědecká fakulta, Katedra fyzické geografie a geoekologie. Praha. p. 23.

Langhammer, J. 2013. HEM–Hodnocení ukazatelů–Metodika pro monitoring hydromorfologických ukazatelů ekologické kvality vodních toků: Aktualizovaná verze s komentáři odboru ochrany vod Ministerstva životního prostředí. Univerzita Karlova v Praze. Přírodovědecká fakulta, Katedra fyzické geografie a geoekologie. Praha. p. 66.

Langhammer, J. 2014. HEM 2014, Metodika typově specifického hodnocení hydromorfologických ukazatelů ekologické kvality vodních toků. Ministerstvo životního prostředí. Univerzita Karlova v Praze. Přírodovědecká fakulta. Praha. p. 59.

LAWA. 1999. Gewässerstrukturgütekartierung in der Bundesrepublik Deutschland – Verfahren für kleine und mittelgroße Fließgewässer. Länderarbeitsgemeinschaft Wasser. p. 190. Available from: www.lawa.de

Lusk, S., Halačka, K., Lusková, V. 2003. Short Communication: Rehabilitating the floodplain of the lower River Dyje for fish river research and applications. 19. 281–288.

Macura, V., Halaj, P. 2013. Úpravy a revitalizácie vodných tokov. Bratislava, STU in Bratislava. p. 228. ISBN 978-80-227-3925-2.

Macura, V., Izakovičová, Z. 2000. Krajinnoekologické aspekty revitalizácie tokov. Bratislava. STU in Bratislava. p. 272. ISBN 80-227-1343-0.

Macura, V., Škrinár, A., Kaluz, K., Jalčovíková M., Škrovinová, M. 2012. Influence of the morphological and hydraulic characteristics of mountain streams on fish habitat suitability curves. River research and applications 28, 1161 – 1178.

Mathur, D., Bason, W.H., Purdy Jr., E. J., Silver C. A. 1985. A Critique of the Instream Flow Incremental Methodology. Canadian Journal of Fisheries and Aquatic Sciences. 42(4). 825-831.

Matoušková, M. 2008. Ekohydrologický monitoring vodních toků v kontextu evropské Rámcové směrnice o vodní politice 2000/60/ES. Vyd. 1. Praha: Univerzita Karlova v Praze. Přírodovědecká fakulta. p. 209. ISBN 978-80-86561-54-7.

McCormick, A., Fisher, K., Brierley, G. 2015. Quantitative assessment of the relationships among ecological, morphological and aesthetic values in a river rehabilitation initiative. Journal of Environmental Management 153. 60 – 67.

Molle, F. 2009. River-basin planning and management: The social life of a concept. Geoforum 40. 484-494.

Neruda, M., Tichonova, I., Kramer, D. 2012. Theoretical and Practical Aspects of Rivers Revitalization. Journal of Earth Science and Engineering 2, 145-154.

Novodomec, R. 2006. Krasové javy v travertínoch dolného Liptova. Výskum, využívanie a ochrana jaskýň 5. 74-79.

Nuttle, W. K. 2002. Is ecohydrology one idea or many?. Hydrological Sciences Journal. 47:5. 805-807.

Pretty, J. L., Harrison, S. S. C., Shepherd, D. J., Smith, C., Hildrew, A. G., Hey, R. D. 2003. River rehabilitation and fish populations: assessing the benefit of instream structures. Journal of Applied Ecology 40. 251–265.

Scott, D., Shirvell, C. S. 1987. A critique of the instream flow incremental methodology and observations on flow determination in New Zealand. Regulated streams, Springer US, 27-43.

Šípek, V., Matoušková, M., Dvořák, M. 2009. Comparative analysis of selected hydromorphological assessment methods. Environ Monit Assess 169. 309–319.

Slezáková, J. 1989. Generel Revúcej: Sprievodná správa. Piešťany. p. 1-38.

Šlezingr, M. 2010. Revitalizace toků: příspěvek k problematice úprav vodních toků. VUTIUM. Brno. p. 255. ISBN 978-80-214-3942-9.

