LIVING NERETVA - TOWARDS EU STANDARDS IN THE NERETVA RIVER BASIN, BOSNIA AND HERZEGOVINA

Living Neretva Environmental Flow Working Group (WFD-WG1)

ENVIRONMENTAL FLOW ASSESSMENT FOR THE RIVER TREBIŽAT, BiH

June 2008

PROJECT:

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Supervisor, WWF Mediterranean Programme Office:
Francesca Antonelli, M.Sc.

Project leader, Living Neretva:
Branko Vučijak, Ph.D.

Expert leader, WFD-WG1:
Nataša Smolar-Žvanut, Ph.D.

Expert in Hydrology:
Esena Kapusovič, M.Sc.

Expert in Chemistry:
Zlatko Grizelj, B.Sc.

Expert in Biology:
Anđelka Mijatović, M.Sc.

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EXECUTIVE SUMMARY

This report is one component of the Living Neretva project, funded by the Norwegian Ministry of Foreign Affairs and implemented by WWF Mediterranean Programme and WWF Norway. The main aims of the project are:

- to test the GEP methodology to identify the environmental flow in the selected Neretva sub-basin (river Trebižat), supported by relevant Bosnia and Herzegovina (BiH) administrations in a previous phase;
- to train the working group on environmental flow assessment;
- to collect data on river ecology, river usage and river pollution;
- to provide recommendations for the development of the articles in the relevant sub-laws on environmental flow, as required by the BiH Water Laws (art. 62 Water Law FBiH, art. 65 Water Law RS).

The study area in southwest Bosnia and Herzegovina covers that part of western Herzegovina mainly situated in the Municipality of Ljubuški, , which is the main settlement in the area. Being part of a very specific and complex karst system, the same water flows under different names, one of which is Trebižat, the right tributary of the Neretva river. The river Trebižat and its tributaries belong to a region of arid limestone plateaus containing caves, potholes, and underground drainage systems. The water regime of the Trebižat river is affected by the extraction of its water for hydropower plants, irrigation and fish farming and by pollution. The Trebižat river flows through an area of remarkable ecological value which includes protected areas – the travertine-forms around Kravice waterfall, the geomorphologic monuments of Tihaljina spring in Peć Mlini, Vrioštica spring in Vitina and the waterfalls of Koćuša, Kravice and Bučine.

In the framework of the project a working group was set up composed of three experts from Bosnia and Herzegovina led by an international senior expert on Environmental Flow. The working group included expertise on hydrology and hydrogeology, biology and chemistry. The three experts were trained at the outset by the leading expert and were then provided with a detailed agenda of tasks to be implemented, including samplings and data collection. Two meetings were held (on April 8-9, 2008 and May 26-27, 2008) during which the work in progress was presented and discussed with representatives of the Federation of Bosnia and Herzegovina (FBiH) Ministry for Agriculture, Water Management and Forestry, the Republic of Srpska (RS) Ministry for Agriculture, Water Management and Forestry, Agency for Adriatic Basin from Mostar, Agency for Sava River Basin from Sarajevo, Directorate for Waters from Bijeljina. At the second workshop draft results were also presented to representatives of dams operators (three major energy production companies in BiH).

During two workshops held in Ljubuški, several experts (all involved in the management of the Neretva river basin) took part in the development of the environmental flow assessment. Using existing hydrological data and samples collected on field trips, environmental flow was assessed according to the GEP methodology at five hydrological stations. Additionally, instream ecological values and critical parameters for environmental flow assessment were evaluated. At five selected sampling sites along the Trebižat river, additional data on macrophytes, phytobenthos and physico-chemical parameters were collected and analysed.

Although there have been many negative impacts in recent years on the Trebižat river, the analyses of aquatic organisms showed their high diversity.

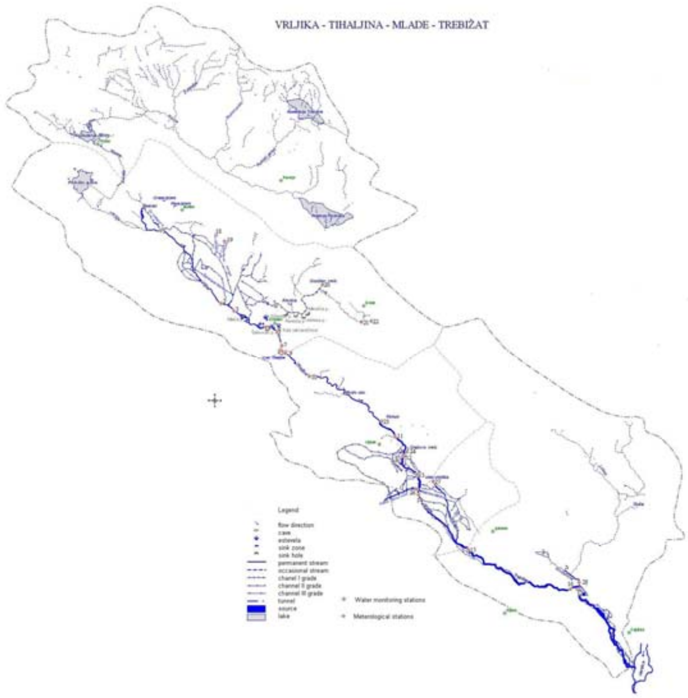
The calculated values of environmental flow according to GEP methodology were higher than the values of 95 % of monthly minimum flow probability, as prescribed at present by the BiH Law. From this point of view adopting the GEP methodology with some changes in BiH sub-law would consequently increase values of river flows downstream of the dams.

GEP methodology belongs to the so-called "hydrological approach" category of environmental flow assessment methods. The testing exercise carried out in the framework of this project led to the conclusion that the GEP methodology provides important advantages but also presents remarkable disadvantages. It is a rather obsolete method, which does not take advantage of globally recognized methods developed after 1990 (when the more comprehensive "holistic approach" began to be applied). Furthermore, testing was applied only to one river (Trebižat) in BiH so no predictions can be made regarding the results which could be expected were this methodology to be applied to other rivers in BiH.

Recent developments in environmental flow assessment have improved existing methodologies and are being applied world-wide. The GEP proved to be an easy-to-apply preliminary method for environmental flow assessment. An update of the method is necessary to ensure the effective protection of the ecological goods and services which rivers provide for people. These modifications would include:

- Stakeholders' involvement in making decisions about the priorities for the sustainable management of rivers;
- The need for explicit links between the hydrology of rivers (as analysed in GEP) and the ecological components, processes and functions which are important for people. Such links provide the motivation for environmental flow assessment which is absent in the purely hydrological methods such as the GEP;
- The accommodation of natural flow variability which is a key process in rivers;
- The need for higher flows on which the biodiversity of flood plains and riparian areas depend.

In the light of the high acceptance of the GEP methodology by BiH administrations and its easy applicability, and taking into account recent developments in the rapidly expanding field of environmental flow assessments, it is proposed to develop a second generation GEP method which would optimize the existing benefits and overcome the present limitations of the method. A final report has been delivered and validated by the national authorities with the intention of adopting the results and conclusions to support the river basin operative water management, as well as for river basin management plan preparation.Although the amount or work performed in four months (March-June 2008) has been remarkable, additional efforts should be made in the future. These efforts should concentrate on i) fully developing the second generation of the GEP method; ii) filling the gaps in biodiversity data of the Trebizat river; and iii) monitoring the implementation of environmental flow, with the objective of defining the ecological status of the river.


VRLJIKA - TIHALJINA - MLADE - TREBIŽAT
Legend
flow direction
cave
estavela
sink zone
sink hole
permanent stream
occasional stream
chanel I grade
channel II grade
channel III grade
tunnel
source
lake
Water monitoring stations
Meteorological stations

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1 PROJECT BACKGROUND

This report is the continuation of the first phase of the project "Living Neretva - Towards EU-standards in the Neretva river basin" running from July 2006 to December 2007. Three working groupswere set up under the supervision of the relevant BiH authorities, to adapt BiH environmental protection practices to the standards of key EU environmental "acquis communautaire", namely the Water Framework Directive (WFD) and the Habitat Directive (HD), During the first phase a working group was established to assess different methods for environmental flow (EF) calculation and, in cooperation with the BiH water authorities, to select one method to be applied to BiH rivers. The analysis led to a tentative selection of the so-called GEP method.

This report is the direct follow up of the first phase of the Living Neretva project and embodies the work of a group of national experts led by an expert in environmental flow, with relevant international experience in environmental flow assessment. To provide the necessary expertise for environmental flow calculation, three BiH experts in hydrology and hydrogeology, biology and chemistry were selected. The biologist and chemist were required to be familiar with the pre-selected area of Trebizat.

The working group was at first trained by the leading expert and then provided with a detailed agenda of tasks to be implemented, including samplings and data collection. There were two meetings (held on April 8-9, 2008 and May 26-27, 2008) during which the work in progress was presented and discussed with representatives of the FBiH Ministry for Agriculture, Water Management and Forestry, the RS Ministry for Agriculture, Water Management and Forestry, the Agency for the Adriatic Basin from Mostar, the Agency for the Sava River Basin from Sarajevo, the Directorate for Waters from Bijeljina. Draft results were also presented to representatives of dams operators (three major energy production companies in BiH) during the second workshop The final report is currently being validated by the authorities mentioned above with the intention of adopting the results and conclusions to support the operative water management of the river basin, as well as for preparation of the plan for its management.

2 WHAT IS ENVIRONMENTAL FLOW FOR ?

Flow for nature should not be seen as being in competition with flow for people. Only a short term approach can justify this damaging attitude. On the other hand, the long term availability of water resources is a prerequisite for healthy and wealthy communities and it depends on the wise use of resources. This wise use relies on balancing nature's needs with human needs. The environmental flow assessment should be seen as a tool for finding this balance and ensuring a long-term and good quality water supply

The indicators used in environmental flow assessment process are the endangered habitats and species (ecosystems) that should be seen as a sort of thermometer of the health of the rivers and their capacity to provide the goods and services that water users need, for hydropower, industry, domestic supply, or the agriculture sector.

The bottom line is that a healthy riverine ecosystem sustains livelihoods. Environmental flow is a tool to balance water needs for healthy ecosystems and water needs from different users.

3 INTRODUCTION

3.1 General information about the impact of dams, water extraction/diversion

The alteration of the water flow downstream of dams is one of the most stressful factors influencing the aquatic and riverine ecosystem. These effects are often related to the fragmentation of water habitats (Maddock et al., 2005), toxic matter in sediments and water, invasive alien species and pollution (Biggs & Close, 1989). When to analysing the effects of damming, water extraction and diversions, one needs to deal with all the factors in a connected manner.

The effects of damming on hydrological parameters are to be found in the changed dynamics of flow below dams, duration and frequency of water flow, and reduction of velocity and temporal uniformity of water flow. The sediments that are not transported are deposited as alluvial deposits (Mikoš, 1989). Anthropogenic effects, such as water channel regulations, may cause reduction in deposition, impoundments and denudation/removal of fine sediment. During periods of low flow, fine sediment accumulates in the watercourses (Milhous, 1998) and deposition of organic matter increases, particularly in river pools and in reaches where the water is impounded (Everard, 1996).

The size and structure of aquatic habitats influence the community of aquatic organisms (Aadland, 1993, Maddock 1999, Gehrke & Harris 2000, Maddock *et al.* 2004). Several methodologies that have been developed world-wide assess the effects of an increased human exploitation of water sources on aquatic habitats (Maddock & Bird, 1996). Results demonstrate significant differences in the mesohabitats of unregulated and regulated reaches. Unregulated reaches are dominated by fast-flowing and turbulent types of mesohabitats while in regulated reaches of rivers, slow-flowing types of mesohabitats are present (Smolar-Zvanut et al, 2007). Reduced flows due to river regulation also significantly reduce the size of mesohabitats, alter their hydraulic character, and affect the longitudinal distribution of types by creating greater habitat fragmentation (Maddock et al, 2007).

The extraction of water results in most cases in changes to its physico-chemical parameters, reduction of biodiversity of aquatic and riparian flora; the changed local conditions enable the increase in the biomass of particular species, which may cause environmental problems (Biggs, 1996).

3.2 Environmental flow definitions

The increasing demand for water is degrading rivers worldwide, resulting in a loss of the vital goods and services they provide. Nowhere is the problem more urgent than in developing countries. Many of these countries acknowledge that environmental protection must be a component of their management of water but have limited data and understanding of their aquatic ecosystems with which to achieve this (King et al. 2003).

Dams are often the most significant and direct modifiers of natural river flows. They are therefore an important starting point for the implementation of environmental flows. Downstream releases from dams are determined by the design of the dam – whether to pass water through, over or around the dam. The operating policies and rules determine the amount and timing of releases for environmental flows. The design and operations of other infrastructure such as distribution canals and weirs, can also contribute to establishing environmental flows (Dyson et al, 2003).

Environmental flow is the term for the amount of water needed in a watercourse – a river, wetland or coastal zone – to maintain healthy, natural ecosystems and their benefits where there are competing water uses and where flows are regulated (Dyson et al, 2003).
The main goal of environmental flow is, according to the Water Framework Directive, to maintain the ecological status of the structure and function of aquatic and riparian ecosystems at least until 2015.

The water laws in BiH (WL, 2006) emphasise that environmental flow should be determined on the basis of the research that has been carried out, in accordance with the methods for its determination, defined in the sub-legal act, and should take into consideration the specific characteristics of the local ecosystem and the flow's seasonal variation. The Water Law establishes the legal basis for sustainable water resource management. Until the environmental flow sub-legal act is enforced, the environmental flow should be established, on the basis of the hydrological characteristics of the water body for a particular season, as the monthly minimum average flow occurring with 95% probability (WWF project Living Neretva, Environmental Flow Group report, 2007).

3.3 Approaches and methodologies for –assessment

Environmental flow assessment requires the integration of a range of disciplines, including engineering, law, ecology, economy, hydrology, political science and communication. It also requires negotiations between stakeholders in order to bridge the different interests that compete for the usage of water, especially in those basins where competition is already fierce (Dyson et al, 2003).

According to Tharme (2003), the main attributes of the specific approach used to define environmental flow can be categorised into four groups:

1) Hydrological methods: simple tables based on hydrological indices;
2) Hydraulic rating methods: fieldwork and rapid desk-top analysis using a combination of hydrological, hydraulic or ecological data;
3) Habitat simulation methods: habitat modelling that determines the relationship between flow and habitat availability;
4) Holistic methodologies: functional analysis that considers a wide range of ecological and hydrological aspects of river systems and often includes the use of panels of experts.

A review of global approaches to environmental flow assessment was presented by Tharme (2003). The methods in groups 1) and 2) described above provide a rapid appraisal of environmental flow requirements and are useful for initial appraisal purposes. They tend to focus on the hydrological and hydraulic parameters of rivers that are deemed to be ecologically important in very generic terms, without a detailed knowledge of how these parameters specifically determine the ecological status of the river. A major criticism of hydrological methods is their exclusion of any explicit consideration of actual habitat requirements, water quality and other geomorphological factors. The methods in groups , 3) and 4) overcome this problem by considering the site-specific linkages between flow, morphology and ecology in much more detail and hence are deemed to be more scientifically robust and defensible. However, they normally have much greater field data requirements, demand personnel with a broad range of expertise and require considerably more time to be implemented (Maddock I, 2008, personal comm.). A high number of methodologies presenting some combination of hydrological, habitat-discharge and/or partial holistic approaches have been developed and applied across the world.

According to Arthington and Zalucki (1998), approaches to environmental flow assessment can also be divided into the following groups:

1. Methods addressing flow requirements for geomorphological purposes
2. Methods addressing flow requirements for wetland, riparian and floodplain vegetation
3. Methods addressing flow requirements of fish
4. Methods addressing flow requirements of aquatic invertebrates

Historically, instream flow studies have focused on determining the low-flow conditions required to maintain particular instream values, because low-flow periods are the time of greatest competition for the limited amount of water that is available, and a time when the river ecosystem is most under stress. However, several aspects of a river's flow regime may influence its ability to maintain particular instream values. These may be summarised as follows (Jowett and Biggs 2006):

- Large floods
- Smaller floods and freshets, with a frequency of a few times each year
- Low flows
- Annual flow regime
- Flow variability.

The main ecologically relevant components of flow regime are:

- Magnitude of discharge
- Frequency of occurence
- Duration of given flow conditions
- Timing or predictability of flow
- Flashiness of flow

River management requires scientifically-sound operational tools for an evaluation of environmental flow that meets instream, riparian and floodplain needs (Petts and Maddock, 1995). The basic components of an environmental flow strategy should include the following flows (Petts, 1996, Erskine et al, 1999):

- ➢ channel maintenance flows
- ➢ habitat maintenance flows
- ➢ minimum flows that preserve aquatic and riparian ecosystem
- ➢ minimum acceptable flows that enable maximum habitats for target species

- flows that enable the seasonality of flood flows.

3.4 Objectives of the project

The objectives of this project derive from the conclusions of the first phase of the Living Neretva Environmental Flow working group, finalized in 2007.
The main aims of this project were:

- to test the selected GEP methodology for the calculation of the environmental flow in a selected pilot area of Neretva, the river Trebižat;.
- to increase the capacity of a selected number of experts on environmental flow assessment;
- to collect data on river ecology, river use, and river pollution;
- to develop recommendations for the preparation of relevant sub-laws on environmental flow, as required by BiH Water Laws (art. 62 Water Law FBiH, art. 65 Water Law RS.

4 STUDY AREA: RIVER TIHALJINA-MLADE-TREBIŽAT

4.1 Study area

The study area in southwest Bosnia and Herzegovina covers that part of western Herzegovina mainly situated in the Municipality of Ljubuški, which is the main settlement in the area. A Broad area of western Herzegovina is represented by the dominance of well developed Karst formations and phenomena, with specific hydrodynamic functioning. The most interesting part under this study was the middle one, with its water courses flowing from the northwest toward the Neretva river, which flows from the southeast but assumes a sharp southwestern flow through the Karst region.
Ljubuški also has several karst-specific arable lowlands ("poljes"): Ljubuško polje, Veljačko polje, Vitinsko polje, Rastok and Beriš, irrigated by the Tihaljina – Mlade – Trebižat river system , with two beautiful waterfalls – Kravica and Koćuša.

On the basis of the field trip and the visit to different sections of the Tihaljina-Mlade-Trebižat river and according to exisiting hydrological data, environmental flow was assessed for the section of the Tihaljina and Mlade river, from the source of Tihajlina (gauging station Peč Mlini uzvodno / nizvodno) to the gauging station Grabovo vrelo (Mlade); that means that environmental flow was assessed for the Tihaljina river and for a part of the Mlade river.

