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Quality assessment of the aquatic habitat of mountain streams in the period of minimal flow using the ichthyofauna as a bioindicator

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A B S T R A C T

This paper describes the IFIM methodology (Instream Flow Incremental Methodology) for determining the minimum discharge, which, in addition to hydrological parameters, takes hydraulic, morphological and ichthyologic parameters into account as well. The basic principle of the method is the relationship between the fish population and its habitat, i.e., that most fish species prefer certain combinations of depths, stream velocities, and bed materials. If the values for a species living in a section of the river investigated are known, the minimum discharge for each fish species may be determined. This method was verified on reference sections of the Teplá River in the town of Sklené Teplice.

Keywords: IFIM Method (Instream Flow Incremental Methodology), Low flow characteristics, Stream Regulation, Abundance, Bioindication, Ichthyomass, WUA - Weighted Usable Area.

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Introduction

In Europe, it is gradually becoming a standard to model the ecological water quality based on the Instream Flow Incremental Methodology (IFIM) [1]. IFIM is an interdisciplinary decision-making system that assists landscape engineers to consider the benefits and consequences of different water management solutions [2]. IFIM methodology was developed in the United States by the U.S. Fish and Wildlife Service (USFWS) to determine the effect of water management projects on the natural environment by quantifying the aquatic environment [3,4]. The basis of the IFIM methodology is the Physical Habitat Simulation System (PHABSIM), which is used to analyse the relationship between the flow and biotic components of the environment. This relationship is a continuous flow function [5]. This method can also be used to predict the impact of climate change on the quality of the aquatic habitat [7]. Climate change has a negative impact on the biota of the flow similarly as contamination of flow [7].

The quality of the aquatic habitats of mountain and piedmont streams was evaluated using the Instream Flow Incremental Methodology (IFIM) decision-making tool. IFIM is based on the knowledge that most fish species prefer certain combinations of water depths, flow velocities [8, 9], availability of cover, and bed materials [10]. IFIM can provide robust assessments of the quality of a river when sufficient data are available. One of the most considerable advantages of IFIM over alternative methods (CCA, RDA, GLM, and related-analyses) is the fact that it incorporates a spatially distributed model in any desired detail.

In the case of morphological changes, the biotic component of the environment represents fish as the most crucial element standing at the top of the food pyramid of aquatic biota. Because of their longevity, their mobility and their sensitivity to habitat modification, fish are good bioindicators [11-13], and they are often used for the assessment of the ecological integrity of rivers [11, 14-16].

In the IFIM methodology, the basic parameters of the flow habitat are divided into abiotic and biotic. A more detailed analysis between abiotic and biotic characteristics is given in the basic abiotic characteristics are depth and flow velocity. The relationship of the abiotic and biotic characteristics of the aquatic area is represented by the suitability curves of individual fish species. A detailed analysis of the relation of the suitability curves to the hydraulics of flow was confirmed mainly in relation to the flow depth [17]. The river regulation changes mainly the morphology of the river bed, which is reflected in the change in depth and flow velocity. For this purpose, the Riverine HABitat Simulation model (RHABSIM) is used to generate quantitative results representing the quality of the aquatic habitat. Habitat quality is determined by depth and velocity parameters, which are derived from suitability curves that represent habitat preference for individual fish species [18]. The habitat quality is represented by the WUA -Weighted Usable Area. WUA expresses the functional relationship between the flow and the surface of the flow.

The following procedure was chosen for the determination of the quality of the aquatic habitat for reference sections of 20 different representative Rivers in Hron River basin:

- measurement of topographic parameters of the reference sections,
- measurement of the velocity field,
- evaluation of the grain-size distribution of the bottom material,
- ichthyological research,
- evaluation of the results in the IFIM model.

The results of the measurements were then evaluated for the selected reference sections of the Teplá River in the town of Sklené Teplice using the RHABSIM model and then compared with the model developed by the authors of this paper.

Topographic measurement of the reference sections

The topography of the reference sections was characterized by cross-sections set at fixed points, which permitted the repeating of measurements in the same profile. The measurements were made by leveling, which has a higher precision for hydraulic modeling.