Šmerousová, K., Matoušková, M. 2011. Ekohydromorfologický průzkum vodních toků pomocí metod EcoRivHab a HEM. Vodní Hospodářství. 11/2011. 409-413.

Stalnaker, S., Lamb, B. L., Henriksen, J., Bovee, K., Bartholow, J. 1995. The Instream Flow Incremental Methodology: A Primer for IFIM. Biological Report 29. National Biological Service. U.S. Department of the Interior. p. 1-53.

Struhár, V. 2009. Ružomberok and vicinity in prehistory and in age of early historic folks. In Ružomberský historický zborník III. Ružomberok. Filozofická fakulta KU. 121-182.

Trimble, S. W. 2008. Encyclopedia of Water Science. Second Edition. CRC Press. USA. Volume I. p. 652. ISBN 978-0-8493-9627-4.

Winter, T. C., Harvey, J. W., Franke, O. L., Alley, W. M. 1998. Ground Water and Surface Water – A Single Resource. U.S. Geological Survey Circular 1139. Denver. Colorado. p. 1-79.

Wang, L., Lyons, J., Kanehl, P., Gatti, R. 1997. Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. Fisheries 22. 6-12.

Young, R. G., Collier, K. J. 2009. Contrasting responses to catchment modification among a range of functional and structural indicators of river ecosystem health. Freshwater Biology 54. 2155–2170.

Zalewski, M. 2002. Ecohydrology—the use of ecological and hydrological processes for sustainable management of water resources. Hydrological Sciences Journal. 47:5. 823-832.

Zalewski, M., Janauer, G. A., Jolankai, G. 1997. Ecohydrology: A new paradigm for the sustainable use of aquatic resources. UNESCO. Paris. p. 1-58.

9. List of Figures

9.1. List of graphs

9.2. List of pictures

All the photographs are taken by the author of the thesis

9.3. List of tables

10. Appendixes

10.1. EcoRivHab mapping form

Formulář ekomorfologického monitoringu vodních toků

Obecné charakteristiky hodnoceného úseku:

Název vodního toku: ....

Poř. číslo, vymezení úseku ř. km ....

Délka hodnoceného úseku vodního toku: ....(km)

Datum, čas pozorování, mapový list: ....

I) KORYTO VODNÍHO TOKU

1. ***Morfologie a průběh trasy koryta***

1.1 typ údolí vodního toku ⇑•

Typ	Označení
soutěska	S
kaňon	K
erozní typu V	V
neckovité	N
úvalovité	Ú
úvalovité s široce vytvořenou údolní nivou	ÚN
umělý tok, přeložka	UP

1.2 stupeň zakřivení ⇑•

typ	Znač	hodnocení u N, Ú, ÚN
meandrující	M	plně odpovídá danému úseku vodního toku 1
zákrutový, větvený	ZV	
zákrutový, nevětvený	ZN	mírně pozměněný 3
divočící	D	změněný, neodpovídá danému úseku 5
přímý	P	

1.3 charakter a tvar koryta ⇑•

Přírodní (přírodě blízký)	body	Umělý	body
pravidelný	2	miskový	3
nepravidelný	1	lichoběžníkový	4
		obdélníkový	5
		kruhový - zatrubnění*	5

Pozn. více než 80 % délky úseku, neprovádí se další hodnocení

1.4 zahloubení koryta toku ⊗•

Typ	hodnocení
extrémní	5
značné	4
střední	3
malé	2
žádné	1

Hodnocení se provádí vzhledem k referenčnímu stavu úseku

Pozn. Parametr má pouze dokumentační charakter

1.5 přítomnost erozních a akumulačních tvarů ⇑•

stupeň výskytu N, Ú,ÚN	hodnocení
vysoký	1
střední	3
žádný	5

2) Podélný profil koryta vodního toku

2.1 typ stavebních úprav (přítomnost umělých stupňů) ⊗•

typ úpravy	hodnocení
žádná, drobné přír. stupně	1
nízký stupeň <10 cm, jez s přirozeným obtokem	1
drsný (kamenitý) skluz s mírným sklonem 1:10 až 1:30	2
stupňovitý jez (jedn. s.<30 cm)	2
hladký skluz s výrazným sklonem 1:30 až 1:50	3
nízký umělý stupeň (jez), výška 10 až 30 cm	3
jez s přechodem pro ryby	3
vysoký stupeň (jez) výška 30-100 cm bez rybího přechodu	4
velmi vysoký stupeň (jez) výška > 100 cm bez rybího přechodu	5