Environmental flow was evaluated for the following gauging / hydrological stations (HS):

1. HS Peć Mlini Tihaljina source
2. HS Peć Mlini downstream (Tihaljina)
3. HS Tihaljina (Tihaljina)
4. HS Klobuk – Kavasbašin most (Mlade)
5. HS Grabovo vrelo (Mlade)

A description with photos of the hydrological stations isin Appendix 1 – Appendix 6.

4.1 Geography

Trebižat is the right tributary of the Neretva river, which flows about 50km from its source in Peć-Mlini (Grude) to its mouth into the Neretva river (Struge, Čapljina). However, being part of a very specific and complex draining system of the karst of western Herzegovina, the same water flows under different names. The section from Peć-Mlini to Klobuk is known as Tihaljina river, that from the source Klokun to the inlet into the water course Vrioštica is called Mlade, and finally, that from Humac to the inlet to the Neretva river, is called Trebižat.

The avalilable elevation from the source in Peć-Mlini (about 127-130 m.a.s.l.)[1] to its mouth into the Neretva river (about 8 m.a.s.l.) is around 120m.

[1] Earlier altitude of the source was around 245 m.a.s.l., at Ravlica cave, much higher than the current one

Going upstream, looking from the Ljubuško Polje at the Imotsko-Bekijsko Polje, we will meet the waters of the Trebižat called by five names: Matica – Vrlika – Tihaljina – Mlade – Trebižat. Moreover, looking at the upper horizons, it becomes a river with the names Ričina – Suvaja – Sija - Matica - Vrlika - Tihaljina - Mlade – Trebižat.
The total orographic catchment area is around 1200km^2, including about 90km^2 of the Imotsko-Bekijsko polje area. It is necessary to note that the hydrological watershed is hard to define correctly, because of the Karst phenomena described above.

Climate conditions

Although Bosnia and Herzegovina is largely cut off from the climatic influence of the Mediterranean by the Dinaric Alps, Herzegovina is more similar to the Dalmatian mountains. Being on the border between Continental and Mediterranean climate, western part of Herzegovina is in a moderate continental climate zone, with abundant precipitation, but hot in summer. The coldest month is January, averaging 6° C, and the warmest month is July, averaging about 26° C. A relatively dry season is from June to September. The remainder of the year is wet, with the heaviest precipitation between October and January.

Historic heritage of the river

Due to its climate with abundance of sun and precipitations, this area has been attractive for the humans since a long time ago. The system of surface watercourses is one of the most significant. For example, Romans conquered Illyrians in the 1st century and built military and civil settlements. As part of one of the military buildings for the numerous Romans legions, a bathing sauna has been found , with an underground system of heating (*hypocausis*). The existence of numerous civil agricultural estates (known as *villae rusticate*) has not yet been investigated.
During the Austro-Hungarian period, an improved system for the Ljubuško polje was built. Irrigation systems for agriculture production, as well as the usage of water power for numerous water mills, have been common practice in this area for a long time.
The beauty of the Trebižat river is well known: it includes numerous water sources surrounded by beautiful nature (source of Tihaljina, Klokun, Modro oko, Vrioštica) and wonderful waterfalls like Koćuša and Kravica. Kravica waterfall runs for 100 meters and drops an impressive 25 meters.

Demography

There has been no precise data regarding Bosnia and Herzegovina's population since the last war. The UNHCR conducted an unofficial census in 1996, but the data have not been recognized.
Generally, according to the latest data available, the ratio between the urban and rural population is 60 to 40. This resettlement trend has led to the complete decline of many rural settlements and the appearance of underpopulated areas. A false image of a highly urbanized country and of heavy pressure on the environment is thus created. [2]

[2] Governments of the Federation of Bosnia and Herzegovina and Republika Srpska, 2003, National Environmental Plan – NEAP

The problems of both poverty and social issues in Bosnia and Herzegovina have been recently comprehensively examined.[3] The solution, it was concluded, lies precisely in economic development, which implies the revitalization of the country's economic capacities and a return to pre-war levels of employment and sustainable rural development.[4]

According to a 1991 census, the number of inhabitants in the Municipality of Ljubuški was 28,340, including Ljubuški with about 5,000 citizens. In the related area of 289km^2, the specific density was 98 inhabitants per km^2.

4.2 Geology of the river and its tributaries

The river Trebižat and its tributaries belong to a region of arid limestone plateaus with caves, potholes, and underground drainage, as a result of natural processes through long geological periods: rain and snow falling in winter absorb carbon dioxide out of air and soil, turning it into weak carbonic acid. This is a consequence of their effects on soluble rocks (limestone and dolomite).
The uplands are often bare and denuded (the result of deforestation and thin soils), but, between the ridges, depressions known as poljes are covered with alluvial soil that is suitable for agriculture.

As rainfall water sinks through cracks very fast, the network of surface water course is poor, sometimes represented by temporary water courses, while Karst formations (sinkholes, zones of sinkholes, estavelles) are present with specific hydrodynamic functioning. The most significant is the characteristic of a high water permeability, often represented by a complicated network of underground channels.

Figure 1 shows zones of high and low permeability, as well as the directions of underground water courses, researched with tracers (Slišković).

[3] «Poverty Assessment in BiH» is the result of a survey conducted on living standards in BiH for the year 2001 by a team of experts from the World Bank in cooperation with representatives from the Institutes for Statistics of RS and FBiH and the BiH Agency for Statistics.
[4] The analysis of the system of settlements shows that there are about 1,500 sub-municipal centres with 500-2000 inhabitants that possess the resources that could be used primarily for healthy food production.

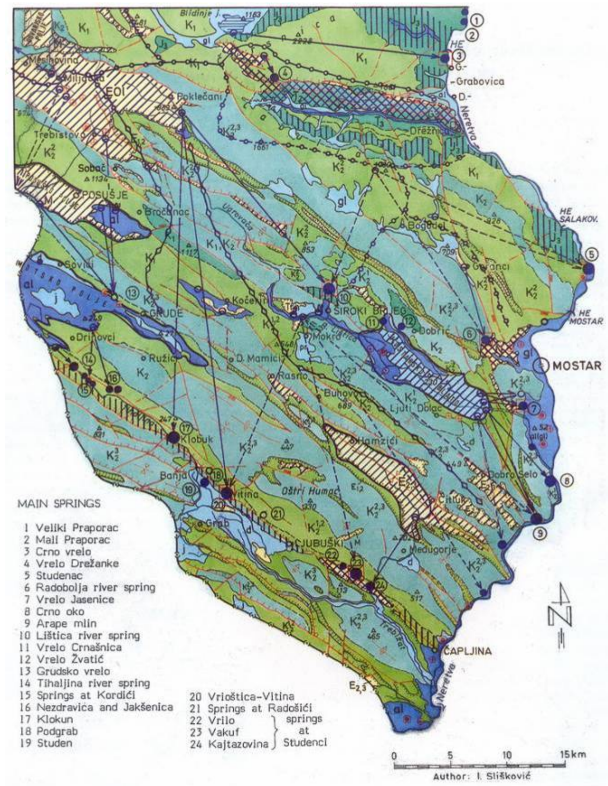

Figure 1 -Hydrogeological map of western Herzegovina

4.3 River hydrology and morphology

When talking about the Trebižat river from a hydrological point of view, it is important to stress the complexity of the natural hydrodynamic water regime of the broader area of western Herzegovina.
As already mentioned, if we are looking from the Ljubuško Polje towards the Imotsko-Bekijsko Polje, we will see the waters of the Trebižat, which has four names: Vrlika – Tihaljina – Mlade – Trebižat (watercourse V-T-M-T). The total length of the V-T-M-T watercourse from the Opačac source (Vrljika) to the mouth into the Neretva river (Trebižat) is around 70km. The orographic catchment area is in total around 1200km^2, including about 90km^2 of the Imotsko-Bekijsko polje area. It is necessary to note that the hydrological watershed is hard to define correctly because of the Karst phenomena described above.

A general preview of the network of the surface watercourse system V-T-M-T is shown in *Figure 2*. The hydrological stations within the V-T-M-T system are shown in Table 1.

Table 1 – Hydrological stations at V-T-M-T system

No	HS	Watercourse	Catchment	Coordinates		Altitude HS «0»
				latitude	longitude	
1	Kamenmost	Vrljika	Adriatic Sea	43°25′53″	17°12′01″	259,69
2	Biočići	Vrljika	Adriatic Sea	43°22′29″	17°15′52″	252,91
3	Rakitovac	Vrljika	Adriatic Sea	43°22′08″	17°16′42″	250,26
4	Drinovci	Ponor Šainovac	Adriatic Sea	43°21′23″	17°18′45″	249,32
5	Drinovci	Plavilo	Adriatic Sea	43°22′22″	17°19′21″	253,06
6	Drinovci	Jezero Nuga	Adriatic Sea	43°21′08″	17°19′27″	248,91
7	Brzotok	Vrljika/Tihaljina	Neretva	43°20′32″	17°19′45″	-
8	Peć Mlini uzv	Tihaljina	Neretva	43°22′13″	17°19′49″	141,39
9	Peć Mlini nizv	Tihaljina	Neretva	43°19′58″	17°19′58″	134,53
10	Tihaljina	Tihaljina	Neretva	43°19′06″	17°21′31″	124,75
11	Klobuk	Mlade	Neretva	43°16′15″	17°26′59″	105,74
12	Grabovo vrelo	Mlade	Neretva	43°15′23″	17°27′30″	96,90
13	Koćuša Veljaci	Mlade	Neretva	43°14′30″	17°28′25″	80,18
14	Grab	Mlade	Neretva	43°13′32″	17°28′30″	77,76
15	Humac	Trebižat	Neretva	43°11′00″	17°31′41″	64,88
16	Stubica	Trebižat	Neretva	43°09′10″	17°38′11″	-
17	Studenci	Trebižat	Neretva	43°09′08″	17°38′38″	21,81
18	Donji Vinjani	Velika Udovica	Vrljike	43°25′41″	17°15′33″	257,34
19	Donji Vinjani	Mala Udovica	Vrljike	43°25′24″	17°16′07″	257,34
20	Grude	Grudsko vrelo	J. mora	43°22′22″	17°22′22″	253,73
21	Farkašev most	Prispa	J. mora	43°21′37″	17°24′51″	244,94
22	Baran	Prispa	J. mora	43°21′39″	17°25′44″	254,89
23	Poljana	Vrelo Klokun	Tihaljine	43°16′58″	17°26′08″	111,56
24	Grabovo vrelo	Grabovo vrelo	Mlade	43°15′33″	17°27′45″	99,19
25	Kapel Mahala	Studena	Mlade	43°15′08″	17°27′08″	-
26	Parilo–Brza voda	Kanal	Mlade	43°13′48″	17°28′23″	78,54
27	Vitina	Vrioštica	Mlade	43°14′11″	17°29′26″	78,65
28	Studenci	Studenčica	Trebižata	43°09′28″	17°38′44″	Rel 24,00

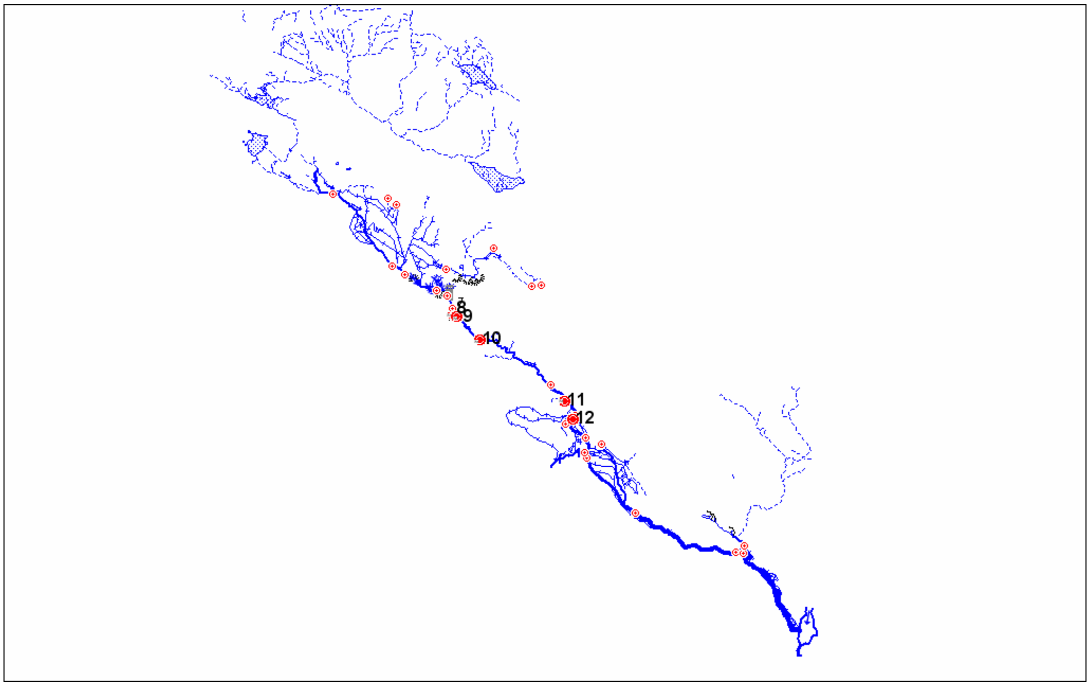

Figure 2 - Hydrography of the V-T-M-T catchment with hydrological stations

The left tributaries to the Tihaljina river are short watercourses: Krupa, Nevidin, Jakšenica, Nezdravica. From the right side, the Zloriba, the Meljava and some small watercourses around the Klobuk source flow into the Tihaljina, *Figure 3*.

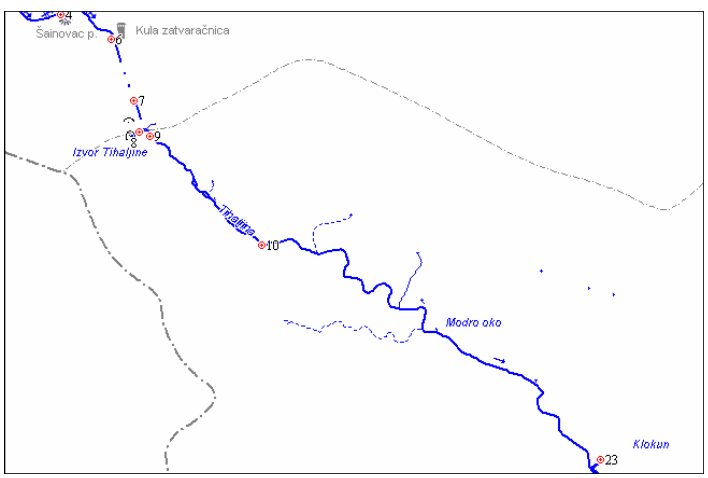

Figure 3 – Hydrography of the Tihaljina river

The main left-tributary to the Mlade is the Vrioštica, as well as a creek forming at D.Proboj. The temporary watercourse Studeni potok flows into the Mlade from the right side, close to the Koćuša waterfall, *Figure 4*.

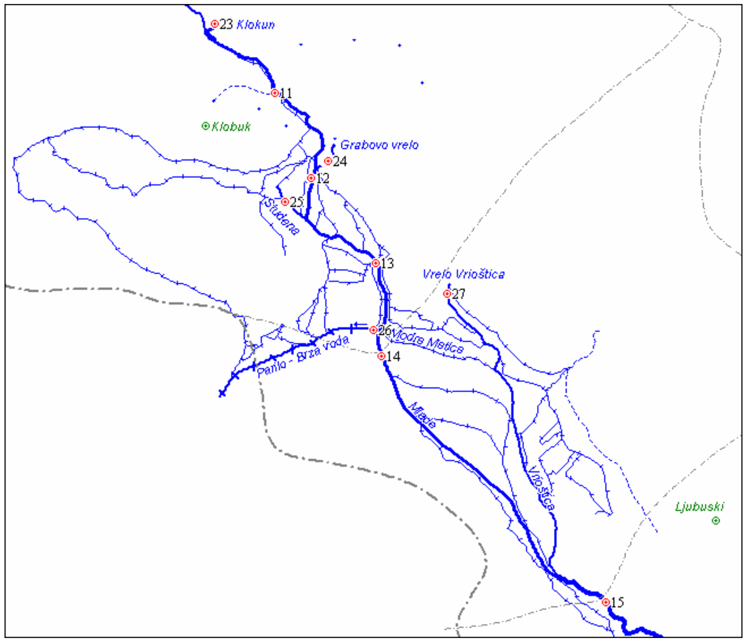

Figure 4 – Hydrography of the Mlade river

The main left tributary of the Trebižata is the Studenčica, which collects the temporary water courses Lukoča and Stube, *Figure 5.*

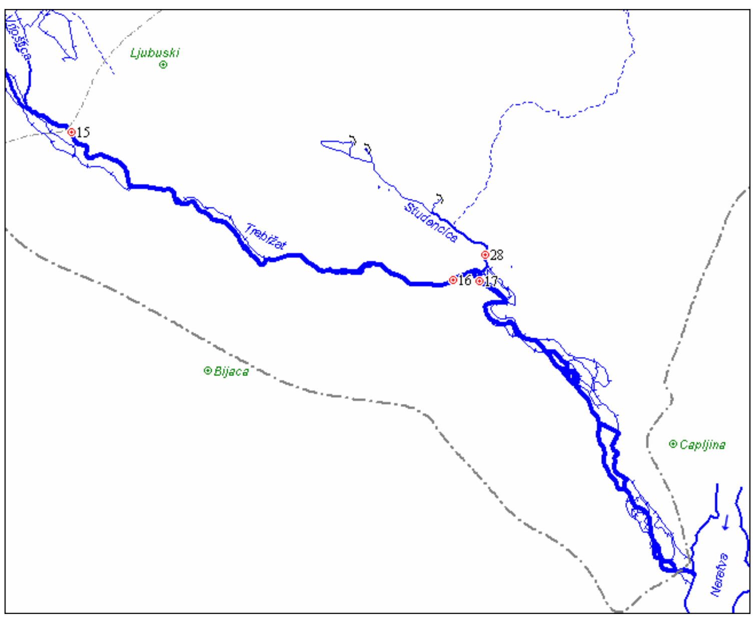

Figure 5 – Hydrography of the Trebižat river

4.4 Ecological characteristics

Ecoregion

The Herzegovina region includes the entire area of the river Trebižat. This region is characterised by the belt of the Mediterranean ecoregion. The region includes the area of the east coast of the Adriatic karst, which stands as a separate Eastern Adriatic sector of the Adriatic province. As to climate, this is an area under varying influence from the Mediterranean climate, characterised by mild and considerably short, rainy winters and dry, hot summers. There are significant differences between the parts of the Adriatic province that directly adjoin the sea, and those more or less distant from it, horizontally and/or vertically. The differentiation is between the Eumediterranean zone and sub-mediterranean zone (including in a broader context the Mediterranean-montane vegetation belt).

