CONTRIBUTION TO DETERMINATION OF MINIMUM DISCHARGE IN STREAMS BY MEANS OF IFIM METHOD.

Viliam Macura, Andrej Škrinár
Department of Land and Water Resources Management, Faculty of Civil Engineering
Slovak University of Technologies Bratislava
Radlinského 11, 813 68 Bratislava, Slovak Republic
macura@svf.stuba.sk, skrinar@svf.stuba.sk

ABSTRACT: This paper describes the IFIM method (Instream Flow Incremental Methodology) for determining the minimum discharge, which, in addition to hydrological parameters, takes hydraulic, morphological and ichthyic 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 of the fish species prefer certain combinations of depths, stream velocities and bed materials. If the values for a species living in the 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 Nitra River. The paper gives the basic results from the section of the Nitra River in which the research was conducted.
KEYWORDS: Low Flow Characteristics, Stream Regulation, Abundance, Ichthyomass, Criteria Curve, IFIM Method (Instream Flow Incremental Methodology)

ZUR BESTIMMUNG VON NIEDRIGWASSER IN FLŰSSEN MIT DER IFIM METHODE.

ZUSAMMENFASSUNG: In diesen Beitrag wird die IFIM Methode beschrieben, die zur Bestimmung von Niedrigwasser in Flűssen dient. In dieser Methode werden nicht nur hydrologische Parameter, sondern auch hydraulische, morphologische und ichthyologische Parameter berűcksichtigt. Das Prinzip dieser Methode is der Zusammenhang zwischen der Fischpopulation und Habitat – die Fische bevorzugen speziele Kombinationen von Wassertiefe, Fliessgeschwindigkeit und Flűssbettmaterial. Wenn diese Werte bekannt sind, fűr spezielle Fischarten, wir kőnnen dann die Werte von Niedrigwasser bestimmen. Die IFIM Methode wurde auf dem Flűss Nitra Ausgewertet. In diesen Beitrag werden die Auswertungen der Resultate der Feldmessungen publiziert.
SCHLŰSSELWORTEN: Niedrigwassercharakteristen, Flűssregulierung, IFIM Methode, Abundance, Ichthyomasse

1. Preface

The increasing use of water sources necessitated practically in all countries the introduction of limits, which should guarantee the preservation of at least minimum natural functions of rivers. In Slovakia this limit is represented by the so-called minimum balance flow (hereinafter referred to as MQ, which is the Slovak abbreviation), its value is defined by the Water Management Master Plan as the water source demand which has to be preferentially applied to considerations on the water balance. The views of its definition and quantification developed and changed in our country just as in other countries in connection with the increasing intensity of use of water sources in the territory, with the need to protect them (from the qualitative and quantitative aspects), with the alteration of priorities of society's economic activities, with the degree of applying ecological criteria and similarly.

The complex hydrobiological solution of MQ presents a very extensive set of interconnected parameters, the full solution would lead to an enormous extension of the problem. Therefore it is primarily necessary to opt for an optimum method which would allow to achieve representative results from reduced inputs for Slovakian rivers. It is important to choose a suitable classification of rivers based on the occurrence and life conditions of typical fish species and invertebrate benthic fauna, whereby it is necessary to establish the status of the aquatic environment for the individual phases of development of the latter (flow velocity, depth, temperature and other conditions).

2. State of the given issues in Slovakia

From the water management point of view the MQ value for the preservation of the biological stability in the aquatic zone has been solved only formally. Pursuant to the 2nd edition of the Water Management Master Plan of the SSR (1975) MQ is defined as the balance value which is a preferentially secured water source demand and which in the water balances includes requirements based on the need to:

- preserve normal biological life in rivers
- preserve life conditions in the nearest surrounding of the river or stream
- ensure general use of water, which does not require the permit of water management bodies.

Only hydrological parameters constitute the input into the practical calculation of MQ. The complexity of the issue requires the inclusion of hydrobiological and hydraulic parameters, in order to be able to characterize the basic requirements on MQ, which are:

- water quality preservation or improvement
- maintenance of favourable life conditions for fish, benthic fauna and fytobenthos
- maintenance of the ecological status and aesthetics of the country
- preservation of a balanced ground water regime

3. Material and methods

The relationship between the fish population and habitat constitutes the basic principle of establishing the effect of flow on the biological environment of the river. The principles of the Instream Flow Incremental Methodology – IFIM – were used to quantify this relationship. The Physical Habitat Simulation System – PHABSIM – was developed in the US for the aforementioned Methodology, which is based on the knowledge that most fish species prefer certain combinations of depths, flow velocities, water temperatures and riverbed material. If these values are known for the fish species concerned living in the scrutinized section, the minimum flow for each fish species may be determined. The PHABSIM model optimises the total fish yield based on the determination of life conditions depending on the water discharge and nature of the riverbed bottom. Each fish species has specific, frequently contradictory demands on the microhabitat. The most important abiotic components of the fish microhabitat are as follows:

- flow velocity
- depth distribution, occurrence, quality and frequency of lurking places.