2.2 zatrubnění (délka úseku) ⊗•

délka úseku v %	hodnocení
0 – 5	1
5-25	3
>25	5

2.3 charakter proudění ⇑•

charakter proudění	hodnocení
vysoce diversifikované proudění	1
středně diversifikované proudění	3
málo diversifikované proudění	5

2.4 variabilita hloubek, střídání tůní a peřejnatých úseků (riffles a pools) •

variabilita hloubek	hodnocení
velmi vysoká >75 % úseku	1
vysoká 50-75 % úseku	2
střední25-50 % úseku	3
nízká 5-25 % úseku	4
žádná <5% úseku	5

Pozn. Hodnoceno vzhledem k potenciálně přirozeným poměrům.

Celkové hodnocení oddílu 2

skupina	hodnota
2.1	
2.2	
2.3	
2.4	
2.5	
celkem	
arit. průměr	

2.5 charakter odtoku ⊗•

Odtok	charakteristika	hodnocení
nezměněný	režim odtoku plně odpovídá danému typu vodního toku	1
pozměněný	režim odtoku neodpovídá plně danému typu vodního toku, provedené technické úpravy (napřímení toku, zpevnění břehů, vzdutí, výpusti odp. vod, atd.) mírně pozměnily přírodní charakter odtoku	3
zcela změněný	charakter odtoku neodpovídá přirozenému odtoku, došlo zde k výstavbě umělých nádrží, kanálů, zavlažov. zařízení atd., pomocí nichž je regulován odtok, zcela zásadně se mění velikost a charakter přirozeného odtoku v průběhu roku	5

3) *Příčný profil*

3.1 typ profilu ⇑•

příčný profil	hodnocení
přírodní, přírodě blízký v rovnováze, stabilní	1
přír. profil, relativně stabilní, drobné projevy eroze	2
přír. erozní profil, nestabilní, nehrozí škody	3
upravený profil umělý, zahloubený, částečně zpev. břehy, významné projevy boční eroze	4
velice silně zahloubený profil (uměle zpevněné břehy)	5

Pozn. záznam projevů nadměrné břehové a hloubkové eroze v mapě

3.2 střední hloubka profilu ⇑•

označení profilu	hloubka
mělký	< 25 cm*
středně hluboký	25-75 cm *
hluboký	> 75 cm *

Pozn. Tento parametr má pouze dokumentační charakter,
** stanovení jednotlivých hloubek, dle ref. stafu*

3.4 technické úpravy příčného profilu ⊗•

úpravy koryta	hodnocení
není uměle zúženo/rozšířeno ve 95-100% úseku	1
zúženo/rozšířeno <25% úseku	2
zúženo/rozšířeno <50% úseku	3
zúženo/rozšířeno <75% úseku	4
zúženo/rozšířeno >75% úseku	5

Pozn. vztaženo na prům. šířku koryta vodního toku

3.3 variabilita šířek koryta ⇑•

stupeň variability V, N, Ú, ÚN	hodnocení
vysoký kv>=1,5	1
střední kv(1,2-1,5)	3
nízký kv<1,2	5

Celkové hodnocení oddílu 3

skupina	hodnota
3.1	
3.3	
3.4	
celkem	
arit. průměr	

4). *Struktury dna*

4.1 typ substrátu dna *

Typ	označení
jílovitý	JI
písčitý	PI
štěrkovitý	ST
kamenitý (kameny, valouny)	KA
balvanitý (bloky, balvany)	BA
skalní	SK
bez pokryvu	BP
aj.	AJ

Pozn. Tento parametr má pouze dokumentační charakter, uvádí se 1-2 dominantní typy