Sub-mediterranean zone

The Herzegovina area is in the sub-mediterranean zone that, includes the belt of decidous vegetation which is a direct continuation of the evergreen zone of the Eumediterranean coast, and the Mediterranean-montane belt of deciduous vegetation situated at higher altitudes.
Compared to the climate of the Eumediterranean zone, this zone has relatively greater amount of precipitation. This fact and the relatively cold winters, cause the break in the vegetation, that is, its deciduous habit.
The lower belt of the sub-mediterranean zone is characterised by the zonal forest association *Carpinetum orientalis adriaticum (Carpinion orientalis* alliance, order *Quercetalia pubescentis*, class *Querco – Fagetea)*. In the large part of the Sub-mediterranean coast of the east Adriatic, the association *Carpnetum – orientalis adriaticum* has developted in the form of bigger or smaller and thinner shrubs or underbrush. The higher Mediterranean – montane belt harbours in the hinterland the zonal forest association *Carpinetum orientalis adriaticum*. Due to degradation, these Sub-mediterranean forests have turned into specific, permanent anthropogenic forms – dry grasslands and rocky pastures of the order *Scorzonero – Chrysopogonetalia.*

Protection status of the river

According to BiH Environmental protection law, **protected environmental landmarks on the Trebižat River are:**

- The travertine-forming around the Kravice waterfall, which is one of the geological monuments of nature,
- geomorphologic monuments: the Tihaljina spring in Peć Mlini, the Vrioštica spring in Vitina, and
- the waterfalls Koćuša, Kravice and Bučine.

4.5 River pollution

In the summer when the water level decreases the water quality can be lower, due to the presence of fecal pollution, which is connected with the fact that the underground flow most probably "collects" the wastewaters from the counties of Grude and Posušje. River pollution can also be caused by agriculture, urbanization and lack of wastewater treatment plants. One of the reasons for the high concentration of sulphate in the Modro oko tributary could be the natural dissolving of the alabaster substrate when the water flows underground.

4.6 River usage

Apart from the unique Karst hydrogeology, anthropogenic processes, with the existence of numerous hydro-technical buildings that affect the water regime, are also significant in this area:

- Water catchments were built for various purposes, especially for agriculture. In the sub-Mediterranean climate the arable terrain (in the Karst polje) needs water for irrigation, especially during the warm season. As a result, a surface network of artificial irrigation water streams is highly developed, with the first one built close to the Tihaljina source;
- Close to the mouth of the Grabovo vrelo there is a water diversion for a fish farm, as well as for irrigation purposes, which influences the flow regime of this section of the Mlade. The remaining water returns to the Mlade at the river section downstream of HS Grabovo Vrelo (river Mlade);
- The water reservoirs Ričica (in 1987), Tribistovo (in 1990), and Rastovača (water supply, irrigation, flood defence) were built along the upper part;
- The underground tunnel Pećnik was built in 1950, together with the tower gate (*Kula zatvaračnica*), to defend the Imotsko polje from floods, e.g. the high water evacuation from the natural temporary reservoir Nuga, during the wet season; the surface part of the evacuation system is represented by a concrete-fast waterway (*brzotok*) that flows into the Tihaljina river;
- The HPP Peć Mlini, located downstream of the Tihaljina source, has been functioning since 2004.. HPP Pec Mlini is a derivation type of hydropower plant, connected with the water reservoir/lake Nuga by a pressure tunnel (diameter 3.6m), then a surface pipe (diameter 2.6m) and with the engine room at Drinovci / Pec Mlini. The water intake from the Nuga lake for the purposes of HPP Pec Mlini also affects the water quantities of the Tihaljina source, because the gate at the Sainovac sink has been in function since 2004 to keep the water in the Nuga reservoire.

4.7 River management

The Agency for the Adriatic Sea catchment (Mostar) is responsible for the Neretva river management, including the river Trebižat, in the BiH Federation. Some of the main responsibilities of the Agency are as follows:

- Data collection on water resources, including establishment and maintainance of the Information System;

- Organization of water quantity and water quality monitoring;
- Preparation of reports on the state of the water;
- Preparation of the River management plan (to 2012);
- Preparation of technical documentation on particular water management issues, in accordance with the Water Law;
- Flood-protection plan preparation;
- Water license issue.

In 2007, “Elektroprivreda HZ HB” Mostar prepared a basic document on the hydrological, land surveying and power generation basis for the potential locations of mini hydropower plants (mini HPP) at the river system Tihaljina-Mlade Trebižat (T-M-T). Five potential locations are recognized: mini HPP Modro oko, mini HPP Klokun, mini HPP Koćuša, mini HPP Kravica and mini HPP Stubica.

4.8 Selection of sampling sites

Environmental flow assessment heavily relies on the knowledge of the structure and function of the river under investigation. At the time when the team were collecting existing data on river ecology and river physico-chemical data, it was found that many data were missing. As a result, it was decided to sample additional parameters, such as macrophytes, phytobenthos and selected physico-chemical variables. Macrophytes are very important primary producers in the Trebižat river and phytobenthos is one of the main groups of organisms with an important function in travertine formation. The objective was to evaluate water pollution of the river Tihaljina through selected physico-chemical parameters. These data have helped assess the river status, the ecological values of the river and select critical parameters for the environmental flow assessment.

The sampling sites were selected between the source of the Tihaljina to the hydrological station Grabovo vrelo. To get more information about the structure and function of the river ecosystem 5 sampling sites were selected (*Figure 6)*:

T1 – near the HS Peč Mlini Tihaljina source (8)
T2 – near the HS Peč Mlini downstream (9)
T3 – at the Modro oko source
T4 – near HS Klobuk (11)
T5 – near HS Grabovo vrelo (12)

The sampling site T3 was selected at the inflow of the Tihaljina, because it is known it contain high values of sulphates.

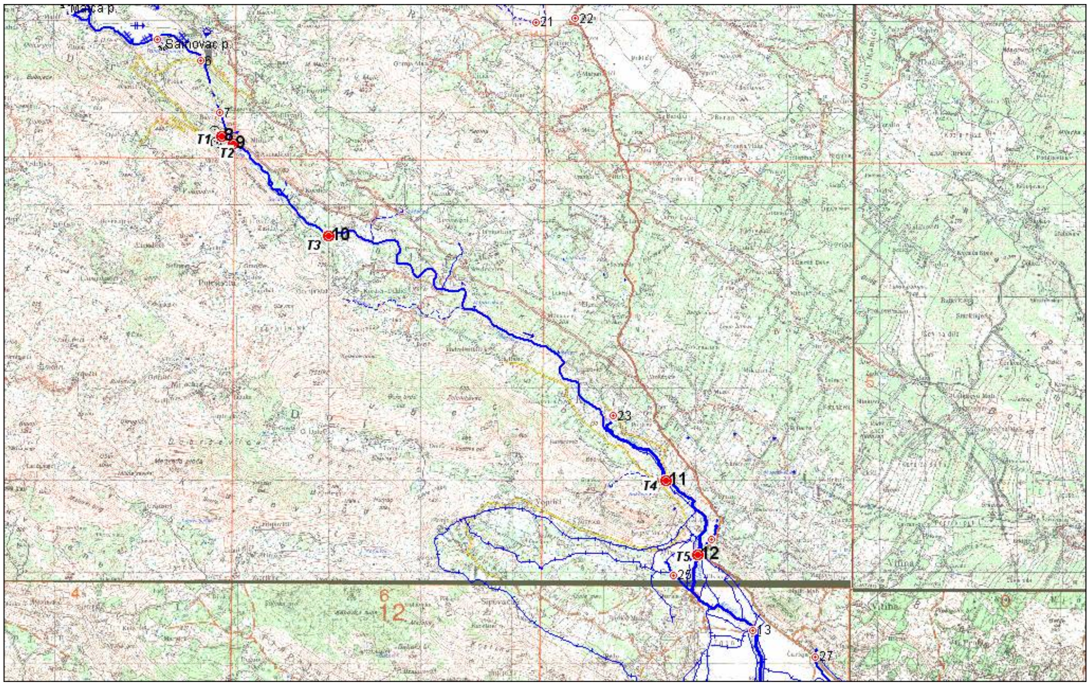

Figure 6 Hydrological stations and sampling sites along a selected section of Tihaljina and Mlade

5 METHODOLOGY

5.1 Procedure for environmental flow assessment of the Tihaljina – Mlade river

Although the main objective of the project was environmental flow calculation only according to the GEP methodology, we followed the main idea that an environmental flow must maintain the river ecosystem. This means that the structure and the function of the ecosystem must be known. As a result of this assessment, the team intends to stress the need for additional criteria with respect to the GEP. These additional criteria play an important role in the holistic approach of environmental flow evaluation, and this was the motive for the collection of additional biological and physico-chemical parameters of the river, that are otherwise unnecessary when applying only GEP methodology.

The working group used a process for calculating environmental flow for the river section consisting of 8 steps, represented in Figure 7.

This project was not intended to reach step 8 (monitoring) because of its limited duration, but it is hoped that monitoring will be incorporated into the next phases of the project.

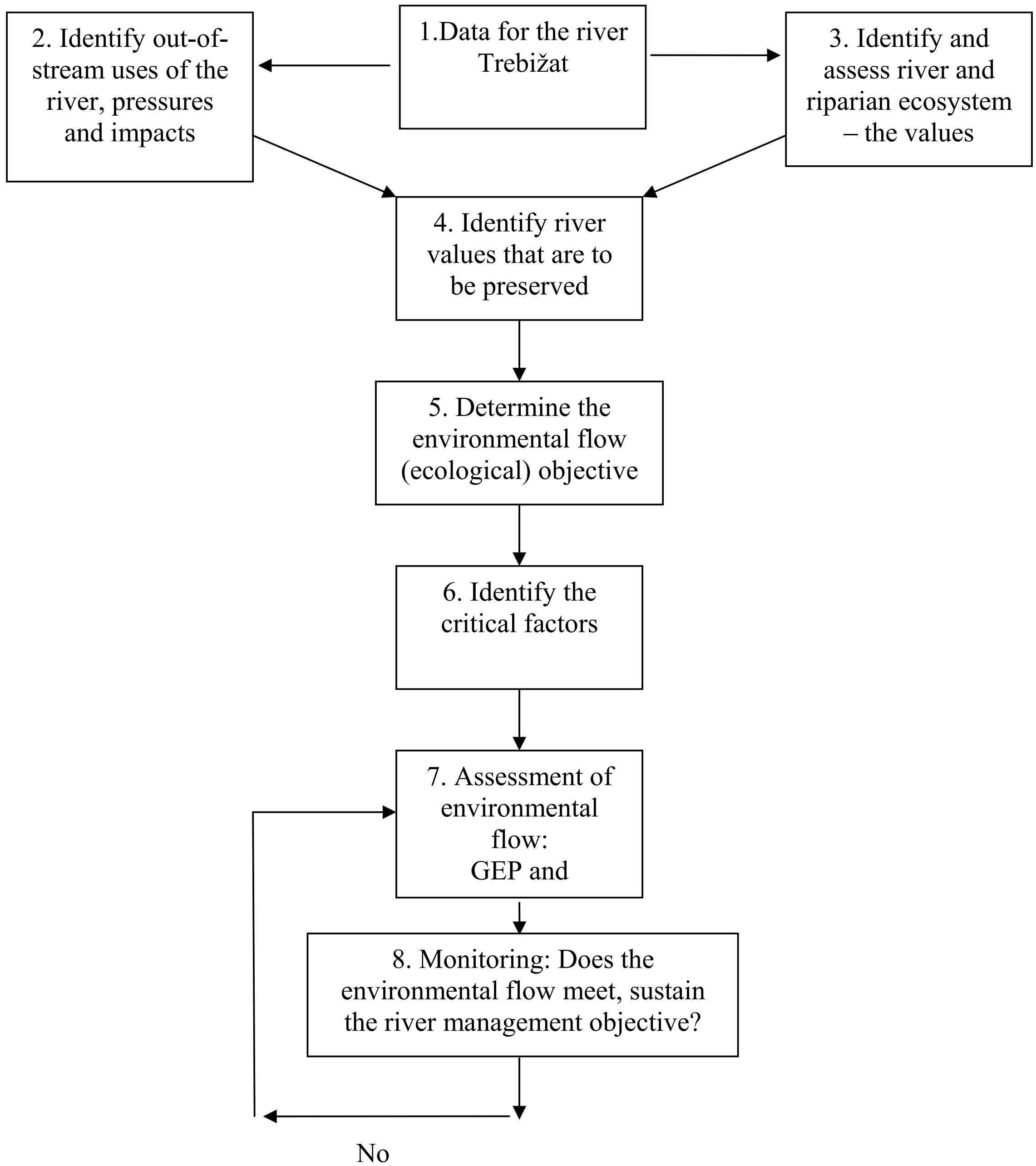

Figure 7 – procedure for environmental flow assessment

In the case of this pilot environmental flow assessment in BiH, a critical constraint in the procedure was the lack of data on river ecology.

5.2 Objectives for environmental flow assessment

In general, the overall goal of an environmental flow assessment is to ensure that river ecosystems are healthy and can provide goods and services for the benefit of people.

The specific objectives for environmental flow assessment in rivers are:
- to protect aquatic and riparian ecosystem from deterioration
- to improve /preserve habitats for aquatic flora and fauna
- to restrict water extraction/diversion during low-flow periods
- to protect habitats, especially for endemic and endangered species.

It was impossible to define more detailed objectives, such as maintaining good ecological status or good ecological potential of the river, for the lack of ecological data mentioned above, and because the thresholds for ecological classes (required by the new BiH water laws) are not yet developed in BiH.

5.3 GEP method (Đorđević, Dašić)

The application of the GEP methodology is based on three parameters: (1) average multiannual flow on the dam profile, eg. location of water diversion ($\overline{Q}$), (2) monthly-minimum low-flow 95% exceedence probability ($Q_{95\%}^{\text{min.monthly}}$), (3) monthly-minimum low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$). If multiannual series of daily flows are available, instead of minimal monthly flow ($Q_{95\%}^{\min.monthly}$) and ($Q_{80\&}^{\min.monthly}$), adequate values of 30-day low flow with the same exceedence probability ($Q_{95\%}^{\text{min.(30)}}$) and ($Q_{80\%}^{\min.(30)}$) can be used[5]. When all mentioned data are available, basic principles are summarized in a clear rule that defines the GEP methodology:

The guaranteed ecological flow (GEP flow – $Q_{ecol\cdot gar}$) adoption is as follows:

(1) During the cold season (October-March), the guaranteed $Q_{ecol\cdot gar}$ should be chosen as the value of the monthly-minimum low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$), e.g. 30-day low-flow with the same exceedence probability ($Q_{95\%}^{\text{min.(30)}}$), but that value should neither be less than $0{,}1\times\overline{Q}$, nor higher than $0{,}15\times\overline{Q}$. That means that $Q_{ecol\cdot gar}$ for the cold season should be chosen on the basis of the equation:

[5] Alternatives are given by operational reasons. Certainly, it is better if the data on the 30-day low-flow appropriate exceedence probability are available, because that is more in accordance with the physics of low flow phenomena: extremely low flow periods defined as the year-low flow of 30-day duration in continuity, can cover parts of two months. However, insisting only on flows ($Q_{95\%}^{\text{min.(30)}}$) and ($Q_{80\%}^{\text{min.(30)}}$) would not make sense, because the daily flows often are not available. …. As a rule, the usage of the monthly-min low-flow instead of the 30-day low-flow issues slightly higher values.

$$\mathrm{Q}_{\text{ecol.gar.}} = \begin{cases} 0.1\times\overline{\mathrm{Q}} & \textit{for} \quad \mathrm{Q}_{95\%}^{\min.\text{monthly}}\ \textit{ili}\ \mathrm{Q}_{95\%}^{\min.(30)} \le 0.1\times\overline{\mathrm{Q}} \\ \mathrm{Q}_{95\%}^{\min.\text{monthly}}\ \textit{ili}\ \mathrm{Q}_{95\%}^{\min.(30)} & \textit{for} \quad 0.1\times\overline{\mathrm{Q}} < \mathrm{Q}_{95\%}^{\min.\text{monthly}}\ \textit{ili}\ \mathrm{Q}_{95\%}^{\min.(30)} < 0.15\times\overline{\mathrm{Q}} \\ 0.15\times\overline{\mathrm{Q}} & \textit{for} \quad \mathrm{Q}_{95\%}^{\min.\text{monthly}}\ \textit{ili}\ \mathrm{Q}_{95\%}^{\min.(30)} \ge 0.15\times\overline{\mathrm{Q}} \end{cases}$$

(2) During the warm season (April-September), the guaranteed $Q_{ecol\cdot gar}$ should be chosen as the value of the monthly- minimum low-flow 80% exceedence probability ($Q_{80\%}^{\min.monthly}$), e.g. 30-day low-flow with the same exceedence probability ($Q_{80\%}^{\min.(30)}$), but that value should not be less than $0{,}15\times\overline{Q}$. e.g. it should be higher than $0{,}25\times\overline{Q}$. That means that $Q_{ecol\cdot gar}$ for the warm season should be chosen on the basis of the equation:

$$\mathrm{Q}_{\text{ekol.gar.}} = \begin{cases} 0.15\times\overline{\mathrm{Q}} & \textit{for} \quad \mathrm{Q}_{80\%}^{\min.\text{mes}}\ \textit{ili}\ \mathrm{Q}_{80\%}^{\min.(30)} \le 0.15\times\overline{\mathrm{Q}} \\ \mathrm{Q}_{80\%}^{\min.\text{mes}}\ \textit{ili}\ \mathrm{Q}_{80\%}^{\min.(30)} & \textit{for} \quad 0.15\times\overline{\mathrm{Q}} < \mathrm{Q}_{80\%}^{\min.\text{mes}}\ \textit{ili}\ \mathrm{Q}_{80\%}^{\min.(30)} < 0.25\times\overline{\mathrm{Q}} \\ 0.25\times\overline{\mathrm{Q}} & \textit{for} \quad \mathrm{Q}_{80\%}^{\min.\text{mes}}\ \textit{ili}\ \mathrm{Q}_{80\%}^{\min.(30)} \ge 0.25\times\overline{\mathrm{Q}} \end{cases}$$

If the values of the GEP flow issued by a defined low-flow exceedence probability are beyond the amplitude defined by the above rules and equations (1) and (2), limiting values should be chosen.