The determination of microhabitat parameters will enable to obtain the characteristics of the fish population inhabiting the given river section and at the same time to simulate alterations induced by the flow.

The implementation of new methods for the water courses in Slovakia requires an analysis and verification of several methods. The PHABSIM software, which currently comprises over 200 independently functioning programmes, was not applied directly to the determination of MQ. A complex of demanding modelling programmes, that are included in the PHABSIM system, frequently prevented from broader understanding and application of the IFIM methodics, which led to undetected errors in the simulation of hydraulic and habitat parameters. RHABSIM (Riverine Habitat Simulation) was developed in order to reduce this complexity and to integrate all these programmes. The results of measurements performed in reference sections of the Váh and Nitra Rivers, which were evaluated by means of the RHABSIM programme, were then compared with the model developed by the authors of this paper.

The following procedure was chosen for the MQ determination:

- measurement of topographic parameters of reference sections
- measurement of the velocity field
- evaluation of the bottom material grain-size distribution
- ichthyologic research
- assessment of relation between depth, velocity and area for the selected discharges and reference sections
- assessment of usable habitat area for the individual fish species and selected discharges
- assessment of function of the usable habitat area as a function of discharge for each fish species and reference section.

4. Topographic measurement of reference sections

The topography of the reference sections was characterised by cross-sections set on fixed points, which enabled to repeat measurements in the same profile. In all the measuring profiles (the Váh River in Dubnica nad Váhom, Kysuca nad Čadcou, the Nitra River in Nedožery) the morphology changed in the course of winter and spring to such a great extent, that the measurements could not have been used for hydraulic modelling, and the topography of the area as well as the velocity field had to be surveyed again as soon as possible.

5. Measurement of velocity field

The discharge was measured in a representative measuring profile by means of hydrometric devices. The velocity field was set on the basis of point measurements in each cross section. The distance between the verticals ranged from 1 to 2 m. The measurement was made in the course of the ichthyologic survey and then separately for different water stages for the purpose of verifying the hydraulic model.

6. Grain-size distribution of the bottom material in the surrounding of Nedožery

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

7. Ichthyologic survey

The reference sections of the rivers were blocked on each end by nets with a mesh size of 10x10 mm. Fish were caught by means of an electric aggregate, afterwards put 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 section, whereby the second and third catches were made 45 minutes after the previous ones. After each catch every fish species was counted separately, the fish were measured, weighed and let out into the river below the last net. The abundance according to Leslie and Davis' method (1939) was calculated in the laboratory. The calculated values combined with the mean weight of the respective species were applied to the calculation of 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, it is given in $kg.ha^{-1}$.

8. Results and discussion

We tried to confine ourselves to the examination of 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 the indicator of quality of the biological environment in the river may be considered as the basic parameters of the river.

Reference sections of the Kysuca River, Váh River near Dubnica nad Váhom and Nitra River in Nedožery were selected for the analysis of morphometric hydraulic and ichthyologic parameters. The paper contains basic results obtained from the reference sections of the Nitra River in the town of Nedožery.

9. Basic characteristics of the Nitra River

The discharge in the water meter station Nitra – Nedožery.

Catchment area = 181.57 km^2, stationing 148.90 km. Water gauge altitude = 287.00 m above sea level, Q_{max} 1941-1997 = 80 m^3.s^{-1}, Q_{min} 1941-1997 = 0.15 m^3.s^{-1}.

Table 1. Overrun of average daily discharges (HP3 1971)

M – days	30	90	180	270	330	335	364
Discharge [m^3.s^{-1}]	5.48	2.68	1.47	0.96	0.65	0.5	0.31

10. Water qualities in the profile Nitra – Nedožery, km 149.0

In the profile situated in the town of Nedožery the effect of the local municipal pollution was demonstrated by the usual increase in the number of coliform (class IV) and psychrophile bacteria (class V), especially in 1993. The organic pollution expressed by BOD (C_{90} = 5.58 mg/l) already exceeds the class II limit value. COD-Mn remains in class II of the classification pursuant to standard ČSN 75 7221. Dissolved oxygen complies with class I even in the case of the minimum value of 7.7 mg/l. Biological activation of the river expressed by the saprogenic index of biosestone corresponds to class III. Compared with the profile Kľačno the contents of nitrogenous substances (N-NH_2^- class II, N-NO_3^- class III, N-NO_2^- class V) and total phosphorus (class III) have worsened by one class.