Measurement of the velocity field

The discharge was measured in a representative measuring profile using hydrometric devices. The velocity field was set by point measurements in each cross section. The distance between the verticals ranged from 1 to 2 meters. The measurement was made in within the ichthyological survey and then separately for different water stages to verify the hydraulic model.

Grain-size distribution of the bottom material

The grain size was analyzed using a sieve directly in the field. Sieves with circular meshes were used. The weight of the samples ranged from 120 kg to 240 kg.

Ichthyological survey

The reference sections of the rivers were blocked at each end by nets with a mesh size of 10x10 mm. Fish were caught using an electric aggregate and put afterward into a fish tank located in the river below the lower net, beyond the reach of the electric field. Three catches were made in each of the blocked sections, whereby the second and third catches were made 45 minutes after the previous ones. After each catch, every fish species was counted separately, and the fish were measured, weighed and let out into the river below the last net. The calculated values, combined with the mean weight of the respective species, were applied to the calculation of the biomass of the individual species and total ichthyomass. At the same time, the mean weight of each species was calculated, and this weight was compared with the number of fish in each of the length groups.

The abundance expresses the number of fish of the respective species. The abundance is given in fish per hectare; the ichthyomass expresses the aggregate weight of the entire fish population and is given in $kg.ha^{-1}$.

Results and discussion

We tried to confine ourselves to an examination of the quantifiable basic parameters of a river, which would implicitly include ecologically relevant information. The width, depth, water level area, velocity field, water temperature and characteristics of the ichthyic fauna as indicators of the quality of the biological environment in a river may be considered as the basic parameters of a river.

An analysis of the morphometric, hydraulic and ichthyological parameters has been made for all selected reference sections in the Hron River basin. This paper contains the basic results obtained from the reference sections of the Teplá River in the town of Sklené Teplice.

Basic characteristics of the Teplá River

Catchment area = 172 km^2, stationing 127 km. Water gauge altitude = 287.00 m above sea level, $Q_{max\ (1941\text{-}2017)}$ = 72 m^3.s^{-1}, $Q_{min\ (1941\text{-}2017)}$ = 0.17 m^3.s^{-1}.

Table.1. *Overrun of average daily discharges*

M-days	30	90	180	270	330	335	364
Discharge [m^3.s^{-1}]	5.65	2.73	1.52	1.05	0.68	0.53	0.32

Water quality in the Teplá River in the town of Sklené Teplice

In the profile situated in the town of Sklené Teplice, the effect of the local municipal pollution was demonstrated by the usual increase in the number of coliform (class IV - fairly clean) and psychrophile bacteria (class V - waters are not classified in class 1-4), especially in 2016. The organic pollution expressed by BOD already exceeds the class II (very clean) limit value. COD-Mn remains in class II of the classification under standard ČSN 75 7221. The dissolved oxygen complies with class I (extra clean). The biological activity of the river expressed by the saprogenic index of biosestone corresponds to class III (medium clean).

Characterization of the riverbed of the reference sections of the Teplá River

Three reference sections were chosen on the Teplá River in the town of Sklené Teplice, and these sections follow one another; therefore, they may be documented in one longitudinal section. The numbering of the sections is identical with the designation of the cross sections; hence, the sections are numbered upstream.

Section No. 1 is in the town of Sklené Teplice. It is 52.58 m long (the stationing of the section in figure 1 starts at 0.00 and ends at 52.58 m). The riverbed bottom is dissected only to a small extent with unmarked alterations of the depth; it consists of gravel sand. This section represents the flow area. The topography of the riverbed bottom in all three sections is partially documented by the longitudinal section in figure 1.

Section No. 2 is 83 m long (the stationing of the section in figure 1 starts at 52.58 and ends at 135.60 m). The riverbed bottom is dissected; trees and shrubs cover the banks. This section represents the flow shadow area.

Section No. 3 is 33.3 m long (the stationing of the section in figure 1 starts at 135.60 and ends at 168.90 m). The riverbed bottom is dissected only to a small extent. Trees and shrubs cover the banks. The longitudinal slope of the water level is large (0.93%), which means greater flow velocities and small depths. This section represents the fording area with small depths and higher flow velocities.