(3) If the water course is used for specific ecological or recreational requests and goals, the values issued on the basis of the above rules and equations could be increased as follows: up to 15% for the cold season, up to 30% for the warm season. A special analysis/justification of the increased value is needed in such a case.

(4) The values of the GEP flow issued for the cold season could be treated as constant, but, if needed, a certain variation is possible (a certain increase of flow in March, during the reproduction period for some fish).

(5) The Values of the GEP flow for the warm season are averages. The meeting of special needs of ichtiofauna and other organisms is required. In critical periods of reproduction, discharge values need to be increased in accordance with eventual requests by the authorities responsible for ecological protection and fisheries. A decrease is possible during proper hydrological situations when flows are favorable, but the values of the flow downstream should not be less than the discharges during the cold season.

(6) The flow released for these purposes is not energetically lost. Small turbines can be applied at such outflow, which will use that discharge. But there is an obligation for such outflow to have separate flow gates that will enable release of water even when the turbine is out of order or is under maintenance.

5.4 Data collection

5.4.1 Hydrology and Geomorphology

The study Tihaljina – Mlade – Trebizat was carried out by «Elektroprivreda» HZ HB, and prepared by the Federal Hydrometeorological Institute in 2001. The main task of the study was i) to assess the hydrological parameters for the river system Vrljika–Tihaljina-Mlade-Trebižat and ii) to assess the flow regime including its spatial and temporal distribution for the period during which data were collected.

5.4.2 Aquatic flora and fauna

5.4.2.1 Existing data

Previous research was carried out in 1963 and 2003 and results are presented in the following papers:

- Matoničkin, I. & Pavletić, Z. 1963. Sudjelovanje pojedinih životinjskih i biljnih skupina u izgradnji životnih zajednica na sedrenim i erozijskim slapovima Bosne i Hercegovine. Iz Biološkog instituta i Instituta za botaniku Sveučilišta Zagreb. This paper mentions the biological communities (flora and fauna) that are involved in the building of the travertine-forming waterfall Kravice on the Trebižat River.
- Bogut, I., Pavličević J., Ivanković, S., Petrović, D., 2003. Kvalitativni i kvantitativni sastav ihtiofaune rijeke Trebižat. Znanstveno stručni simpozij s međunarodnim sudjelovanjem Voda u kršu slivova Cetine, Neretve i Trebišnjice, Zbornik radova, Neum.This paper is referred to further in the chapter titled Ihtiofauna.

5.4.2.2 Additional sampling done by the project

Macrophytes

Field research was carried out during 2007 at sampling sites T4 and T5 for the Ph.D. thesis of a working group member, and at sampling sites T1, T2 and T3, in April 2008 for the Living Neretva project. The main disadvantage during the time of sampling was a quite high water flow. The families of macrophytes are determined by using standard keys and iconography (FIORI 1923 – 1929, 1933; TUTIN et all. 1964 – 1980; TRINAJSTIĆ 1975 – 1986; PIGNATTI 1982; DOMAC 1994; BURNIE 1995; DELFORGE 1995, 2001; BLAMEY i GREY – WILSON 1998). The plants are collected and stored in the Department of Biology of the Faculty of science and education, at the University of Mostar.

Phytobenthos

Five samples of phytobenthos were collected in April 2008 from the river Tihaljina within the framework of the project. The samples were brushed from the surface of stones and rocks with a razor and also squeezed out of water moss. The samples were immediately preserved in a 4% formaldehyde solution. Each of the samples was treated with concentrated HNO_3 in order to determine Bacillariophyceae species (APHA, 1992). Species were determined by a light microscope Nikon Eclipse E400 (magnification 1000×) and the following identification monographs: Krammer & Lange-Bertalot (1997-2004), Hindák et al. (1978), Hindák (1996), Komárek & Anagnostidis (1998, 2005). Relative abundance was estimated according to Pantle & Buck (1955) with numbers 1, 3 and 5 (1-single, 3-customary, 5-dominant).

Scale for estimation of each algae taxa abundance:

abundance	presence of taxa in % of the visible field
1-single	1-15
3-common	>15-60
5-dominant	>60-100

The **saprobity** of the river Tihaljina (Saprobic Index) was calculated on the basis of the list of indicator organisms, in order to assess the present water quality (according to Wegl, 1983) using the Pantle-Buck index (Pantle-Buck, 1955).

A hierarchical **cluster analysis** comparing similarity in species' structure and the relative abundance estimations of algae species (Bray-Curtis coefficient of similarity) (Clarke et al., 1990) was performed on the matrix of relative abundance estimations.

5.4.3 Physico-chemical parameters

5.4.3.1 Existing data

Monitoring of the water quality on the river Tihaljina is the responsibility of the Agency for the Adriatic Sea catchment (Mostar). Some data on water quality are also collected by "Elektroprivreda" HZ HB.
In the periods of lower water level during summer the water quality can be lower, due to the presence of fecal pollution, which is connected to the fact that underground flow is likely to "collect" the wastewaters from the counties of Grude and Posušje. The causes for river pollution can also be found in agriculture, urbanization and the lack of wastewater treatment plants.

5.4.3.2 Additional sampling carried out during the project

Additional sampling was done on in April 2008 at 5 sampling sites. To get more data about physico-chemical status of the river Tihaljina -Mlade the parameters presented in Table 2 were sampled:

Table 2 – Parameters of additional sampling

Parameter
Geographical latitude
Geographical longitude
Date
Temperature water (^{o}C)
Turbidy (NTU)
pH value
m-alkalinity (mg $CaCO_3$/l)
Conductivity 20^{o}C (µS/cm)
Suspend. solid (mg/l)
Disolved oxygen (mg O_2/l)
Saturation (%)
Total hardness (mg $CaCO_3$/l)
Carbonat hardness (mg $CaCO_3$/l)
COD- $KMnO_4$ (mg/l)
Biological oxygen dem BPK_5 (mg/l)
Amonium (mg N/l)
Nitrate (mg N/l)
Nitrite (mg N/l)
Orthophosphate (mg P/l)
Phosphorus (mgP/l)
Sulphate (mg SO_4/l)
Ca-$CaCO_3$ (mg/l)
Mg-$MgCO_3$ (mg/l)
Natrium (mg/l)
Silica (mg SiO_2/l)
Coliform bacteria in 100 ml of water
Enterococcus faecalis
Flow (m^3/s)

Analyses were done in the laboratory at “Komunalno poduzeče Ljubuški”.

6 RESULTS

6.1 Hydrology

River flow data are essential for environmental flow assessment. Not only the amount, but also the timing, quantity and duration are important. Other priorities are an inventory of the ecologically relevant information that already exists in the country, and to quantify how hydrology impacts the river ecology. Daily flow data are the important starting point for assessing environmental flow. Monthly flow data are also a good alternative. But because the natural flow patterns vary so much from year to year, the data sets need to cover at least 20 years. Generally, for a statistical analysis of temporal variability and trends, long-term **homogeneous** time series are required.

The study period with available hydrological data for the area should be divided into two sub-periods: that with a natural regime of flow, up to 1950, and that with an artificial one, since 1950, when the flood-prevention system had been built (i.e. the high water evacuation from upstream lake Nuga). The concrete-fast waterway (*brzotok*) built as part of this system was situated downstream close to the Tihaljina river source, so that the river system T-M-T is influenced during high water, as well as during maintaining operations.
Water intakes for irrigation purposes are present along the whole section. The first one is situated immediately downstream of the Tihaljina source.
HPP Pec Mlini has been functioning since 2004. The period 1950-2004 is characterized as "reference" by the Study.

Characteristic hydrological values were calculated on the basis of the daily average flows for the period of stations activity (Table 3) and for the common period for all the stations, e.g. the period 1975-1987.

Table 3 – Available data for hydrological analyses

No	*HS*	*Water course*	*Period*
8	Peć Mlini Tihaljina source	Tihaljina	1975-1991
9	Opeć Mlini Downstream	Tihaljina	1967-2001
10	Tihaljina	Tihaljina	1963-1989
11	Klobuk	Mlade	1965-2001
12	Grabovo vrelo	Mlade	1968-1987
24	Grabovo vrelo	Grabovo vrelo	1968-1987

As an example, the hydrograph for the Mlade at HS Klobuk, in 1987, is presented in *Figure 8.*

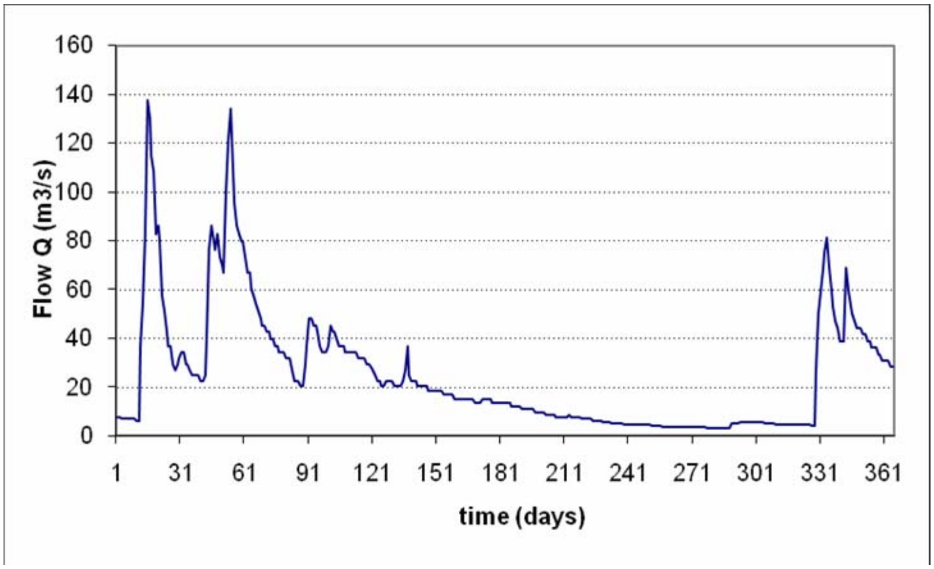

Figure 8 – Hydrograph of Mlade river at HS Klobuk, 1987
MIN Q = 3,35 m3/s, date 9.10; AV Q= 25,3 m3/s; MAX Q = 144 m3/s, date 15.1.

From Figure 8 we can see that minimum flows are common in summer time, while higher flows occur in winter and spring time.
The hydrological calculations of the basic parameters needed for the GEP evaluation are given below for each hydrological station (Table 3 to Table 14). Detailed hydrological analyses are presented in Appendix 1 -6.

HS Peć Mlini source of Tihaljina*

**Remark: water extraction for irragation is situated upstream of the station and it was not calculated in our analyses. There are no exact data on water quantity flowing through artificial channels and this accounts for the gaps in our analyses. Characteristic hydrological values and GEP methodology parameters shown in* Table 4 *and* Table 5 *have been calculated on the basis of the Tihaljina data.*

Table 4 – Characteristic hydrological values, HS Peć Mlini-Tihaljina source

Station No	Period	Qmin. (m^3/s)	meanQmin (m^3/s)	Q mean (m^3/s)	Q max. (m^3/s)
8	*1975-1991*	*0,102*	*0,359*	*1,88*	*28,3*
8	*1975-1987*	*0,188*	*0,368*	*2,04*	*28,3*

Table 5 – GEP-methodology-based parameters calculated, HS Peć Mlini-Tihaljina source

HS Pec Mlini Tihaljina source, Period 1975 - 1987					
(1) average multiannual flow ($\overline{Q}$) m^3/s	*2,04*				
Probability, serie N=12	*Gumbel*	*Log Normal*	*Frechet's*	*Pearson III*	*Log Pearson III*
(2) monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	*0,339*	*0,308*	*0,335*	*0,304*	*0,309*
(3) monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	*0,388*	*0,375*	*0,377*	*0,387*	*0,376*

HS Peć Mlini downstream, Tihaljina

Table 6 – Characteristic hydrological values, HS Peć Mlini-downstream, Tihaljina

Station No	Period	Qmin. (m^3/s)	meanQmin (m^3/s)	Q mean (m^3/s)	Q max. (m^3/s)
9	*1967-2001*	*0,119*	*0,451*	*11,1*	*65,0* *69,9 - peak*
9	*1975-1987*	*0,119*	*0,478*	*12,8*	*69,9*

Table 7 – GEP-methodology-based parameters calculated, HS Peć Mlini-downstream

HS Pec Mlini downstream, Tihaljina, Period 1975 - 1987					
(1) average multiannual flow ($\overline{Q}$) m^3/s	*12,8*				
Probability, series N=12	*Gumbel*	*Log Normal*	*Frechet's*	*Pearson III*	*Log Pearson III*
(2) monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	*0,277*	*0,319*	*0,393*		*0,320*
(3) monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	*0,552*	*0,521*	*0,527*	*0,542*	*0,521*

HS Tihaljina, Tihaljina

Table 8 – Characteristic hydrological values, HS Tihaljina, Tihaljina

Station No	Period	Qmin. (m^3/s)	meanQmin (m^3/s)	Q mean (m^3/s)	Q max. (m^3/s)
10	*1963-1989*	*0,119*	*0,660*	*16,5*	*128*
10	*1975-1987*	*0,119*	*0,671*	*17,6*	*128*

Table 9 – GEP-methodology-based parameters calculated, HS Tihaljina

HS Tihaljina, Tihaljina, Period 1975 - 1987					
(1) average multiannual flow ($\overline{Q}$) m^3/s	*17,6*				
Probability, serie N=13	*Gumbel*	*Log Normal*	*Frechet's*	*Pearson III*	*Log Pearson III*
(2) monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	*0,266*	*0,287*	*0,365*		*0,288*
(3) monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	*0,584*	*0,507*	*0,514*	*0,572*	*0,507*

HS Klobuk, Mlade

Table 10 – Characteristic hydrological values, HS Klobuk, Mlade

Station No	Period	Qmin. (m^3/s)	meanQmin (m^3/s)	Q mean (m^3/s)	Q max. (m^3/s)
11	*1965-2001*	*2,26*	*4,06*	*25,5*	*214*
11	*1975-1987*	*2,77*	*4,14*	*27,5*	*214*

Table 11 – GEP-methodology-based parameters calculated, HS Klobuk

HS Klobuk, Mlade, Period 1975 - 1987					
(1) average multiannual flow ($\overline{Q}$) m^3/s	*27,5*				
Probability, serie N=12	*Gumbel*	*Log Normal*	*Frechet's*	*Pearson III*	*Log Pearson III*
(2) monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	*3,14*	*3,03*	*3,32*	*2,69*	*3,03*
(3) monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	*3,78*	*3,77*	*3,79*	*3,76*	*3,75*

HS Grabovo vrelo, Mlade

Table 12 – Characteristic hydrological values, HS Grabovo vrelo

Remark: Average flow, absolute minimum flow and mean minimum flow, and mean flow, profile Grabovo vrelo mouth, Mlade, are calculated on the basis of daily scores

$Q_{GRABOVO\ VRELO\ MOUTH\ (MLADE)} = Q_{HS\ KLOBUK(MLADE)} + Q_{HS\ GRABOVO\ VRELO\ (GRABOVO\ VRELO)}$

Station No	Period	Qmin. (m^3/s)	meanQmin (m^3/s)	Q mean (m^3/s)
12	*1968-1987*	*2,77*	*4,24*	*30,4*
12	*1975-1987*	*2,77*	*4,14*	*29,8*

Table 13 – GEP-methodology-based parameters calculated, HS Grabovo vrelo

Profile Grabovo vrelo mouth, Mlade, Period 1975 - 1987					
(1) average multiannual flow ($\overline{Q}$) m^3/s	*29,8*				
Probability, serie N=13	*Gumbel*	*Log Normal*	*Frechet's*	*Pearson III*	*Log Pearson III*
(2) monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	*3,15*	*3,04*	*3,33*	*2,71*	*3,04*
(3) monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	*3,79*	*3,77*	*3,79*	*3,77*	*3,77*

Guaranteed ecological flow – GEP

The GEP was calculated for all hydrological stations in the selected section of the river Tihaljina -Mlade, according to data covering the period 1975-1987.
The results of the GEP calculation for the hydrological stations are presented in Table 14.

No	Station	average flow $\overline{Q}$ m^3/s	0,1 $\overline{Q}$ m^3/s	0,15 $\overline{Q}$ m^3/s	0,25 $\overline{Q}$ m^3/s	monthly-min low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$) m^3/s	monthly-min low-flow 80% exceedence probability ($Q_{80\&}^{\min.monthly}$) m^3/s	**GEP Cold season Q m^3/s**	**GEP Warm season Q m^3/s**
8	Peć Mlini Tihaljina source	2,04	0,204	0,306	0,510	0,309	0,376	**0,306**	**0,376**
9	Peć Mlini downstream	12,08	1,21	1,81	3,02	0,320	0,521	**1,21**	**1,81**
10	Tihaljina	17,6	1,76	2,64	4,40	0,365	0,514	**1,76**	**2,64**
11	Klobuk	27,5	2,75	4,13	6,88	3,03	3,75	**3,03**	**4,13**
12	Grabovo vrelo (Mlade)	29,8	2,98	4,47	7,45	3,04	3,77	**3,04**	**4,47**

6.2 River ecology

Introduction

A habitat (from an ecological point of view) is an area inhabited by a particular species or the physical environment that surrounds (influences and is utilized by) a species population.. The habitat in combination with the biological community (Biocoenosis) is a higher unit which is called ecological system (Ecosystem).

The diversity of a certain habitat is closely linked to its geographical location, topography, geological, climatic and hydrographical circumstances and human influences. Human has activities have destroyed many habitats in rivers. With the increase in human population and human activities, habitats are being destroyed ever more rapidly on a global scale. Therefore, the efforts of the international community and a number of associations to protect and preserve the diversity of habitats, as well as the diversity of flora and fauna, are fundamental.

It is known that Bosnia and Herzegovina is a country with diverse habitats and ecosystems. Many of these habitats are endangered and some of them have already been destroyed. Many organisms are endangered and some of them are considered to be extinct in this area.

In BiH there is no list of endangered habitats. Because the river Trebižat is close to Croatia, the habitat classification from Croatia was used. Habitats noted as endangered in Croatia are shown in

Table 15 (According to: Antonić, O.; Kušan, V.; Bakran-Petricioli, T.; Alegro, A.; Gootstein-Matočec, S.; Peternel, H.; Tkalčec, Z. (2005): Habitat classification of the Republic of Croatia. Drypis 1/1 : 1-12.)