11. Characterisation of reference sections of the Nitra River bed

Three reference sections were chosen on the Nitra River 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.

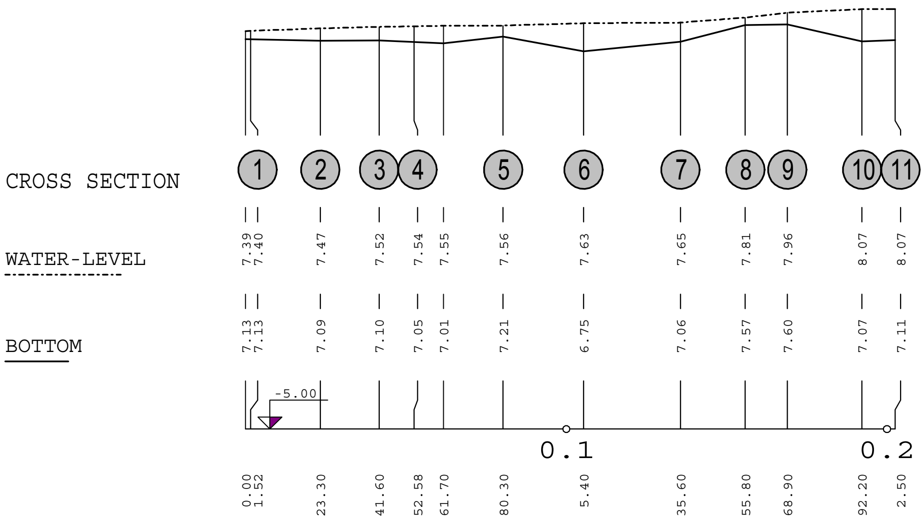


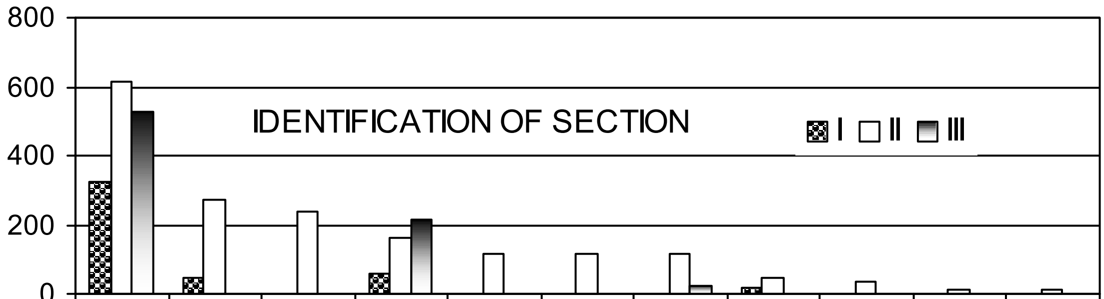
Figure 1. Longitudinal section of reference sections 1-3 of the Nitra River in Nedožery

Section No. 1 is located in the town of Nedožery. It is 52.58 m long (the stationing of the section in Fig. 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 Fig. 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, the banks are covered by trees and shrubs. This section represents the flow shadow area.

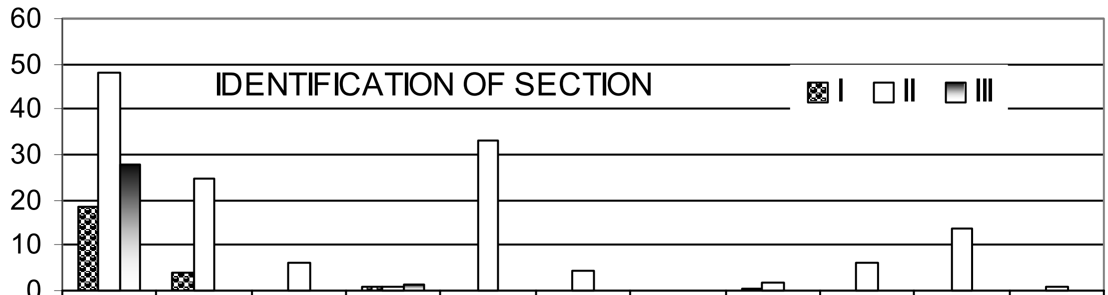
Section No. 3 is 33.3 m long (the stationing of the section in Figure 1 starts at 135.60 and ends at 168.90 m). The riverbed bottom is dissected only to a small extent. Trees and shrubs cover the banks. The longitudinal slope of the water level is large = 0.93%, which means greater flow velocities and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