4.2 úpravy dna ⊗•

typ úpravy	> 50% hodnoceného úseku
žádná úprava	1
vložené jedn.volné kameny, vegetační materiály apod.	2
zpevnění kulatinou (dřevem)	2
zpevnění lomovým kamenem (rovnanina)	3
vegetační tvárnice	4
beton. desky/ kamen. dlažba překrytá přírodním substrátem	4
betonové desky/kamen. dlažba bez překryt. souvislý betoní	5
jiný typ úpravy	

4.3 existence mikrohabitatů (diverzita substráty, akumulace detritu, listí, mrtvé dřevo, aj.) ⇑•

stupeň výskytu u V, N, Ú, ÚN	hodnocení
vysoký	1
střední	3
žádný	5

Celkové hodnocení oddílu 4

skupina	hodnota
4.2	
4.3	
celkem	
arit. průměr	

5) Břehové struktury

5.1 vegetace břehů *∅

dominantní druh porostu	LB	PB
žádná z důvodu přírodních poměrů	1	1
mokřadní vegetace, poten. přirozené byliny, trávy, K+S	1	1
poten. přirozené byliny, trávy s jedním poten. přír. vegetačním patrem (K/S)	2	2
poten. nepřirozené S/K, invazní druhy, ruderální vegetace	3	3
zatravnění, ruderální vegetace, invazní druhy	4	4
žádná z důvodů úprav koryta, projevů boční eroze apod.	5	5

Vysvětlivky: K keřové patro, S stromové patro

5.2 struktura břehové vegetace (keřové a stromové patro)•

struktura vegetace	hodnocení
žádná z důvodu úpravy břehu	5
solitery (jednotlivé stromy/keře)	4
galeriový pás (souvislý pás LB a PG, zastínění toku)	3
galeriový pás (střídající se stromy LB a PB)	2
souvislý lesní porost	1
žádná z důvodu přírodních poměrů	1

5.3 technické úpravy břehů ⊗•

charakter úpravy	LB >50 %	PB >50 %
žádná	1	1
zatravnění, vrbové plůtky	2	2
zpevnění lomovým kamenem (typ rovnanina, zához, pohoz), přír. pro lokalitu	2	2
opevnění kulatinou, haťoštěrkové válce	3	3
kámen nepřirozený pro danou lokalitu, gabiony	4	4
vegetační tvárnice	4	4
kamenná/betonová dlažba na sucho	4	4
kamenné/betonové zdivo, souvislý beton	5	5

5.4 pohyblivost břehů ⇑•

charakter pohyblivosti	hodnocení
velmi pohyblivé břehy s velkými nátržemi	5
pohyblivé břehy s nátržemi v části břehového svahu	4
mírně pohyblivé břehy s drobnými nátržemi v patách svahu	3
nepohyblivé břehy se stabilizovanými nátržemi	2
stabilní břehy bez nátrží	1

Celkové hodnocení oddílu 5

skupina	hodnota
5.1 LB / PB	
5.2	
5.3 LB / PB	
5.4	
celkem	
arit. průměr	

6) Jakost povrchových vod

6.1 hydrochemické vlastnosti ⊗•

jakostní třída dle ČSN 75 72 21	Hodnocení
I.	1
II.	2
III.	3
IV.	4
V.	5

Pozn. hodnocení se provádí ve vybraných úsecích

6.2 hydrobiologické vlastnosti ⊗•

saprobní index	hodnocení
<1,2	1
<2,2	2
<3,2	3
<3,7	4
>3,7	5

Pozn. hodnocení se provádí ve vybraných úsecích

6.3 výpusti odpadních vod do toku

výpust odpadních vod	ano	ne

Pozn. Tento parametr má pouze dokumentační charakter, je možno zaznamenat počet

Celkové hodnocení oddílu 6

skupina	hodnota
6.1	
6.2	
celkem	
arit. průměr	

II). DOPROVODNÉ VEGETAČNÍ PÁSY (PŘÍBŘEŽNÍ ZÓNA) DVP

7.1 přítomnost DVP (min. šíře 10 m) ⇑•

DVP	LB	PB
existující	1	1
částečně existující	3	3
neexistující	5	5

7.2 vegetace DVP - se zřetelem na stromové patro •∅

typ	LB	PB
les s poten. přirozenou druhovou skladbou, mokřad	1	1
skupinová vegetace / galeriový pás s poten. přirozenou druhovou skladbou s průhledy na koryto	1	1
roztroušená vegetace/ solitery s poten. přirozenou druhovou skladbou	2	2
les s poten. nepřirozenou druhovou skladbou)	3	3
skupinová vegetace / galeriový pás s poten. nepřirozenou druhovou skladbou, zatravnění	3	3
roztroušená vegetace / solitery s poten. nepřirozenou druhovou skladbou	4	4
pouze zatravnění, ruderální veg. invazní druhy.	4	4
žádná vegetace (výjimka přír. pom.)	5	5
jiný typ		