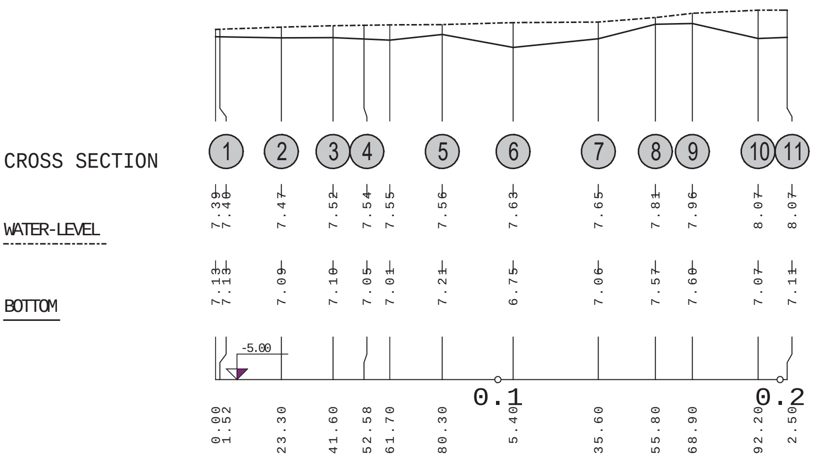


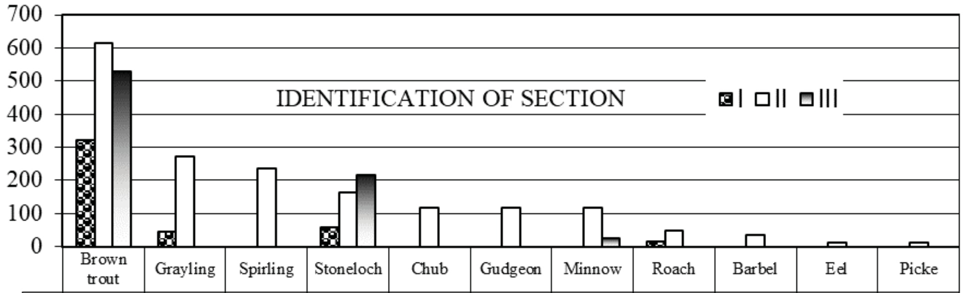
Fig. 1. *Longitudinal section of reference sections 1-3 of the Teplá River in the town of Sklené Teplice*

Basic abundance and ichthyomass data are given in Figures 2 and 3; the list of fish found in the reference sections of the Teplá River is given in Table 2.

Table 2. *List of fish species found in the reference sections of the Teplá River*

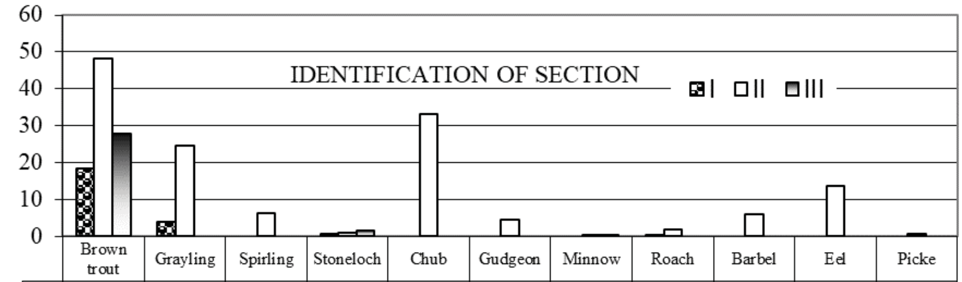
Fish name	Scientific name
Barbel	Barbus barbus
Brown trout	Salmo labrax m.fario
Chub	Leuciscus cephalus
Eel	Anguilla anguilla
Grayling	Thymallus thymallus
Gudgeon	Gobio gobio