<u>Explanation of abbreviations from table 15</u>

NATURA – NATURA 2000 is an ecological network of the European Union which includes areas that are important for the preservation of endangered species and habitat types. This program, which is the basic protection of nature in EU, emerges from a Council Directive on the conservation of wild birds (Council Directive79/409/EEC) and a Council Directive on the conservation of natural habitats and wild fauna and flora (Council Directive 92/43/EEC).

PHYSIS – database on habitat types created by the Institut Royal ales Sciences Naturelles de Belgique.

NKS – National habitat classification is a database on habitats of the Republic of Croatia.

Table 15 – Endangered habitats

Habitat type	NATURA	PHYSIS	NHC
Pannonian salt grassland	1340	15.4	C.37
Juniper formations on heaths	5130	31.882	D1215
Petrifying springs	7220*	54.12	A34
Bog birch woods on sphagnum peat bog	91D0*	44.A12	E327
Oleander galleries	92D0	44.81	D322
Mediterranean and stone pine woods and plantations	9540	42.83	E8210
Travertine-forming riparian communities		24.422	A35
Travertine-forming waterfall vegetation		24.423	A36
Complex	**NATURA**	**PHYSIS**	**NHC**
Estuaries	1130	11.2; 13.2	K1
Coastal lagoons	1150*	21	K2
Large shallow inlets and bays	1160	12	K3

In the area of the Tihaljina - Mlade several habitat types can be treated as endangered. These include:

- Calcareous sources, such as the spring of Tihaljina in Peć Mlini and the spring of Modro oko;
- Travertine-forming riparian communities that are common in the river Trebižat;
- Travertine-forming waterfall vegetation.

For all the above-mentioned "possibly" endangered habitats there are no data about their flora and fauna, or the data are very old (from 1963).

The Tihaljina spring is a revolving type spring, with strong water aeration and rocky ground. Limestone wells are a specific form from which, during rainy periods, a great quantity of water pours out, thus creating a strong, sudden stream, while during dry periods they dry out. This type of habitat is considered as a unique ecological unit.

Travertine-forming riparian communities

The river Trebižat is well-known for travertine formation. The formation of calcareous sinter or travertine is common for karst rivers and results in the formation of certain geomorphologic shapes, especially waterfalls. A development of calcareous sinter is the formation of calcareous barriers and waterfalls on the Trebižat River . The community of calcareous creators is very sensitive because it depends on a combination of conditions, and especially on fresh clean water. The creation of calcar is a complex process involving various physical, chemical and biotic factors. Limestone particles are exuded more intensively as the area of the water surface in contact with the atmosphere grows.

$CaCO_3$ is actually made in areas of intensive turbulence because of the greater area of contact between air and water and the varying pressure between CO2 in the air and water. Here the CO2 breaks away from the H2O and thus the balance of reaction is disturbed towards a higher concentration of carbonates, thus producing particles of CaCO3.

$$2\ HCO_3^- \rightarrow CO_3^{2}- + CO_2 + H_2O$$

Apart from favourable physical conditions in the Trebižat River there are also favourable temperature conditions. The temperature of the water is almost always higher than its sedimentation limit temperature. In summer the temperature of the water is always higher than its sedimentation limit temperature of 14°C. Lower temperatures at that time occur only in the spring area or in places where there are wells in the river flow. Thus, sedimentation fails only in those habitats. Calcareous layers grow slowly and occur in those parts of the river or the spring where splashing and aeration of water is very intensive. In the winter the temperature is not suitable, so there is no calcareous creation in those conditions. However, for the creation of calcareous layers the presence of certain organisms is necessary, especially hygrophyte and hydrophytes moss and algae. In cases of strong splashing, aeration and streaming of water, excreted particles are carried away by the current down to places where they begin alluvial sedimentary processes. That happens in very fast waters (when the speed is higher than 3.5 m/s). In areas of slower flow the vegetative bodies of organisms keep the excreted particles of calcium carbonate and create calcareous layers, which grow along with the growth of calcareous organisms. The most optimal speed is 1-2 m/s, where the biggest number of calcareous organisms is retained.

Together with the splashing, aeration and streaming of water, and necessary alkalinity and temperature of water, the light also influences the creation of calcar. In younger calcareous creations, which are exposed to light, heliophilous vegetation develops, which has a more or less friable sod. This occurs at springs and in the upper flows of rivers where the temperature is not suitable, thus the calcareous creations are formed very slowly. Old calcareous barriers, which are the most developed forms of calcareous layers, are sometimes covered in higher vegetation, which overshadows the calcareous vegetation habitats. Thus the old barriers develop in downstream flows, and the growth of calcareous layers is much more intense. With the growth of calcareous layers, the ecological situation changes. The consequence is populations of different biocoenosis which are in a mutual successive relationship. Some animals also participate in the creation of calcareous layers, not only plants, moss or algae (Matoničkin & Pavletić 1972).

At big old barriers in natural vegetation succession, woody species occur, mostly willow and alder which can destroy the barriers with their roots. These destructive effects have been known to change the water regime, creating a periodic insufficient water flow. When out of water, calcareous organisms die, and the barriers can cave in (Nikolić 2006). The recommended safety measures are to maintain a sufficient constant flow of clean fresh water and prevent the covering of the barrier by woody species.

6.2.1 Fish

The Adriatic basin is famous for its high level of endemism (44 Mediterranean, 40 Adriatic and 18 Croatian endemic plants), which is a direct consequence of the variety of karst habitats. Freshwater fish are one of the most endangered types of vertebrates. 89 species are included in the Red book of freshwater fish in Croatia. The colonisation by allochtonus species, pollution, water flow regulations and destruction of habitats, building dams, irrigation, extraction of water for domestic use and industry, as well as uncontrolled fishing, have had the most negative influence on freshwater fish. According to information on the qualitative and quantitative content of ihtiofauna of the Trebižat River from Bogut, I., Pavličević, J., Ivanković, S., Petrović, D., 2003, the following fish species are recorded in the river Tihaljina i Mlade:

Table 16 – Fish species of the Tihaljina river

type of fish	The Red book of Croatia
Brown trout *Salmo trutta* m. *fario*	VU
Rainbow trout *Oncorhynchus mykiss*	-
White chub *Leuciscuc cephalus albus*	VU
Sraper *Leuciscus svallize*	VU
Butterwort *Rutilus rubilio rubilio*	VU
Scardinius plotizza *Scardinius erytrophthalmus scardofa*	DD
Nose-carp *Chondrostoma kneri*	EN*
Carp *Cyprinus carpio*	EN
Tench *Tinca tinca*	-

Table 17 – Fish species of the Trebižat river (Mlade part)

type of fish	The Red book of Croatia
Brown trout *Salmo trutta* m. *fario*	VU
Neretva dentex trout *Salmothymus obtusirostris oxyrhynchus*	CR*
Rainbow trout *Oncorhynchus mykiss*	-
White chub *Leuciscuc cephalus albus*	VU
Sraper *Leuciscus svallize*	VU
Nose-carp *Chondrostoma kneri*	EN*

Butterworth *Rutilus rubilio rubilio*	VU
Scardinius plotizza *Scardinius erytrophthalmus scardofa*	DD
Tench *Tinca tinca*	-
Carp *Cyprinus carpio*	EN
Spotted minnow *Phoxinellus adspersus*	VU*

With every mentioned type there is a category of endangerment, according to Mrakovčić, M., et all. (2007): the Red book of freshwater fish in Croatia (National Institute of Environment Protection, Zagreb).

CR – critically endangered – there is an extremely high risk of extinction.
EN – endangered – there is an extremely high risk of extinction;
VU – risk – there is a high risk of extinction;
DD – not known enough – there isn't enough information for the assessment of the risk of extinction (population and distribution state).

Endemic species are labeled with a star (*) beside the category.

Endemic species are especially sensitive and usually lack the capacity to adapt to changes in external factors. They are mostly spread in former glacial refugia and closely connected to the environment where they live.
In the upper part of the Tihaljina river the habitats are characterised by high current velocity and low water temperature. The concentration of oxygen is high, and there is almost no water pollution. This area is populated with brown trout (Salmo trutta m. fario). They spawn from October to January, in cold rather than in warm waters. Females then make an egg-shaped cavity of 20-50cm and lay around 1000 eggs per kg of their weight,. The eggs are 4-5mm big, yellow-red or orange. When they grow, the fish travel upstream.
Then, the downstream current velocity is also high, the water is rich with oxygen, but with a rather higher temperature than the river source. In this river section, white chub, scraper, scardinius plotizza and rainbow trout are common.
Different fish species which live in different sections of the river can be sorted according to the way they spawn: on gravel or plants. For those that spawn on plants the so-called soft progress and hard water plants retrogress are important. Myriophyllum, Ceratophyllum, Ranunculus fluviatilis and different types of pondweed (Potamogeton) are representatives of soft water plants. Hard water plants are cane (Phragmites), rush (Typha), common rush (Juncus).
Floods are extremely important biological events for every river and related area. During floods, wide canals (side), sleeves, isles and swamps are created by erosion processes and there is a great diversity of habitats in which animals eat, hide and breed. Floods help the preservation of biological diversity, enabling animals and plants to take new as well as current habitats. Floods are important for fish breeding

and feeding: during high water levels, they migrate massively from the river bed to the new flooded areas (Mrakovčić 2007).

None of the freshwater fish present in Trebižat has been legally protected in BiH. Practically, the protection of the majority of species can be implemented only by the protection of their habitats.

6.2.2 Invertebrates

Representatives of the karst spring among the spineless, the so called krenobionti, are some crustaceans (*Fontogammarus dalmatinus, Gammarus balcanicus, Gammarus Fossarum, Niphargus castellanus*), insect larva from the groups *Diptera* (*Atherix* spp.), *Ephemeroptera* (*Baetis rhodani, Ecdynurus spp., Ephemerella spp.), Odonata (Cordulegaster), Plecoptera (Leuctra* spp., *Protonemura* spp.) and *Trichoptera (Drusus synagapetus*), water ambrosia beetles (*Helmis* spp.), turbellaria *(Crenobia alpina*), snails *Ancylus fluviatilis* and *Belgrandiella, Bithynia, Dalmatella* , etc.(Matoničkin & Pavletić 1972)

6.2.3 Macrophytes

For the distribution of water and swamp plant communities, the most important factor is water, and especially the water level in the ecosystem (Fernández – Aláez and associates 1999., Jasprica and associates. 2003).
In the tables we mark the species which are in the Red book of BiH, (according to Šilić Č., 1996).
Species are labelled in accordance with International Union for Conservation of Nature (IUCN) standards.
The system of evaluating endangerment consists of the following categories:

- **Ex** – extinct-vanished species. This category includes the species which have not been found during the repeated search at or near the location where they had been found before;
- **Ex?** – probably extinct species;
- **E –** very endangered species. This category includes the species which are so endangered that they could easily become extinct or vanish if the harmful influences remain;
- **V –** endangered and vulnerable species. Species which live in habitats with an ecological balance very sensitive to even the smallest humanogene interventions (e.g. warm springs, frosters, peat bogs, ponds, etc.). A continuous negative influence to the habitat unavoidably places the given species in category "E";
- **R** – rare or potentially endangered species. They are the rare and scarce species which are not directly endangered, but could easily become so. Those are the species living in small areas, particularly endemic and relic species;
- **K** – insufficiently known species. This category includes the species which are assumed to belong to one of the categories, but there is no information for an accurate categorization.

The results of sampling of macrophytes are presented in Tables 18-22.

PEĆ – MLINI TIHALJINA SOURCE

Table 18 – T1 Peć Mlini Tihaljina source

Tihaljina spring in Peć Mlini	**Red list B&H**
Plant species:	
Carex vulpina L	
Carex divulsa Stokes	
Rumex obtusifolius L.	
Lysimachia vulgaris L.	
Campanula fenestrellata FEER	
Trifolium fragiferum L.	
Arabis verna (L.) R. Br.	
Hepatica nobilis L.	V
Rorippa amphibia (L.) Bess.	
Sedum sp.	
Polypodium vulgare L.	
Tussilago farfara L.	
Scutellaria galericulata L.	
Carex elata All.	
Sium erectum Huds.	
Galium palustre L.	
Mentha pulegium L.	
Polystichum lochitis (L.) Roth	
Papaver rhoeas L.	
Silene sp.	
Fraxinus angustifolia Vahl.	
Salix alba L.	
Sedum album L.	
Opsponax chironium (L.) KOCH	R
Coronilla emerus spp. *emeroides* L.	
Umbilicus horizontalis L.	
Parietaria judaica L.	
Arabis turrita L.	
Asplenium trichomanes L.	
Adiantum capillus veneris L.	V
Clematis vitalba L.	
Populus alba L	
Alnus glutinosa L.	
Ficus carica L.	
Ceterach officinarum DC.	

On a rocky bottom, individually in smaller turfs, the water moss *Fontinalis antipyretica* occurs. The *Fontinalis antipyretica* moss is an important species near spring waters where it builds the distinctive biological community *Fontinaletum antipyreticae* (Jasprica 2001). That is a community of very polymorph moss on the rocks by the springs where the water is fast. Approx. 0,5 m long turfs detach by the water flow and can be found floating on the water surface.
By the river shore, on the grounds that are periodically flooded or are humid because of the height of underground waters, there is a narrow zone of flood forests which include: Willow (*Salix alba*), poplar (Alnus glutinosa), ash (Fraxinus angustifolia) and others.
In shallow water by the shore, where the river bed is dominated by gravel, *Sium erectum, Mentha pulegium, Rumex obtusifolius, Rorippa amphibia* develop. On the

rocks by the river, which are exposed to the light and have enough humidity, *Campanula frenestellata, Hepatica nobilis, Parieteria judaica, Lysmachia vulgaris, Umbilicus horizontalis* develop. On half-caves and caves next to the spring, which are in the shadow, the following species are noted: *Adiantum capillus veneris, Asplenium trichomanes, Polystichum lochitis i Polypodium vulgare.*
Species noted on this site are characteristic of the mentioned habitat types.

PEĆ – MLINI DOWNSTREAM

Table 19 – T2 Peć Mlini downstream

Peć – Mlini Downstream	Red list B&H
Plant species:	
Veronica anagallis – aquatica L.	
Euphorbia sp.	
Cornus mas L.	
Carex vesicaria L.	
Clematis vitalba L.	
Parietaria judaica L.	
Cicerbita muralis (L.) WALLR.	
Lathyrus niger (L.) BERNH	
Geranium lucidum L.	
Poa bulbosa L.	
Sedum sp.	
Ficus carica L.	
Ranunculus trichophylus Chaix	
Sium latifolium L.	
Potamogeton crispus L.	

The broomrape family is very rare in this area. Species like *Ranunculus trichofilus, Sium latifolium and Potamogeton crispus* occur individually and are noted near riverbanks when water level is the lowest. As there are no higher plants in the river, the role of primary producer is taken by algae. A lack of plentiful water vegetation can be explained by the type of river bottom (rocky), the banks (steep and rocky) and the high flows. All of that makes it impossible for water vegetation to take root in the ground. Recorded species are on the higher parts of banks which are periodically splashed.

BLUE EYE SPRING

Table 20 – T3 Blue eye spring (Modro oko)

Blue eye spring	Red list B&H
Plant species:	
Rhamnus catarthica L.	
Aristolochia rotunda L.	R

Seseli annuum L.	
Galium pumilum Murr.	
Astragalus allyricus BERNH.	
Ranunculus parviflorus L.	
Ajuga reptans L.	
Carex vulpina L	
Arabis hirsuta (L.) Scop.	
Clematis viticella L.	
Phragmites australis (Cav.) Trin.	
Mentha pulegium L.	
Mentha aquatica L.	
Asplenium petrarchae (Guer.) DC.	
Thelypteris palustris Schott	V
Pteridium aquilinum (L.) Kuhn	
Limodorum abortivum (L.9 Swartz	E
Potamogeton pectinatus L.	
Edraianthus graminifolius (L.) DC.	
Galium lucidum All.	

The Blue eye well, which forms a small creek, is a left confluent of the Trebižat River. The water is transparent and the bottom can be seen clearly. Water plant species recorded included, at a deeper level, *Potamogeton pectinatus.* In shallow water *Mentha pulegium, Mentha aquatica and Ajuga reptans* were recorded near the banks. At the higher level of the banks we found *Phragmites australis, Asplenium petrarchae*, *Thelypteris palustris* and others. A little bit further, on flooded meadows, which were under water (where the ground is soft and muddy) *Edraianthus graminifolius, Galium lucidum, Limodorum abortivum* were recorded. At this locality the anthropogenic influence is almost insignificant, and the vegetation is specific for this ecosystem.

THE KAVASBAŠA BRIDGE

Table 21 – T4 The Kavasbaša Bridge

The Kavasbaša Bridge	**Red list BiH**
Plant species:	
Eleocharis palustris (L.) R.S.	
Lythrum scalicaria L.	
Galium palustre spp. *lanceolatum* UECHTR	
Ajuga reptans L.	
Ajuga genevensis L.	
Thymus pulegioides L.	
Lycopus exaltatus L. f.	
Rumex obtusifolius L.	
Equisetum fluviatile L.	
Equisetum palustre L.	
Centaurium pulchelum (Sw.) Druce	
Plantago maior L.	
Ranunculus repens L.	
Carex pendula Hudson	

Iris pseudacorus L.	
Phragmites australis (Cav.) Trin.	
Ranunculus fluitans LAM.	
Holoschoenus vulgaris Link	
Schoenoplectus lacustris (L.) Pala	
Alisma plantago-aquatica L.	
Sium latifolium L.	
Juncus articulatus L.	

Downstream from the Kavabaša Bridge on the right side, in shallow water up to 1m high and with a sandy bottom, swamp vegetation has developed, mainly from the Phragmitetalia family. Communities of this family present developed vegetation with a high number of flora species. Here swamp vegetation developed better than water vegetation, because the water level was very high and the river flow was very fast. At this locality, the species *Iris pseudacorus*, which in BiH is otherwise recorded only in Hutovo Blato, was especially noted. According to the ecological conditions and habitat type, the recorded flora species are characteristic.