7.3 využití ploch v doprovodných pásech •±

Typ	>50% LB	>50% PB
les (poten. přiroz. skladba), mokřad	1	1
louky, pastviny, parky	2	2
les (poten. nepřir. druh. skladba)	3	3
plocha ležící ladem, ruderální p.	3	3
zahrady, sady, vinice	3	3
pole, orná půda	4	4
dopravní komunikace, zástavba, umělé povrchy	5	5

Záznam převládajícího typu využití

Celkové hodnocení oddílu 7

skupina	hodnota
7.1	
7.2	
7.3	
celkem	
arit. průměr	

10.2. HEM mapping form

HEM 2014 - Hydroekologický monitoring
Mapovací formulář

Název toku	
ID úseku	
Délka úseku (m)	

Mapovatel	
Datum, čas	
ID vodního útvaru	

Geometrické charakteristiky úseku

Hranice úseku	*Říční km*		*Souřadnice X (m)*		*Souřadnice Y (m)*	
Dolní hranice						
Horní hranice						
Tvar údolí (zaškrtnout)	*Soutěska*	*Tvar V*	*Tvar U*	*Neckovitý*	*Plochý*	*Asymetrický*

1. Upravenost trasy toku (TRA)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Převládající typ*	*Známky napřímení*	*Známky revitalizace*	*Historický stav*
Divočící tok				
Rozvětvený tok				
Meandrující				
Zákruty				
Přímý úsek				

2. Variabilita šířky koryta (VSK)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Minimum*	*Maximum*
Šířka koryta (m)		
Šířka hladiny (m)		
Šířka údolní nivy *L břeh (m)*		
Šířka údolní nivy *P břeh (m)*		

3. Variabilita zahloubení v podélném profilu (VHL)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*	*Uměle zvýšené*	*Uměle snížené*
0-1 m			
1-2 m			
2-4 m			
4 a více m			

4. Variabilita hloubek v příčném profilu (VHP)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*
Vysoká	
Střední	
Přirozeně nízká	
Nízká z důvodu úpravy koryta	

5. Dnový substrát (DNS)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*
Skalní podloží	
Balvany (256 mm a více)	
Kameny (64 - 256 mm)	
Štěrk (2 - 64 mm)	
Písek (0,06 - 2 mm)	
Prach/bahno (méně než 0,006 mm)	
Rašelina	
Pevné jílovité dno	
Umělý substrát	

6. Upravenost dna (UDN)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*
Dno bez známek úprav	
Zpevnění dna kamennou dlažbou	
Zpevnění dna kamenným pohozem	
Zpevnění dna betonem	
Zatrubnění, zakrytí toku	
Pravidelná prohrábka koryta/ zvýšené zahloubení	
Přidávání splavenin a umělého substrátu	

7. Mrtvé dřevo v korytě (MDK)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*		
Mrtvé dřevo a dřevní zbytky v korytě			
Intenzita odstraňování	žádné	občasné	systemat.

8. Struktury dna (STD)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*
Žádné pozorované struktury dna	
Lavice	
Ostrovy	
Mělčiny	
Tůně	
Peřeje	
Skalní stupně	

9. Charakter proudění (PRO)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah* (%)*
Vodopád	
Stupně, kaskáda	
Peřejnatý úsek	
Slapový proud	
Klouzavý proud	
Tůně	

10. Ovlivnění hydrologického režimu (OHR)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah**
Dynamika beze změn (rozsah %)	
Trvalá regulace průtoku (hráz aj.) (rozsah %)	
Trvalé vzdutí (jez aj.) (rozsah %)	
Periodické vzdutí (rozsah %)	
Vypouštění (rozsah %)	
Odběry vody (rozsah %)	
Extrémně snížený průtok (% doby)	
Špičkování, rychlé zvyšování průtoku (% doby)	

** Záznam rozsahu jevu nebo úpravy*
Procentuální rozsah výskytu jevu nebo úpravy v rámci úseku se zaokrouhluje na celé desítky procent.
V případě lokálně omezeného, ale intenzitou významného výskytu jevu se zaznamená hodnota 1%.