Fish name	Scientific name
Minnow	Phoxinus phoxinus
Perch	Perca fluviatilis
Picke	Exox lucius
Roach	Rutilus rutilus
Spirling	Alburnoides bipunctatus
Stoneloach	Barbatula barbatula



	Brown trout	Grayling	Spirling	Stoneloch	Chub	Gudgeon	Minnow	Roach	Barbel	Eel	Picke
I	323	44	0	59	0	0	0	15	0	0	0
II	614	272	236	165	118	118	118	47	35	12	12
III	529	0	0	217	0	0	24	0	0	0	0

Fig. 2. *Abundance [fish.ha^{-1}] in the reference sections of the Teplá River in the town of Sklené Teplice*



	Brown trout	Grayling	Spirling	Stoneloch	Chub	Gudgeon	Minnow	Roach	Barbel	Eel	Picke
I	18.4	4	0	0.7	0	0	0	0.4	0	0	0
II	48.3	24.7	6.2	1.1	33	4.4	0.14	1.7	6	13.6	0.8
III	27.8	0	0	1.4	0	0	0.03	0	0	0	0

Fig. 3. *Ichthyoses [kg.ha^{-1}] in the reference sections of the Teplá River in the town of Sklené Teplice*

Hydraulic and topographic parameters of the reference sections in the Teplá River in the town of Sklené Teplice

The hydraulic model of all reference sections was developed in a two-dimensional program. The purpose of the model was to complement the velocity field and water level for the selected discharges.

The velocity field of the reference sections in the Teplá River in the town of Sklené Teplice was measured twice: 20th July 2017, at a discharge of 1.85 $m^3.s^{-1}$ and on 7th September 2017, at a discharge of 0.5 $m^3.s^{-1}$. Two discharges were modeled: 0.32 $m^3.s^{-1}$ (Q_{365} = 0.32 $m^3.s^{-1}$) and 0.15 m3.s-1 ($Q_{min\ (1941-1997)}$ = 0.17 $m^3.s^{-1}$). The basic hydraulic characteristics, water depth, and the velocity field, for reference sections 1 to 3 at a discharge of 0.5 $m^3.s^{-1}$ are shown in Figure 4.

The expected hydrobiological changes in the river may be simulated by changing the basic hydraulic parameters using the suitability curve.

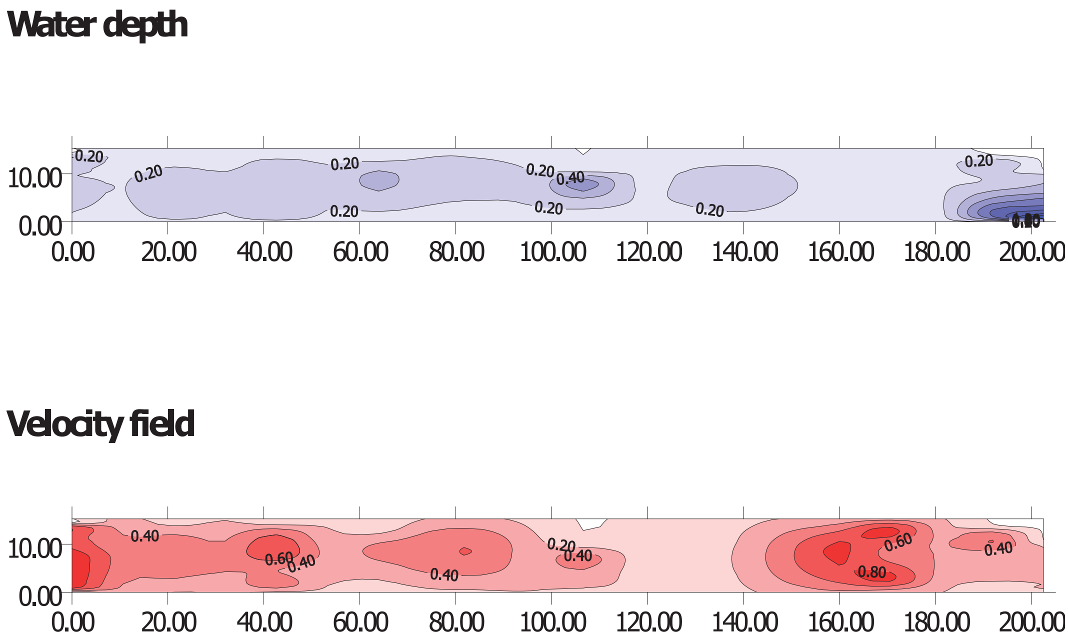


Fig. 4. *Water depths [m] and flow velocities [m.s^{-1}] in the reference sections Teplá River in the town of Sklené Teplice*