GRABOVO VRELO

Table 22 – T5 Grabovo vrelo

Grabovo vrelo	**Red list B&H**
Plant species:	
Equisetum maximum LAM.	
Carex vesicaria L.	
Papaver rhoeas L.	
Carex vulpina L	
Anthemis arvensis L.	
Myriophyllum verticillatum L.	
Nymphaea alba L.	
Sium latifolium L.	
Veronica beccabunga L.	
Myriophyllum spicatum L.	
Rorippa amphibia (L.) Pala	
Potamogeton lucens L.	
Nuphar luteum Sibth. et Sm.	V
Alisma plantago-aquatica L.	
Alisma gramineum Lej.	
Phragmites australis (Cav.) Trin.	
Cyperus longus (L.)	
Juncus articulatus f. *palidiflorus* L.	
Holoschoenus vulgaris Link.	
Eriophorum latifolium Hoppe	
Scirpus litoralis (Schrad.) Palla	
Scirpus lacustris (L.) Palla	
Briza media L.	
Oenanthe aquatica (L.) Poir.	
Carex acutiformis Ehrh.	V

Carex paniculata L.	
Juncus articulatus L.	
Gratiola officinalis L.	
Eleocharis palustris (L.) R. et S.	
Lysimachia nummularia L.	
Galium palustre L.	
Mentha aquatica L.	
Lycopus europaeus L.	
Lythrum scalicaria L.	
Artemisia annua L.	
Mentha pulegium L.	
Calystegia sepium (L.) R. Br.	
Veronica anagallis – aquatica L.	
Asparagus acutifolius L.	
Symphytum officinalis L.	
Rumex pulcher L.	
Ruscus aculeatus L.	V
Zannichellia palustris L.	V
Polygonum amphibium var. *terrestre* L.	
Typha latifolia L.	
Iris pseudacorus L.	

At this locality the river bed is sandy. In deep water, where the current velocity was low, some types of storks occur periodically: *Myriophyllum, Nuphar lutea and Nymphaea alba*. These species take small areas of the river. In the deepest parts, regardless of the current, there is a complete underwater meadow of pondweed. This is especially abundant at times of low water levels. Swamp vegetation in which *Phragmites australis* dominates is very abundant and developed here, as the slower current of water and light suits it and here there is no woody vegetation on the banks to create shadow.

Conclusions:

The water regime determines the species composition of the flora (including macrophytes) in the studied area of the river Tihaljina and Mlade. According to the structure of the plant communities, the aquatic vegetation in the river Trebižat (Tihaljina and Mlade) does not show serious degradation trends, despite the fact that the area is influenced by multiple human impacts.

6.2.4 Phytobenthos

Species composition

The analysis of phytobenthos showed a high number of species in the sampling sites included in the study (*Table 23*), with Bacillariophyceae as the largest group. In addition, in the research of algae on the travertine barriers of the the Krka river in Slovenia, Bacillariophyceae was the most numerous group (Vrhovšek et al., 1996;

Krivograd Klemenčič et al., 2004). In total, 69 taxa and 5 algal classes were identified in all five sampling sites. In the number of identified taxa, diatoms prevailed with 58 taxa, followed by Cyanophyceae with 5, Chlorophyceae with 3, Florideophyceae with 2 and Zygnematophyceae with 1 takson. Customary (relative abundance=3) found species were: *Gloeocapsa* sp. (T2), *Heteroleibleinia* sp. (T1), *Phormidium* sp. (T1, T2), *Achnanthes* sp.1 (T1), *Nitzschia fonticola* (T1) and *Ulothrix* sp. (T2). *N. fonticola* was also a common species on the travertine barriers of the Krka river (Krivograd Klemenčič et. al., 2004). In all five samples, the following species were recorded: *Achnanthes* sp.1, *Cymbella silesiaca*, *Gomphonema angustum* and *Nitzschia dissipata.* Most of the taxa belonged to the *Navicula* (10) and *Nitzschia* (10) genera. The lowest number of taxa (20) was determined in the sampling sites T1 and T3 and the highest one (40) at the sampling site T4.

Red algae *Audouinella chalybea* and *Bangia atropurpurea* (Rhodophyta, Florideophyceae) are occasionally found on travertine. Both require turbulent water. Filaments of *A. chalybea* are sometimes found growing on the surfaces of oncoids and stream crusts in the shaded watercourses of Europe (Pentecost, 2005). We determined *A. chalybea* in the sampling site T4 and *B. atropurpurea* in the sampling site T2. *Gloeocapsa* species are to be found on a wide range of travertine, because they remain dry for much of the year (Pentecost, 2005). Also *Pleurocapsa* is widely distributed on travertines in Europe and frequently reported. *Gloeocapsa* sp. was a common species in the sampling site T2, *Pleurocapsa minor* was determined in the sampling sites T2 and T4. The filamentous cyanobacteria are among the most frequent colonisers of active travertine surfaces (Pentecost, 2005). *Phormidium* sp. was a common species in the sampling sites T1 and T2 and *Heteroleibleinia* was a common species in the sampling site T1. Filamentous Zygmemales are common on travertine; they include taxa belonging to the genera *Mougeotia*, *Spirogyra* and *Zygnema*. All of these filamentous algae are also known from non-travertine-depositing waters (Pentecost, 2005). We determined the species *Mougeotia* sp. in the sampling site T2. In the samples from the Tihaljina river we recorded 58 diatom taxa, among them 24 taxa are frequently recorded from active travertine (they are marked in Table 23 with an asterisk). Some of these diatoms are: *Achnanthes lanceolata*, *A. minutissima*, *Amphora ovalis*, *Cocconeis pediculus*, *C. placentula*, *Cymatopleura solea* and *Nitzschia palea*. *Nitzschia fonticola* was a common species in the sampling site T1, but it was nor recognized as travertine typical species by other authors (Pentecost, 2005).

The initial stages of travertine formation as a result of morphological, biological, and chemical factors are (i) moss settling on small ridges in the creek courses, (ii) epiphytes (diatoms and cyanobacteria) settling on the moss surface, (iii) micrite particles resuspending from lake bottoms and being trapped on the mucous excretions by bacteria and diatoms, and (iv) inorganic calcite precipitating as sparite at nucleation sites provided by these crystal seeds (Emeis, 1987).

The Saprobic Index (*Table 24)* ranged from 1.46 (T1) to 1.62 (T4). According to the results of the Saprobic Index, we can classify the Tihaljina River as at an oligosaprobic (unpolluted) level at the sampling site T1 and from an oligosaprobic (unpolluted) to β-mesosaprobic (moderate impurity) level at the other four sampling sites.

Table 23 – Algal species list with abundance estimations from the river Tihaljina, 28.4.2008
*** Diatoms frequently recorded from active travertines by Pentecost (2005)**

Taxa	Sap. value	Sampling sites				
		T1	T2	T3	T4	T5
PROKARYOTA						
CYANOPHYTA						
CYANOPHYCEAE						
Calothrix sp.	o	1	1			
Gloeocapsa sp.	o		3			
Heteroleibleinia sp.		3	1		1	
Phormidium sp.	o-a	3	3		1	
Pleurocapsa minor Hansgirg			1		1	
EUKARYOTA						
HETEROKONTOPHYTA						
BACILLARIOPHYCEAE						
Achnanthes delicatula (Kützing) Grunow				1		
*Achnanthes lanceolata (Brébisson) Grunow	o			1		1
*Achnanthes minutissima Kützing	o	1	1	1		1
Achnanthes sp.1	b	3	1	1	1	1
Achnanthes sp.2	b		1			
Achnanthes sp.3	b			1		
Amphora libyca Ehrenberg						1
*Amphora ovalis Kützing	o-b				1	1
Amphora pediculus (Kützing) Grunow	o-b	1	1	1	1	
*Cocconeis pediculus Ehrenberg	b		1		1	
*Cocconeis placentula Ehrenberg	o		1	1	1	1
Cyclotella sp.	o-b		1		1	
Cymatopleura elliptica (Brébisson) W.Smith	b	1				
*Cymatopleura solea (Brébisson) W. Smith	b				1	
*Cymbella affinis Kützing	o	1			1	1
*Cymbella cistula (Ehrenberg) Kirchner	o		1		1	
*Cymbella microcephala Grunow	o	1	1		1	
Cymbella naviculiformis Auerswald	o					1
Cymbella prostrata (Berkeley) Cleve	b				1	
Cymbella silesiaca Bleisch	o-b	1	1	1	1	1
Cymbella sinuata Gregory	o-b		1			
*Denticula tenuis Kützing	o		1		1	1
*Diatoma vulgaris Bory	b		1		1	
Fragilaria capucina Desmazières	o-b		1		1	1
Fragilaria pinnata Ehrenberg	o		1			
*Fragilaria ulna (Nitzsch) Lange-Bertalot	b				1	1
Frustulia vulgaris (Thwaites) De Toni	b			1	1	
*Gomphonema angustatum (Kützing) Rabenhorst	b			1		
*Gomphonema angustum Agardh	o	1	1	1	1	1
*Gomphonema olivaceum (Hornemann) Brébisson	b		1		1	1
Gyrosigma attenuatum (Kützing) Rabenhorst	b	1	1		1	1
Gyrosigma nodiferum (Grunow) Reimer		1			1	
Melosira varians Agardh	o-b				1	
*Meridion circulare (Greville) C. A. Agardh	o	1				
Navicula capitatoradiata Germain	b					1

Taxa	Sap. value	Sampling sites				
		T1	T2	T3	T4	T5
*Navicula cryptotenella Lange-Bertalot	o	1	1	1	1	
Navicula mutica Kützing	o		1			
Navicula placentula Ehrenberg	b					1
*Navicula pupula Kützing	b				1	
Navicula radiosa Kützing	o-b		1			
Navicula sp.	b	1		1		1
*Navicula tripunctata (O. F. Müller) Bory	o-b	1	1		1	1
Navicula trivialis Lange-Bertalot			1		1	1
*Navicula viridula (Kützing) Ehrenberg	b-a				1	
Neidium binodis (Ehrenberg) Hustedt				1	1	
Neidium bisulcatum (Lagerstedt) Cleve				1		
Neidium sp.		1	1	1	1	
*Nitzschia amphibia Grunow				1	1	1
*Nitzschia dissipata (Kützing) Grunow	o	1	1	1	1	1
Nitzschia fonticola Grunow	o	3	1			1
Nitzschia gracilis Hantzsch	o-b		1		1	
Nitzschia heufleriana Grunow			1			1
Nitzschia linearis (Agardh) W. Smith	o-b			1		
*Nitzschia palea (Kützing) W. Smith	b-a		1			
Nitzschia recta Hantzsch	o-b				1	
Nitzschia sigmoidea (Nitzsch) W.Smith	b-a				1	
*Nitzschia sinuata var. tabellaria Grunow	o				1	1
Surirella angusta Kützing	o-b			1		
CHLOROPHYTA						
CHLOROPHYCEAE						
Trentepohlia aurea (L.) Martius					1	
Ulothrix sp.	b		3			
Ulothrix zonata Kützing	o		1			
ZYGNEMATOPHYCEAE						
Mougeotia sp.	o-b		1			
RHODOPHYTA						
FLORIDEOPHYCEAE						
Audouinella chalybea (Lyngbye) Fries	b-a				1	
Bangia atropurpurea Agardh	o		1			
Number of taxa 69		20	38	20	40	25
Saprobic index		1.46	1.52	1.51	1.62	1.50

Table 24 – Number of indicator taxa for single saprobic level

	T1	T2	T3	T4	T5
oligosaprobic	10	15	6	9	9
oligo-betamezo saprobic	3	9	3	9	4
beta mezosaprobic	4	7	4	9	7

betamezo-alfamezo saprobic	/	1	/	3	/
oligo-alfamezo saprobic	1	1	/	1	/

Cluster analysis

The dendrogram (*Figure 9*) shows the largest similarity between the sampling sites T2 and T4 and the most different one at sampling site T3.

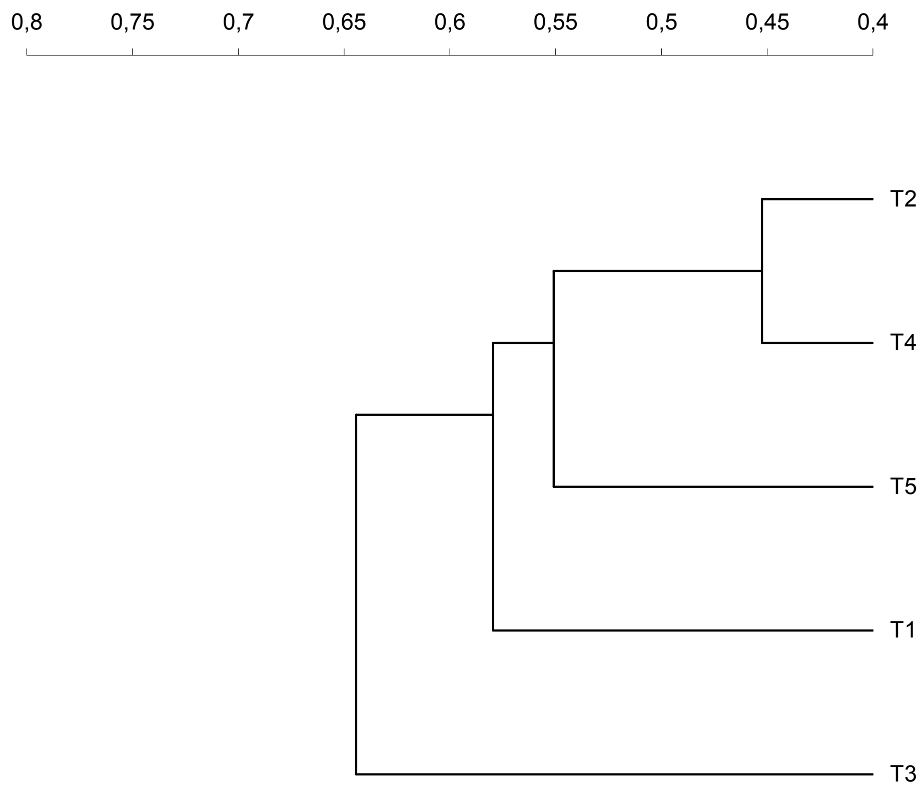

Figure 9 – Bray-Curtis coefficient of similarity for the sampling sites in the Tihaljina river

The results of the Bray-Curtis coefficient of similarity, especially the differences in species composition at sampling site T3, coincide with the increasing organic pollution on sampling site 3 and the fact that this sampling site is the tributary of the Tihaljina river.

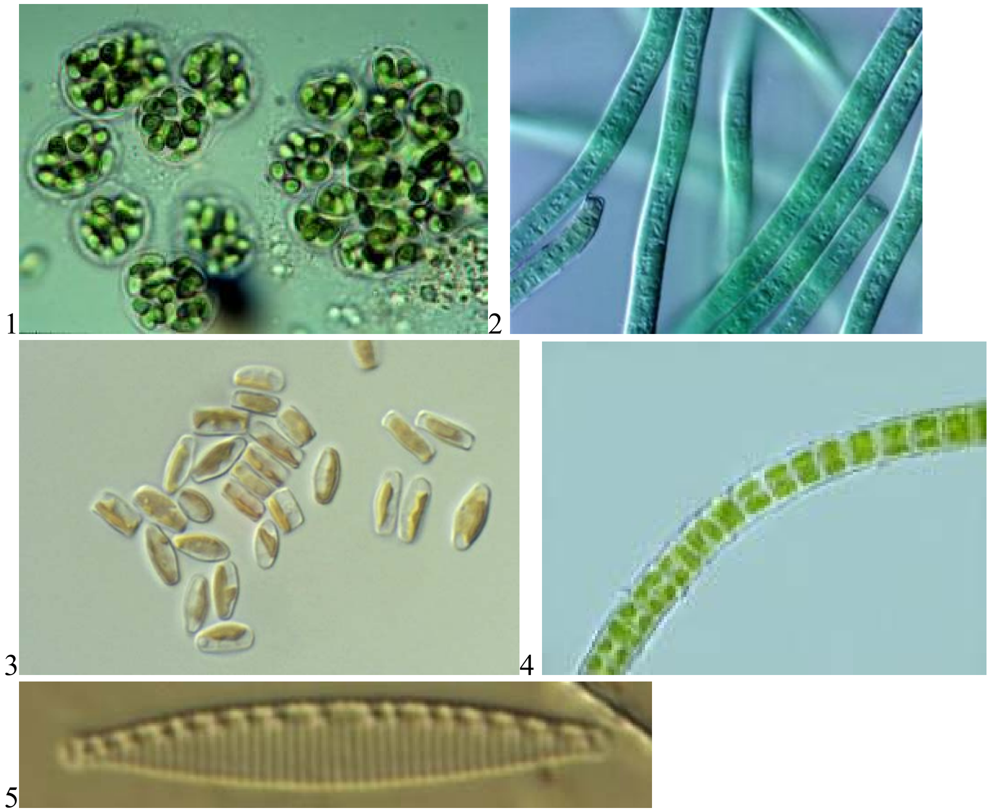

Figure 10 – 1-*Gloeocapsa* sp., 2-*Phormidium* sp., 3-*Achnanthes* sp., 4- *Ulothrix* sp., 5-*Nitzschia fonticola*

6.3 Physico-chemical parameters

According to the Directive of the European Parliament and of the Council 2000/60/EC, which establishes a framework for community action in the field of water policy, Annex 5, Article 1.1.1. – the quality of the physical – chemical characteristics of the surface waters, and the water quality at the given localities is referred to as **good status**, meaning:

- Temperature oxygen balance, pH, acid neutralizing capacity and salinity do not reach levels outside the range established to ensure the functioning of the type specific ecosystem and the achievement of the values specified above for the biological quality elements.

- Nutrient concentrations do not exceed the levels established to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.

The results of the physico-chemical parameters at selected sampling sites are as follows:

Sampling site T1 and T2:
Waters flow through the lithosphere which consists of carbonate rocks where calcium carbonate dominates (carbonate rock). Cations dominating are: Ca and Mg and from anions SO_4 are HCO_3 (actually Ca^{2+} , SO_4^{2-} , HCO_3^- etc).

Sampling site T3:
Water flows through the lithosphere where calcium carbonate and alabaster $CaSO_4$ dominate. Due to high waters, organic pollution is extremely fast infiltrating (high concentration of NH_3). This shows the direct pollution of nutrients and extremely short period of staying in the underground. Due to that, the process of oxidation of ammonium into NO_2 and NO_3 could not take place. Cations dominating are Ca, Mg and Na and anions are SO_4 and HCO_3.

Sampling site T4 and T5:
The quality of water is as per expectations. Water quality at location 5 is changed by the periodical springs in Grabovo vrelo. Cations dominating location 4 are Ca and Mg and anions are SO_4 and HCO_3. At location 5 dominating cations are Ca, Mg and Na and dominating anions are SO_4 and HCO_3

Referring to all five sampling sites in total, the quality of water does not change a lot downstream; the concentration of the parameters observed are connected to the flows (if the flow is higher, the concentration is lower and vice versa). Springs like Modro Oko, Klokun are the main suppliers of the high concentration of sulphates, which is probably due to the quality of the ground which surrounds their flows.