11. Podélná průchodnost koryta (PPK)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Počet výskytů*	*Z toho počet dočasných překážek*	*Z toho počet migračně průchodných*
Úsek bez překážek			
Nízké stupně s výškou nižší než 0,3 m			
Stupeň nebo jez s výškou 0,3 - 1 m			
Stupeň nebo jez vyšší než 1 m			
Skluz			
Propustek			
Hráz			

Ministerstvo životního prostředí

12. Upravenost břehu (UBR)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah výskytu (%)*	
	L břeh	*P břeh*
Břeh bez známek úprav		
Vegetační opevnění břehu (zatravnění)		
Vegetační opevnění břehu (kulatina)		
Rozpad, zpřírodnění úpravy (pohoz, zához, rovnanina)		
Kamenný pohoz, zához, rovnanina		
Gabiony		
Polovegetační tvárnice		
Zpevnění břehu kamennou dlažbou		
Zpevnění břehu betonem		
Souvislá úprava profilu		

13. Břehová vegetace (BVG)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah výskytu (%)*	
	L břeh	*P břeh*
Přirozený les		
Hospodářský les		
Liniová vegetace		
Přerušované pásy vegetace		
Jednotlivé stromy, keře		
Travobylinná vegetace		
Ruderální společenstvo		
Břehy bez vegetace		

14. Využití příbřežní zóny (VPZ)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah výskytu (%)*	
	L břeh	*P břeh*
Přirozený skalní povrch		
Les		
Louka		
Pastvina		
Plochy ponechané přirozenému vývoji		
Vodní plochy		
Mokřad		
Zemědělská plocha		
Roztroušená zástavba		
Intravilán, průmysl		

15. Využití údolní nivy (VNI)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah výskytu (%)*	
	L břeh	*P břeh*
Přirozený skalní povrch		
Les		
Louka		
Pastvina		
Plochy ponechané přirozenému vývoji		
Vodní plochy		
Mokřad		
Zemědělská plocha		
Roztroušená zástavba		
Intravilán, průmysl		

16. Průchodnost inundačního území (PIN)

Zdroj dat: T D Spolehlivost stanovení: A B C		*Výskyt*	
		L břeh	*P břeh*
Žádné liniové stavby v nivě	*(Zaškrtnout)*		
Liniové stavby napříč nivou - násypy komunikací aj.	*(Počet)*		
Povodňové hráze podél koryta	*(Rozsah* %)*		
Liniové stavby vedené paralelně s korytem, násypy komunikací aj.	*(Rozsah* %)*		
Odsazení hrází/valů od koryta	*(m)*		
Zkapacitnění koryta	*(Rozsah* %)*		

17. Stabilita břehu a boční migrace koryta (BMK)

Zdroj dat: T D Spolehlivost stanovení: A B C	*Rozsah výskytu (%)*	
	L břeh	*P břeh*
Stabilní břeh bez nátrží a akumulací		
Drobné břehové nátrže (do 5 m)		
Rozsáhlé břehové nátrže (nad 5 m)		
Drobné fluviální akumulace (do 100 m²)		
Rozsáhlé fl. akumulace (nad 100 m²)		
Omezení bočního pohybu koryta		

Invazní druhy

Zdroj dat: T D Spolehlivost stanovení: A B C	*Druhy*	*Četnost* *1 – jednotky* *2 – desítky* *3 – stovky* *4 - tisíce*
Levý břeh		
Pravý břeh		

Fotodokumentace

10 fotografií struktur a úprav vztahujících se k danému úseku

Poznámky

Ministerstvo životního prostředí