Habitat Suitability Curves

The Habitat Suitability Curves (HSCs) represent the main abiotic components of the microhabitat (flow velocity, water depth, and hiding places) preferred by the individual fish species. HSCs express a preference of each species for various habitats. The curves are based on the assumption that every fish species prefers certain combinations of abiotic environmental parameters [19]. Suitability curves for the Teplá River for water depth are given in figure 5.

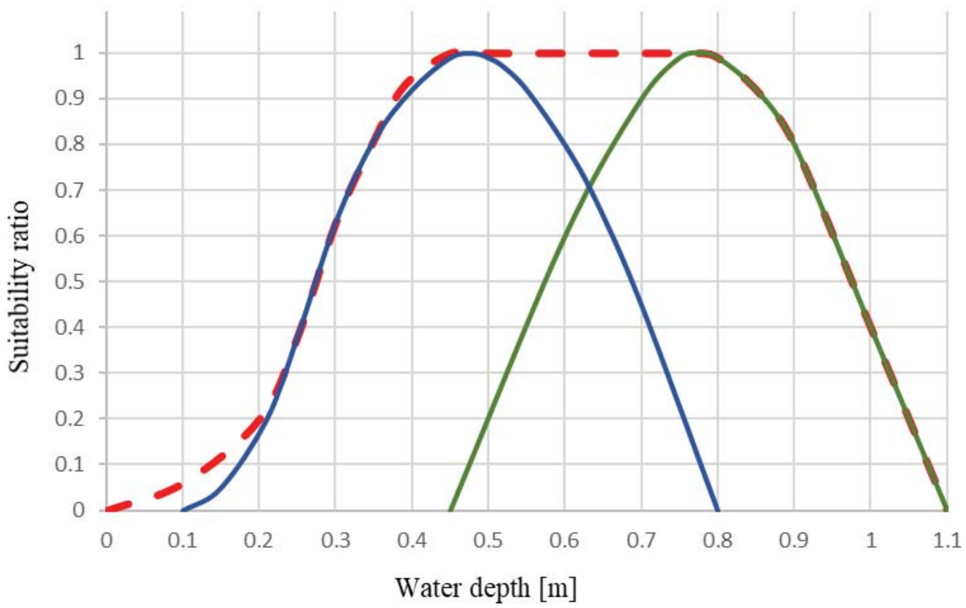


Fig. 5. *Suitability curves of brown trout (salmo trutta m. fario) for the water depth evaluated at two discharges (blue at 0.03 m^3.s^{-1} and green at 1.5 m^3.s^{-1}) with the generalized curve (red dashed)*

Evaluation of the relation between the depth, velocity and water level area

The relation between the depth, velocity and water level area was quantified using two methods.

First method was a method of means of the RHABSIM software, which simplifies the evaluation of parameters. Depths and velocities are evaluated independently; therefore, the results remain constant from one river profile to another (two-dimensional solution model). The depth and velocity values are multiplied individually by parameters from the suitability curves for the individual fish species, while when applying the second method, these values are multiplied by one value, which is the intersection of the depth and flow velocity with a standard weight.