Results of chemical analyses show that the Tihaljina at the sampling sites T1, T2 and the Mlade at the sampling sites T4 and T5 belong to the II. Class (Decree on classification of freshwater and coastal water of Yugoslavia inside Bosnia and Herzegovina, Official Gazette SRBiH, 19/80). The new by-law regulation that should be in accordance with WFD has not been prepared yet. So, the old Decree is still in use. It is important to note that a limited number of parameters is treated by the Decree; for example, there is no requirement value for the sulphates.

All tables and figures of physico-chemical analyses are presented in Appendix 7.

6.4 Identification of instream ecological values and other river values

The objective of an environmental flow strategy is the achievement of good ecological status or potential. A basic knowledge of the river's ecology is crucial. So, although the main objective of this study was not to identify instream ecological values, we have attempted to evaluate them according to existing data and sampled parameters.
According to the Environmental protection law of BiH, **protected environmental areas on the Trebižat River are:**

- The travertine-forming area around the Kravice waterfall, which is one of the geological monuments of nature,
- geomorphologic monuments: the Tihaljina spring in Peć Mlini, the Vrioštica spring in Vitina
- waterfalls: Koćuša, Kravice and Bučine

All these protected areas have very important instream ecological values.

According to our data and additional sampling, other remarkable main instream ecological values of the river Tihaljina-Mlade-Trebižat are:

- The calcareous sources of the Tihaljina in Peć Mlini and the spring of Modro oko – left confluent of the Mlada river;
- Travertine-forming riparian communities in the river Trebižat
- Travertine- forming waterfall vegetation
- Travertine forms with the phytobenthos species
- Macrophyte species:

Aquatic species:

Nuphar luteum Sibth. et Sm, *Zannichellia palustris* L.

Litoral and other species:

Hepatica nobilis L., *Opsponax chironium* (L.) KOCH, *Adiantum capillus veneris*L., *Aristolochia rotunda* L., *Thelypteris palustris* Schott, *Limodorum abortivum* (L.) Swartz., *Carex acutiformis* Ehrh., *Ruscus aculeatus* L.

- Fish species in the Tihaljina river: *Salmo trutta* m. *fario, Leuciscuc cephalus albus, Leuciscus svallize,* Scardinius plotizza, *Chondrostoma kneri, Cyprinus carpio*
- Fish species in the Trebižat –Mlade river: *Salmo trutta* m. *fario, Salmothymus obtusirostris oxyrhynchus, Leuciscuc cephalus albus, Leuciscus svallize, Chondrostoma kneri, Rutilus rubilio rubilio, Cyprinus carpi, Phoxinellus adspersus (Anđelka)*

The main other instream values of the river are:

- Recreation: swimming, angling
- Landscape values of the river

Because we do not have a complete list of species in the river ecosystem (structure and function) there could be gaps in the identification of instream values. Because of time constraints, the working group could only focus in this phase on the stream values in the riparian zone and the water dependent organisms.

6.5 Definitionof the critical parameters for the ecological value of the river

Although we do not have the complete list of the river flora and fauna, information about the river structure and function, we tried to define the critical parameters for the ecological values of the river with the emphasis on the critical time of the low flow period from June to October. Critical parameters mean essential parameters for the ecological value of the river, which can be mostly affected by an excessive low flow.

<u>Important values are:</u>

- **Flow variability**: it has i) to ensure processes like flushing sediments, algae, detritus ii) to ensure minimum water flow ii) to identify the different components of the flow regime which play a role in the structure and function of the river and the riparian ecosystem (minimum flow, mean minimum flow, mean annual flow, high flow).

Floods are extremely important biological events for every river and related area. During floods, , wide canals (side), sleeves, isles and swamps are created by erosion processes and there is great diversity of habitats in which animals eat, hide and breed. Thus, floods help the preservation of biological diversity, enables animals and plants to take new as well as current habitats. Floods have a special meaning for breeding and feeding of fish (Mrakovčić 2007).

- **Water quality**: low flow occurs during summer, and as a consequence the values of sulfate increase downstream of the inflow of Klokun. It is very important to assess what happens with physico-chemical parameters in case of water extraction and during low flow conditions (related to nutrients, organic matter, toxic contaminants, temperature etc.).

- **Habitat preferences:** including hydraulic habitats (cross-section, average water velocity: minimum 0,3 m/s, average water depth: minimum 0,2m), water depth (the critical values for target species) and water velocity (the critical values for target species).

- **Travertine** with flora and fauna

- **Landscape value**: waterfalls, visible from road

In the following phases of the project the important values listed should be treated and analysed in more details.

6.6 Environmental flow assessment according to GEP and environmental flow assessment including critical parameters

The working group found that the pre-selected GEP method has a number of disadvantages and decided to try to better match its results with the river habitat requirements. For this purpose additional requirements were selected by the working group as follows:

Requirement 1: to define the flow (Q) for which the average depth (h_{av}) decreases below 0,2m (which is the minimal depth requirement for many fish species);
Requirement 2: to define the flow (Q) for which the average velocity (v_{av}) decreases below 0,3 m/s (which is the minimal velocity requirement for many fish species);
Both of these values (depth and velocity) could be critical parameters to preserve the habitats for a number of fish species.

Results of analyses are presented in Table 25, with a written comment below the table.

Table 25 – Analyses of the flow at average velocity of 0,3 m/s and average depth of 0,2m.

Hydrological station	*GEP Q m^3/s*	*Q (m3/s) at velocity 0,3 m/s*	*Q (m3/s) at average depth 0,2 m*
Pec Mlini Tihaljina source	0,306; 0,376		1,08*
Pec Mlini downstream, Tihaljina	1,21; 1,81	1,08*	0,863*
Tihaljina, Tihaljina	1,76; 2,64	1,18*	
Klobuk, Mlade	3,03; 4,13		
Grabovo vrelo, Mlade	3,04; 4,47		

According to these two requirements, it is possible to conclude that the values of environmental flow determined according to the GEP methodology would assure the average water depth of 0,2m and the average current velocity of 0,3 m/s at the hydrological station Pec Mlini downstream.

**Comment:*

Numerous hydrometric measurements were available for each station, including measured and calculated parameters: flow rate, water level, cross section area, cross section width, average velocity and average depth. However, the low-water measurement, which is the most interesting in this case, often gave different values of v_{av} and h_{av} for a very closed value of Q. This is caused by the changeability of the river bed during the period when the measurements were performed (keeping in mind that for each station several flow rating curves were constructed by the study, for the analyzed period). It can also be caused by the fact that the measurement cross section was not exactly the same for each measurement, but several meters upstream or downstream.

A correlation-regression analysis that is one of the most common and most useful statistics to determine the relationship between two variables, has been implemented. Only the results of the regression with a coefficient of correlation r >0,6 are presented in Table 25. Full details of calculations are presented in Annex 4.

7 RECOMMENDATIONS FOR THE DEFINITION OF SUB-LAWS ON THE APPLICATION OF ENVIRONMENTAL FLOW

7.1 Gaps, advantages and disadvantages in environmental flow assessment for the Trebizat river – evaluation of the GEP method

Since the BiH public administration supported the evaluation of the applicability of the GEP method to BiH for environmental flow calculation, the working group assessed this method and came to the conclusions reported below.

The GEP method presents the characteristics of the following groups of methods: Montana-Tennant method, modified Tennant method, method of wetted perimeter and some statistics elements of low flows (Đorđevič, Dašić). The hydrological Montana-Tennant method is one of the most widely used for environmental flow assessment in North America (Tharme, 2003). Compared to environmental flow methods applied elsewhere, the GEP method combines elements of the hydrological methods (using simple hydrological indices like the Montana-Tennant elements, statistics elements), and the hydraulic rating methods (wetted perimeter method). Therefore, the GEP method could be considered a hybrid of existing techniques.

In contrast to holistic approaches, the GEP method does not examine and analyse the community of aquatic organisms (periphyton, zoobenthos, fish, macrophytes) as a whole, but only target-specific species, examining their requirements individually. However, similar to other methods, the main deficiency is the lack of evidence that biota responds to changes in flow regime.

The main advantages of the GEP method proposed by the BiH administrations are:

- it is a simple, fast and cheap method
- it is general, could be useful for different types of rivers (lowland, karst, Mediterranean) and it is not site specific
- it is based on existing hydrological data
- it is based on existing, world-wide used methods
- the need of analyses of low flows
- the use of long term probability of low flow
- the need of analyses of river morphology
- it considers the basic relation between river hydrology and morphology as abiotic characteristics for fish habitats
- it includes the basic requirements for fish habitats
- inside environmental flow evaluation, it is possible to make corrections of prescribed flows according to the river, from case to case
- it uses the river bed wetted perimeter method for fish habitats in the time of low flow
- if there is an ecological value or recreational value of the river, environmental flow could be 15 % higher in the cold period and 30 % higher in the warm period
- at the outlet from the reservoir, the characteristics of physico-chemical parameters of water should be as similar as possible to those in the river
- it monitors the fish populations

- it uses experience from other methods.

The main disadvantages assessed by this project of the proposed GEP method are:

- the GEP method does not have a clearly established procedure for evaluating environmental flow;
- it does not foresee the consultation of various stakeholders in setting objectives thus increasing the likelihood of conflicts;
- it does not define the analysis of critical parameters in environmental flow evaluation and the objectives which should be achieved by environmental flow evaluation;
- environmental flow is evaluated only for two periods of the year: the cold and the warm period and does not take into account the dynamics of natural flows and flood flows;
- the method takes into account mostly the values of low flows;
- few parameters are used for environmental flow evaluation;
- it does not thoroughly include the site-specific linkages between flow, morphology and ecology;
- it does not include the proportion between minimum flow, mean annual minimum flow and mean daily flow;
- the values of the environmental flow under assessment are likely to be too low to achieve at least a good ecological status of the river ;
- environmental flow for the cold period is fixed, allowing higher values only in March to respond to fish spawning needs (but not all fish species spawn in this month);
- depending on the river type and its location, the cold period is not always between October-March (as required by GEP);
- it is an obsolete method and in fact the literature referred to by the GEP method does not include globally recognized methods developed after 1990, when holistic approaches were developed;
- it does not cover requirements for important aquatic organisms (algae, macrophytes, invertebrata) and riparian flora and fauna;
- the flow regime does not include timing, magnitude, duration and frequency of different flows.

7.2 Additional important criteria needed for environmental flow assessment, which are missing in the GEP methodology

In the GEP method some very important criteria for environmental flow evaluation are missing, namely:

- Habitat requirements for different groups of aquatic flora and fauna,
- water velocity,
- water depth,
- geology,
- the structure of river sediments,
- the presence of fish spawning grounds,
- habitat mapping,
- water quality
- landscape picture,

- tributaries in the river section with water extraction,
- the quantity and duration of water extraction,
- river connection with riparian zone,
- habitats connectivity,
- the length of the river reach affected by water extraction,
- other water uses that may effect the river section
- timing, magnitude, duration and frequency of different flows during the year.

In environmental flow evaluation most of these criteria have to be considered with the aim to maintain the river and riparian ecosystem (for this project phase relating to the river Tihaljina-Mlade-Trebižat). This is proposed to be carried out as part of an environmental flow evaluation process in the next phase of the project.

7.3 Recommendations for Sub-Laws in BiH legislation

Most EU countries do not have sub-laws that detail environmental flow application. Rather, they have recommendations about the type of analyses that should be included in environmental flow assessment. i.e. article 62 of the FBiH Water Law says that, till the proposal of sub-laws will be fully developed, the values of 95 % probability for the monthly minimum flow should be applied. The water laws, though, require the development of a sub-law that should provide more details on how environmental flow should be calculated.

The application of the GEP methodology implemented in the framework of this project has highlighted a number of weaknesses and disadvantages. It would not be appropriate, therefore, to set it as the standard method for environmental flow calculation in BiH. Nevertheless, it can provide a very good starting point for a process of environmental flow assessment which should afterwards be cross-checked and upgraded according to the ecological needs of the river ecosystem and in consultation with various stakeholders when setting obejctives. It is strongly advised that the sub-law on environmental flow should specify the parameters that need to be assessed, and a provisory list is provided in chapter 7.2. The methodology itself should be defined separately for each of the rivers and/or sections by the responsible agencies, i.e. Agencies based in Mostar and Trebinje for the Adriatic basin rivers, and Agencies based in Sarajevo and Banja Luka / Bijeljina for the Sava basin rivers.

Although we do not recommend the nomination of a specific method in the sub-law, it is nevertheless necessary that recommendations on the principles guiding environmental flow assessment are provided. A list of these follows.

i. The implementation of environmental flow should be an adaptive process where an initial decision is taken on the basis of the available information and is then improved when better and more extensive information become available via a monitoring programme;
ii. The process of environmental flow calculation should begin by setting the objectives which would achieve a sustainable balance of environmental social and economic needs;

iii. The objectives should be discussed and agreed upon with all the stakeholders directly or indirectly affected by the water management;
iv. It is essential to envisage the assessment of the ecological values of the river;
v. The methodologies that can be used for environmental flow assessment are grouped into: hydrological methods, hydraulic rating methods, habitat simulation methods and holistic methods. Different methods are appropriate in different circumstances depending on the type of water resource, availability of information, expertise, funding, and time.
vi. Holistic approaches are the only ones that ensure a full understanding of ecological needs;
vii. Decisions regarding which method should be used in each particular case should be taken by the basin agencies with advice from experts with experience in environmental flow assessment (see point viii);
viii. The basin agencies should set up a group of experts covering at least the following expertise:
    - Hydrology
    - Hydraulics
    - Geomorphology
    - River biology
    - Water quality
    - Social sciences
ix. If the flow calculated with the selected method does not fulfil the needs of the assessed ecological values of the river, the environmental flow should be gradually increased to fulfil those needs, or should be assessed using a different method;
x. An environmental flow strategy should not deteriorate the good ecological status or good ecological potential of the river, as required for example by article 22 of the RS water law.
xi. Monitoring the achievement of environmental flow objectives is essential if the management agency is to be able to judge whether the flows are achieving the desired objectives;
xii. The monitoring programme should include the ecological, water quality and geomorphological aspects, as identified in the objectives setting process for environmental flow, as well as the hydrological conditions;
xiii. The overall objective of environmental flow is to maintain the long-term sustainable protection of water resources and therefore the implementation of flows has to be continous in the long term;
xiv. Considerable research has demonstrated the importance of maintaining the natural flow variability in river systems. The variability of flows is in many ways as important as the volume of flows in maintaining ecological diversity and functionality in river ecosystems;
xv. Where the values of environmental flow are lower than 1 m^3/s, the values are rounded to the third decimal place; where the values of environmental flow are higher than 1 m^3/s, they are rounded to the second decimal place.

The testing of GEP methodology carried out in the framework of this project led to the following conclusion: if the GEP methodology is chosen, it should be modified in order to comply with the minimum requirements as specified in Chapter 8. Guidelines on environmental flow assessment at agency level should be prepared according to the specific conditions of the rivers.

If the BiH river basin agencies are interested in pursuing these modifications, WWF would be interested in supporting this process in the next project phase.

8 SECOND GENERATION GEP METHOD

The application of the GEP methodology is based on three parameters: (1) average multiannual flow on the dam profile,for example the location of water diversion ($\overline{Q}$), (2) monthly-minimum low-flow with 95% exceedence probability ($Q_{95\%}^{\min.monthly}$), (3) monthly- minimum low-flow with 80% exceedence probability ($Q_{80\&}^{\min.monthly}$). If multiannual series of daily flows are available, adequate values of 30-day low flow with the same exceedence probability ($Q_{95\%}^{\min.(30)}$) and ($Q_{80\%}^{\min.(30)}$) can be used[6], instead of the minimal monthly flow ($Q_{95\%}^{\min.monthly}$) and ($Q_{80\&}^{\min.monthly}$).

When all the above-mentioned data are available, the basic principles can be summarized in clear rules that define the GEP methodology:

The adoption of the guaranteed ecological flow (GEP flow – $Q_{ecol \cdot gar}$) must comply with the following directions:

(1) During the cold season (October-March), the guaranteed $Q_{ecol \cdot gar}$ should be chosen as the value of the monthly- minimum low-flow 95% exceedence probability ($Q_{95\%}^{\min.monthly}$), e.g. the 30-day low-flow with the same exceedence probability ($Q_{95\%}^{\min.(30)}$), but that value should neither be less than $0{,}1\times\overline{Q}$, nor higher than $0{,}15\times\overline{Q}$. That means that$Q_{ecol \cdot gar}$ for the cold season should be chosen on the basis of the equation:

$$Q_{ecol.gar.} = \begin{cases} 0.1\times\overline{Q} & for \quad Q_{95\%}^{\min.monthly}\ ili\ Q_{95\%}^{\min.(30)} \le 0.1\times\overline{Q} \\ Q_{95\%}^{\min.monthly}\ ili\ Q_{95\%}^{\min.(30)} & for \quad 0.1\times\overline{Q} < Q_{95\%}^{\min.monthly}\ ili\ Q_{95\%}^{\min.(30)} < 0.15\times\overline{Q} \\ 0.15\times\overline{Q} & for \quad Q_{95\%}^{\min.monthly}\ ili\ Q_{95\%}^{\min.(30)} \ge 0.15\times\overline{Q} \end{cases}$$

(2) During the warm season (April-September), the garanteed $Q_{ecol \cdot gar}$ should be chosen as the value of the monthly- minimum low-flow 80% exceedence probability ($Q_{80\%}^{\min.monthly}$), e.g. 30-day low-flow with the same exceedence probability ($Q_{80\%}^{\min.(30)}$), but that value should not be less than $0{,}15\times\overline{Q}$. e.g. it should be higher than $0{,}25\times\overline{Q}$. That means that $Q_{ecol \cdot gar}$ for the warm season should be chosen on the basis of the equation:

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[6] Alternatives are given according to operational reasons. Certainly it is better if the data on the 30-day low-flow appropriate exceedence probability are available, because that is more in accordance with the physics of low-flow phenomena: extremely low-flow periods defined as the year-low flow of 30-days continuous duration, can cover parts of two months. However, insisting only on flows ($Q_{95\%}^{\min.(30)}$) and ($Q_{80\%}^{\min.(30)}$) would not make sense, because the daily flows are often not available. …. As a rule, the usage of the monthly- minimum low-flow instead of the 30-day low-flow issues slightly higher values.

$$Q_{ekol.gar.} = \begin{cases} 0.15 \times \overline{Q} & for \quad Q_{80\%}^{min.mes}\ ili\ Q_{80\%}^{min.(30)} \leq 0.15 \times \overline{Q} \\ Q_{80\%}^{min.mes}\ ili\ Q_{80\%}^{min.(30)} & for \quad 0.15 \times \overline{Q} < Q_{80\%}^{min.mes}\ ili\ Q_{80\%}^{min.(30)} < 0.25 \times \overline{Q} \\ 0.25 \times \overline{Q} & for \quad Q_{80\%}^{min.mes}\ ili\ Q_{80\%}^{min.(30)} \geq 0.25 \times \overline{Q} \end{cases}$$

If the values of the GEP flow issued by a defined low-flow exeedence probability are beyond the amplitude defined by the above rules and equations (1) and (2), limiting values should be chosen.