The second method was developed by the authors of this paper, mainly as a reference method for the verification of standard models; therefore, accuracy was the primary criterion. The modeling of the habitat's degree of accessibility is based on the physical essence of the individual phenomena without simplification. It may be assumed that the results of such a model are of high quality and are substantially suitable for the verification of other models; therefore, in the further text, the term of the reference model for this methodic will be used. The measurement and hydraulic modeling results are not evaluated two-dimensionally, but as a three-dimensional contour plan, which was used for the evaluation of the velocity field and water depth intersection areas at a specific flow. The intersection areas were corrected by the parameters of the suitability curves with the same weight. The evaluation of the habitat quality assumes that a function defined as WUA may characterize the degree of accessibility of the physical habitat of the targeted fish species. WUA for the reference section of Teplá River in the town of Sklené Teplice is given in figure.

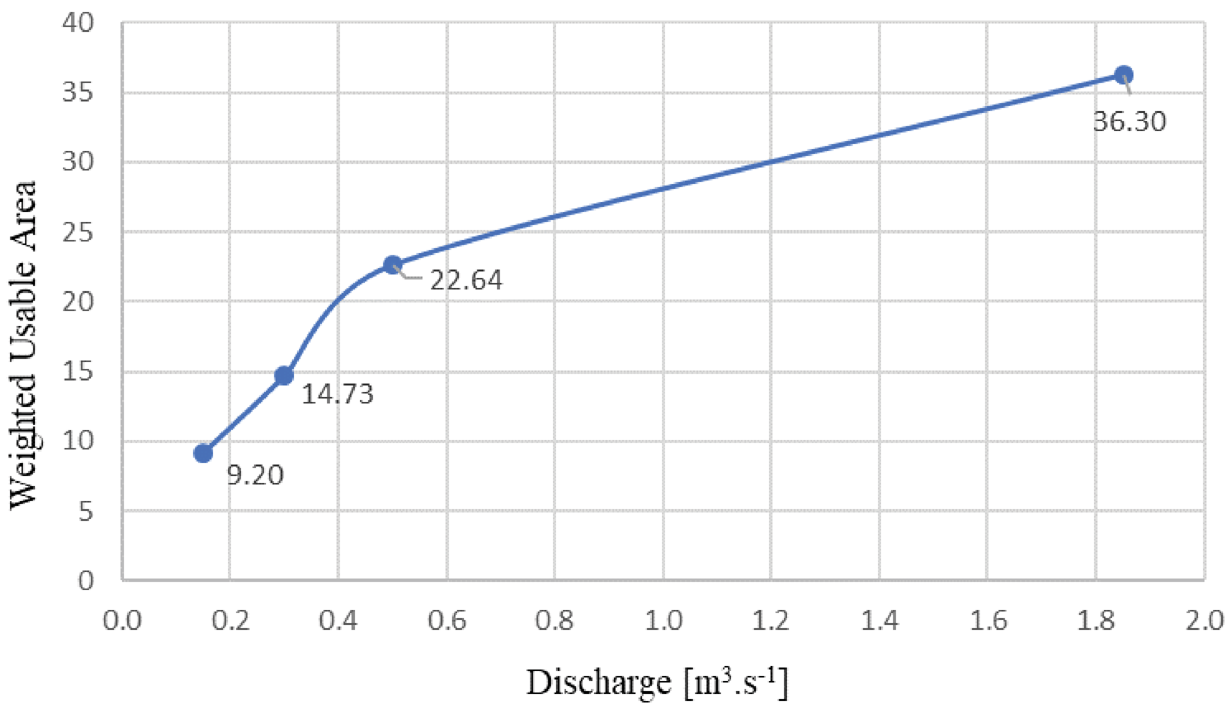


Fig. 6. *The weighed usable area (WUA) as a function of discharge [$m^3.s^{-1}$] in reference section for the brown trout*

Comparison of the results of the evaluation of the weighed usable area (WUA) by two methods

An evaluation of the quality of habitat assumes that the degree of accessibility of the physical habitat of targeted fish species may be characterized by a function that is defined as the weighted usable area (WUA). The quantification of the relation between the depth, velocity and water level area was used as the basis for an evaluation of the weighed usable area – WUA for the individual fish species.

WUA values obtained by both methods vary. It is necessary to remember that the WUA value represents the qualitative depiction of the biota development in a watercourse depending on the discharge, morphology or other parameters; therefore, the WUA development trend which is maintained is decisive. This is also documented by figure 7, which depicts the evaluation of the WUA curve by both methods, whereby the RHABSIM model values are corrected, i.e., reduced by the average difference between the results obtained by both methods. It may be anticipated that in the case of small watercourses with considerable differences in velocities and depths, more significant differences in the trend could occur; in this case, it is useful to verify or confirm the trend, even by the reference method.

Results and discussion

When applying the described method, it is necessary to bear in mind that fish are characterized by high variability, just as are all living organisms. Some limits determine their habitats and their behavior in these habitats, but these are quite extensive and do not enable the making of an unambiguous decision. This also leads to the conclusion that the parameter of channel should not be designed in a general manner but has to be determined individually for each river.

The following recommendations for the determination of the effect of the discharge and a riverbed's nature on the biological environment of a river may be formulated from the results obtained:

- The number of reference sections should be representative of the habitats existing in the section in question. We recommend that the reference sections and the percentage of represented habitats be selected based on the tachometric survey of the section of interest and be specified in the field together with ichthyologists.
- The collection of hydraulic and ichthyological data should be done simultaneously, and the hydrometric measurement of the velocity field for the verification of the hydraulic model should be performed as soon as possible; an ichthyological survey is not necessary for this measurement.
- The RHABSIM method objectively features the WUA development trend; the evaluation based on the methodology characterized in second method is appropriate only in controversial cases.
- We recommend evaluating WUA by the RHABSIM model, especially for the hydraulic module, which is optimized for modeling in the area of minimum discharges, but also for trouble-free communication of the individual modules.

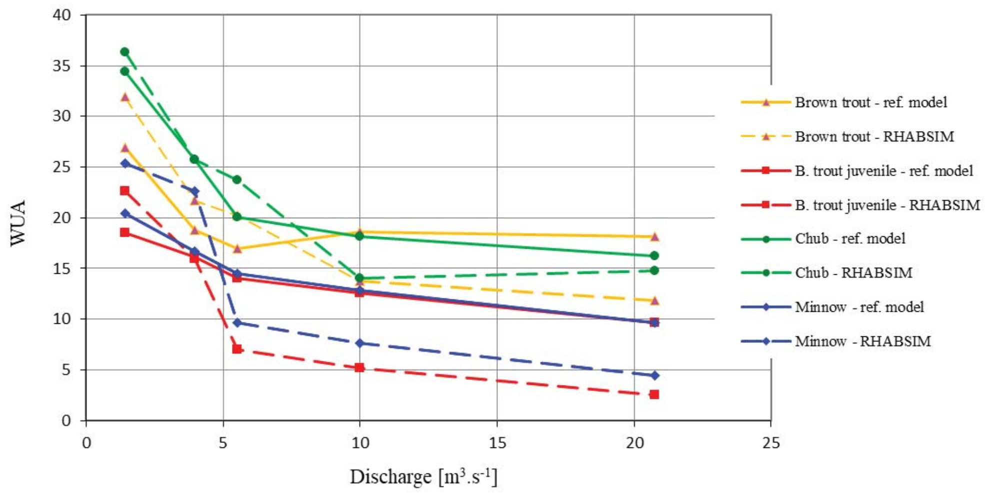


Fig. 7. *Comparison of WUA trends evaluated by both methods*

Based on the research results we may state that the method represents a new qualitative stage in determining the effect of the discharge and riverbed's nature (including technical work done within the river regulation) on biological alteration in an aquatic area despite the fact, that only a limited number of environmental factors (dissection of the riverbed, velocity field, river bed grain-size distribution, ichthyological survey) were evaluated.

Summary

The measurements made in the reference sections of the Teplá River demonstrated that the relation between the fish population and characteristics of the habitat gives a real picture of the changes induced by the topography of the riverbed (for instance by river regulations) and by discharge. The main advantage of the IFIM methodology is that it quantifies biological changes in the river as a function of the WUA and discharge through fish, which are bioindicators of environmental quality. In this way, quantitative data for experts on biotic and abiotic environments may be obtained. These experts can then establish an ecological flow or the parameter of flow restoration more objectively.

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