(3) If the river is characterized by specific ecological or recreational interests the above-mentioned rules and equations can be increased as follows: up to 15%for the cold season, up to 30% for the warm season. A special analysis and justification of the increased value is needed in such a case.

(4) The values of the GEP flow calculated for cold seasons could be treated as constant for the whole cold period, but if needed for specific river ecology targets, certain variations in flow are possible (e.g. a certain increase of the flow in March, during the reproduction period for some fish).

(5) Values of the GEP flow for the warm season should take into account the special ecological needs of ichtiofauna and other organisms. In critical periods of reproduction, discharge values must be increased in response to a request made by the authorities responsible for the ecological protection and fishery. A decrease in discharge values is possible when the flows are favorable (= abundant), but the values of the flow downstream should not be less than the discharges during the cold season.

(6) In addition to the evaluation of environmental flow that is required by the GEP method, it is essential to assess the ecological values of the river.

(7) If the flow calculated with the GEP method does not fullfil the needs of the assessed ecological values of the river, the environmental flow should be gradually increased until it fulfils those needs.

(8) Environmental flow should not cause deterioration in the good ecological status or good ecological potential of the river as required by article 22 of the RS water law.

(9) The monitoring of environmental flow should be automatically ensured at the gauging station of the river section with water extraction (maximum100 m downstream).

(10) Environmental flow has to be ensured continuously.

9 CONCLUSIONS

Environmental flow is a tool for balancing the needs of ecosystems with the needs of various users. Maintaining healthy river ecosystems ensures the long term availability of water for the various users and contributes to the community's livelihood.

Environmental flow for the river Trebižat (Tihaljina, Mlade) was evaluated using the original GEP methodology, but later results were upgraded with the requirements for river ecology. Calculated values of environmental flow were much higher than the values of the 95 % monthly minimum flow probability, as prescribed by the BiH Water Laws. From this point of view, even prescribing the GEP methodology in the BiH sub-laws would require an increase of river flows downstream of dams. The GEP method is based purely on hydrological measurements and does not use a holistic approach[7], which is the environmental flowapproach recommended by scientists and experts around the world.

The GEP method has a number of disadvantages, and it does not take advantage of more recent environmental flow assessment methodologies developed after the GEP. It has been applied only to one river in BiH so far (Trebižat), hence it is important to be cautious in drawing conclusions in terms of national application. Its application at a national level should be further investigated.

In the light of the high acceptance of the GEP by the BiH administrations and its easy applicability, and taking into account recent developments in the rapidly expanding field of environmental flow assessments, it is proposed to fully develop a second generation GEP method which would optimize the existing benefits and overcome the present limitations of the existing method.

9.1 Monitoring of the river ecosystem to assess environmental flow and its effectiveness

It is recommended that the river ecosystem is monitored, which includes:

- The selection of representative sampling sites for sampling hydromorphological, biological and physico-chemical parameters;
- The collection of more data about the Trebizat river structure and function especially during the summer low flows;
- The selection of parameters according to the set ecological objectives and related critical parameters: (f.e. macrophytes, fish, phytobenthos, invertebrates, mesohabitats, physico-chemical parameters, selected hydro-morphological parameters).

[7] It is an approach that considers a wide range of ecological and hydrological aspects of the river systems and often implies the set up of a panel of experts.

9.2 Monitoring environmental flow

Monitoring environmental flow should be automatically ensured at the gauging station of the river section with water extraction (maximum 100m downstream) and has to be ensured continuously.

9.3 Recommendations for future work

In four months (March-June 2008) a remarkable amount of work has been done, nevertheless, additional efforts are needed in the future to fine tune the GEP method to the more recent developments in the environmental flow field.

Potential lines of work for the future are:

- To fix sustainable flow objectives as required by the water laws;
- To involve the various actors in the environmental flow process and set sustainable flow objectives;
- To sample flora and fauna in order to know the structure and function of the aquatic and riparian ecosystem (fill the gaps in biodiversity data);
- To investigate the links between flora / fauna and ecosystem services and the hydrological data requirements for the GEP and define more precisely the relationship between qualitative parameters (biological, physico-chemical) and flow defined by the GEP methodology;
- To define environmental flow using methods other than GEP, to overcome the weaknesses identified by the GEP; morespecifically provide a detailed description of other favourable methods that could be appropriate for BiH conditions;
- The application of the environmental flow concept to the river basin management plan;
- To set up the monitoring of environmental flow implementation (identification of indicators, monitoring mechanisms, etc.) in order to achieve ecological objectives;

10 REFERENCES

Aadland, L.P. (1993). Stream habitat types: their fish assemblages and relationship to flow, *North American Journal of Fisheries Management* **13**, 790-806.

Acreman, M. /Dunbar M.J. 2004. Defining environmental river flow requirements – a review. Hydrology and Earth System Sciences 8 (5), 861-876, EGU.

Antonić, O., Kušan, V., Bakran-Petricioli, T., Alegro, A., Gootstein-Matočec, S., Peternel, H., Tkalčec, Z. (2005): Klasifikacija staništa Republike Hrvatske. Drypis 1/1 : 1-12.

Biggs, B. J. F., Close, M. E. (1989). Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients, *Freshwater Biology* **22,** 209 - 231.

Biggs, B.J.F, Duncan, M.J., Surren, A.M., Holomuzki, J.R. (2001). "The importance of bed sediment stability to benthic ecosystems of streams" in M.P. Mosley, Ed., *Gravel-Bed Rivers V.* New Zealand Hydrological Society Inc, The Caxton Press: Christchurch, 423–443.

Biggs, B.J.F. (1996). "Patterns in Benthic Algae in Streams" in R.J. Stevenson, M.L. Bothwell, R.L. Lowe, Eds., *Algal Ecology Freshwater Benthic Ecosystems.* Academic Press, Inc: San Diego, 31–56.

Biggs, B.J.F., Goring, D.G., Nikora, V.I. (1998). Subsidy and stress responses of stream periphyton to gradients in water velocity as a function of community growth form, *J. Phycol.* **34** , 4, 598 – 607.

Blamey, M., Grey – Wilson, C., 1998: Mediterranean wild flowers. Harper Collins Publisher, London.

Bogut, J., et all. 2003: Kvalitativni i kvantitativni sastav ihtiofaune rijeke Trebižat.

Brown, C. / King, J. 2006. Environmental flows: Striking the balance between development and resource protection. *Ecology and Society* 11(2): 26.

Brown, C. and King, J. 2006. Environmental flows: Striking the balance between development and resource protection. *Ecology and Society* 11(2): 26. attached PDF document – to focus on chapters 1-3.

Burnie, D., 1995: Wild flowers of the Mediterranean. Dorling Kindsley, London – New York – Stuttgart.

Decree on classification of freshwater and coastal water of Yugoslavia inside Bosnia and Herzegovina, Official Gazette SRBiH, 19/80

Delforge, P., 1995: Orchids ofBritain and Europe. Harper Collins Publishers, London.

DIRECTIVE 2000/60/EC OF THE EUROPEN PARLIAMENT AND OF THE COUNCIL, Luxembourg, 2000.

Domac, R., 1994: Flora Hrvatske. Priručnik za određivanje bilja. Školska knjiga, Zagreb.

Đorđević B, 1990, Vodoprivredni sistemi, Naučna knjiga, Beograd

Đorđević B, Dašić T, Garantovani protoci nizvodno od brana

Đorđevič, B. / Dašić, T. Guaranteed flows downstream the Hydro power plants: GEP method.

Dyson, M./ Bergkamp, G. / Scanlon, J. (Eds) 2003. Flow, the essentials of environmental flows (Gland: IUCN).

Erskine, W.D. / Terrazzolo, N. / Warner, R.F. 1999. River rehabilitation from the hydrogeomorphic impacts of a large hydro-electric power project: Snowy River, Australia. Regulated Rivers: Research and Management, 15, s. 3 - 24.

Everard, M. (1996). "The importance of periodic droughts for maintaining diversity in the freshwater environment" in D. Sutcliffe, Ed., *Freshwater Forum - Volume 7*. Freshwater Biological Association, 33 - 50.

Federal Hydrometeorological Institute, 2001, Hydrological Study Tihaljina – Mlade – Trebižat, ordered by «Elektroprivreda» HZ HB

Fernandez – Alaez, C., Fernandez Alaez, M., Becares, E., 1999: Influence of water level fluctuation on the structure and composition of the macrophyte vegetation in two small temporary lakes in the northwest of Spain. Hydrobiologia 415, 155 – 162.

Fiori, A., 1923 – 1929: Nuova flora analitica d'Italia. Firenze.

Fiori, A., 1933: Iconographia florae Italicae. Firenze.

Gehrke, P.C., Harris, J.H. (2000). Large-scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia. *Marine and Freshwater Research* **51**: 165-82.

Governments of the Federation of Bosnia and Herzegovina and Republika Srpska, 2003, National Environmental Plan – NEAP

Hawkins, C. P., Kershner, P., Bisson, A., Bryant, D., Decker, L. M., Gregory, S. V., McCullough, D. A., Overton, C. K., Reeves, G. H., Steedman, R. J., Young, M. K. (1993). A hierarchical approach to classifying stream habitat features. *Fisheries* **18,** 3-12.

Ivan slišković:On the Hydrogeological Conditions of Western Herzegovna (Bosnia and Herzegovina)and Possibilities for New Groundwater Extractions, Zagreb 1994.

Jasprica, N., 2003: Identification and preservation of endangered marine, freshwater and terrestrial habitats, and plant communities in the Mediterranean zone ofBosnia and Herzegovina. Action Plan. UNEP, MAP, RAC/SPCA, Tunis.

Maddock, I. P., Smolar, N., Hill, G. 2007. The effect of flow regulation on the spatial distribution and dynamice of channel geomorphic units (CGU's) in the Soča river, Slovenia. V: *Bridging the gap between hydraulics and biology : extended abstracts, posters of the 6th international symposium on ecohydraulic, 18 - 23 february 2007, Christchurch, New Zealand*. Chistchurch, 2007, str. [1-4].

Maddock, I.P. (1999). The importance of physical habitat assessment for evaluating river health. *Freshwater Biology* **41**, 373-391.

Maddock, I.P., Bickerton, M.A., Spence, R., Pickering, T. (2001). Reallocation of compensation releases to restore river flows and improve instream habitat availability in the Upper Derwent catchment, Derbyshire, UK. *Regulated Rivers: Research and Management* **17**, 417-441.

Maddock, I.P., Bird, D. (1996). The application of habitat mapping to identify representative PHABSIM sites in the River Tavy, Devon, U.K., in M. Leclerc, H. Capra, S. Valentin, A. Boudreault, Y. Côté, Eds. "Proceedings of the 2nd International Symposium on Habitats and Hydraulics", Quebec, Canada. Vol. B, 203-214.

Maddock, I.P., Hill, G., Smolar-Žvanut, N. (2005). The effect of flow regulation on channel geomorphic unit (CGU) composition in the Soča River, Slovenia, in, A.Harby, M. Baptist, H. Duel, M. Dunbar, P. Goethals, A. Huusko, A. Ibbotson, H. Mader, M.L. Pedersen, S. Schmutz, M. Schneider et al., Eds. "Proceedings of the 7th meeting of the EU COST Action 626 in Aquatic Habitat Modelling", Silkeborg, Denmark, May 2005, 205-216.

Maddock, I.P., Thoms, M., Jonson, K., Dyer, F, & Lintermans, M. (2004). Identifying the influence of channel morphology on physical habitat availability for native fish: application to the Two-Spined Blackfish (*Gadopsis bispinosus)* in the Cotter River, Australia. *Marine and Freshwater Research* **55**, 173-184.

Matoničkin, I., Pavletić, Z. 1963: Sudjelovanje pojedinih životinjskih i biljnih skupina u izgradnji životnih zajednica na sedrenim i erozijskim slapovima Bosne i Hercegovine. Iz Biološkog instituta i Instituta za botaniku Sveučilišta Zagreb.

Matoničkin, I., Pavletić, Z., 1972: Život naših rijeka. Školska knjiga – Zagreb.

Mikoš, M. (1989). Urejanje hribovskih vodotokov (Management of mountainous streams), *Acta hydrotechnica* **6** (7), 1-59 (in Slovenian).

Mikoš, M. (1999). Navodila za uporabo ZPP - verzija 1999 (Instruction for use ZPP – version 1999). Univerza v Ljubljani, FGG, Katedra za splošno hidrotehniko, 18 p (in Slovenian).

Milhous, R.T. (1998). Modelling of instream flow needs: the link between sediment and aquatic habitat. *Regulated Rivers: Research and Management* **14**, 79 – 94.

Mrakovčić, M., et all. (2007): Crvena knjiga slatkovodnih riba Hrvatske. Državni zavod za zaštitu prirode, Zagreb.

Nikolić, T.,et all., 2006: Biološka raznolikost Hrvatske. Državni zavod za zaštitu prirode, Zagreb.

Petts, G.E. / Maddock, I. 1995. Flow Allocation for In-river Needs. V: The Rivers Handbook Hydrological and Ecological Principles, Vol. 2, (eds. Calow, P. / Petts, G. E.), Blackwell Scientific Publications, Oxford, s. 289 – 307.

Petts, G.E. 1996. Water allocation to protect river ecosystems. Regulated Rivers: Research and Management, 12, s. 353 – 365.

Petts, G.E., Armitage, P. & Castella, E. (1993). Physical habitat changes and macroinverebrate response to river regulation: the River Rede, UK, *Regulated Rivers: Research and Management* **8**, 167-178.

Pignatti, S., 1982: Flora d'Italia, 1 – 3. Edagricole, Bologna.

Rott, E., Pfister, P. (1988). Natural epilithic algal communities in fast-flowing mountain streams and rivers and some man - induced changes, *Verh. Internat. Verein. Limnol*. **23**, 1320 - 1324.

Šilić Č. 1996: List of botanical species (Pteridophyta and Spermatophyta) for the Red book of Bosnia and Herzegovina. National Museum of Bosnia and Herzegovina, Sarajevo.

Slišković I, 1994, On the Hydrogeological Conditions of Western Herzegovina (Bosnia and Herzegovina)and Possibilities for New Groundwater Extractions, Zagreb

Smolar, N., Mikoš, M., Breznik, B., Krivograd Klemencic, A. 2007. Effects of small hydroelectric power plants on aquatic ecosystems in Slovenianrivers. V: *Bridging the gap between hydraulics and biology : extended abstracts, posters of the 6th international symposium on ecohydraulic, 18 - 23 february 2007, Christchurch, New Zealand*. Chistchurch, 2007, str. [1-4].

Smolar-Žvanut, N. (2001). Vloga perifitonskih alg pri določanju ekološko sprejemljivega pretoka vode v tekočih vodah / The role of periphytic algae in the determination of the ecologically acceptable flow in running waters, *Acta hydrotechnica* **19/30**, 65-89.

Smolar-Žvanut, N., Krušnik, C., Kosi, G., Vrhovšek D. (2004a). Uporaba perifitona in večjih vodnih nevretenčarjev pri določanju ekološko sprejemljivega pretoka na reki Rižani, Slovenija / The use of periphyton and macrozoobenthos in determination of ecologically acceptable flow for the Rižana river, Slovenia. *Acta hydrotechnica* 21/35, 129-143.

Smolar-Žvanut, N., Mikoš, M., Burja, D., Breznik, B., Vrhovšek, D., Kosi, G., Padežnik, M. (2005). Primerjava vodnega ekosistema reke Bistrice nad in pod pregrado za MHE Mojstrana. (The comparison of water ecosystem in the river Bistrica up and downstream of the Dam for hydropower Mojstrana). Proceeding »16. Mišičev Vodarski dan 2005«, Maribor 9.12.2005, 118-123 (in Slovenian).

Smolar-Žvanut, N., Vrhovšek, D., Kosi, G. (1998a). »Effects of low flow on periphyton in three different types of streams in Slovenia" in G. Bretschko, J. V. Helešic, Eds., *Advances in River Bottom Ecology*. Backhuys Publishers, Leiden, The Netherlands, 107 – 116.

Smolar-Žvanut, N., Vrhovšek, D., Kosi, G. (1998b). Ocena vpliva odvzema vode iz Tržiške Bistrice na perifitonske alge (An estimation of influence of water abstraction from the stream Tržiška Bistrica on periphytic algae), *Ichthyos* **15**, 29-46 (in Slovenian).

Smolar-Žvanut, N., Vrhovšek, D., Kosi, G. (2004b). Pojavljanje fitobentosa v različnih hidroloških okoljih v reki Branici (Distribution of phytobenthos in different hydraulic environments in the river Branica, *Ichthyos* **19**, 18-29 (in Slovenian).

Standard American methods (Standard Methods for Examination of Water and Wastewater, 1985)

Traen, T.S., Lindstrøm, E.A. (1983). "Influence of current velocity on periphyton distribution" in R. G. Wetzel, Ed., *Periphyton of Freshwater Ecosystems.* Dr W. Junk Publishers, 97 - 99.

Trinajstić, I., (ed.), 1975 – 1986: Analitička flora Jugoslavije. 2(1 – 4). Institut za botaniku Sveučilišta u Zagrebu, Zagreb.

Tutin, T. G., Heywood, V. H., Burges, N. A., Moore, D. M., Valentine, D. H., Waters, S. M., Webb, D. A. (eds.), 1964 – 1980: Flora Europea 1 – 5. Cambridge University Press, Cambridge.

Znanstveno stručni simpozij s međunarodnim sudjelovanjem Voda u kršu slivova Cetine, Neretve i Trebišnjice, Zbornik radova, Neum

11 APPENDICES

Appendix 1 – Hydrology of HS Pec Mlini Tihaljina source (No 8)

Appendix 2 – Hydrology of HS Pec Mlini downstream (No 9)

Appendix 3 – Hydrology of HS Tihahljina (No 10)

Appendix 4 – Hydrology of HS Klobuk (No 11)

Appendix 5 – Hydrology of HS Grabovo vrelo (No 12)

Appendix 6 – Hydrology of HS Grabovo vrelo (No 24)

Appendix 7 – Physico-chemical parameters

Appendix 8 –environmental flow assessment with including critical parameters