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



	Brown trouth	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

Figure 2. Abundance [fish/ha] in the reference sections of the Nitra River in Nedožery



	Brown trouth	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

Figure 3. Ichthyomass [kg/ha]in the reference sections of the Nitra River in Nedožery

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

English name	Barbel	Brown trout	Chub
Scientific name	Barbus barbus	Salmo labrax m.fario	Leuciscus cephalus

English name	Eel	Grayling	Gudgeon
Scientific name	Anguilla anguilla	Thymallus thymallus	Gobio gobio

English name	Minnow	Perch	Picke
Scientific name	Phoxinus phoxinus	Perca fluviatilis	Exox lucius

English name	Roach	Spirling	Stoneloach
Scientific name	Rutilus rutilus	Alburnoides bipunctatus	Barbatula barbatula

12. Hydraulic and topographic parameters of the reference sections in the Nitra River

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

The velocity field of the reference sections in the Nitra River was measured twice. On 19 July, 1999 at a discharge of 1.85 $m^3.s^{-1}$ and on 4 September, 1999 at a discharge of 0.5 $m^3.s^{-1}$. The measurement of 23 October 1998 could not have been used due to the already mentioned alteration in the riverbed topography. Two discharges were modelled: 0.3 $m^3.s^{-1}$ (Q_{365} = 0.3 $m^3.s^{-1}$) and 0.15 $m^3.s^{-1}$ (Q_{min} 1941-1997 = 0.14 $m^3.s^{-1}$). 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 Fig. 4.

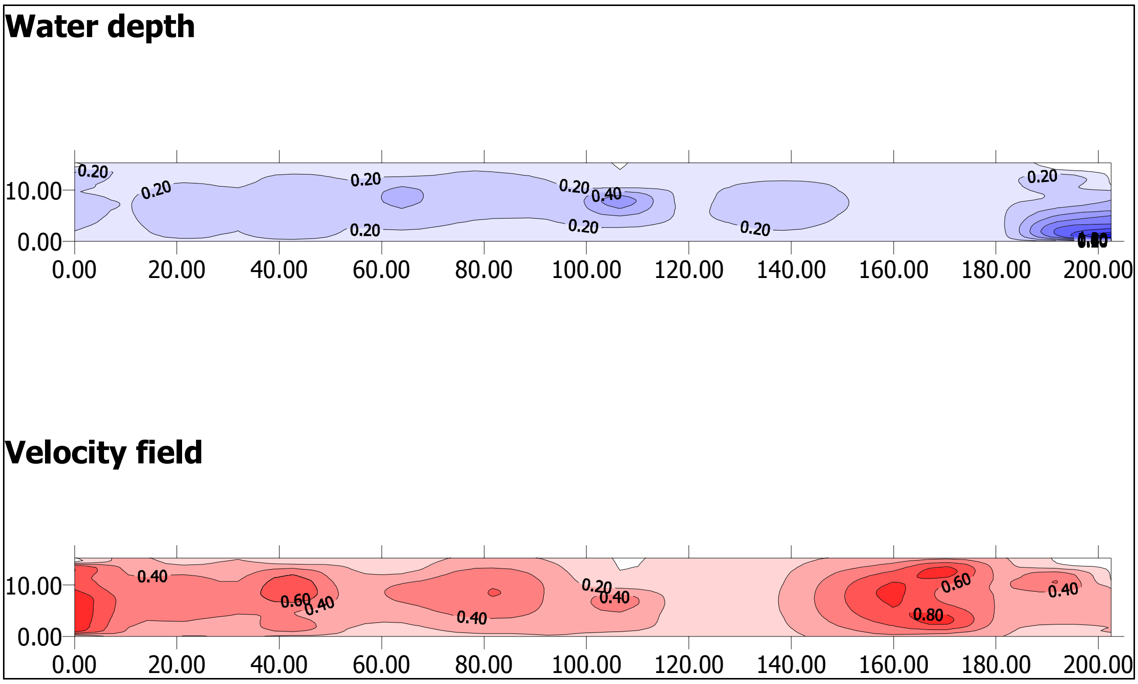


Fig. 4 Water depths [m] and flow velocities [$m.s^{-1}$] in the reference sections of the Nitra River in Nedožery

The expected hydrobiological changes in the river may be simulated by changing the basic hydraulic parameters by means of the criteria (suitability) curve.

13. Criteria curves

The criteria curves represent the main abiotic components of the microhabitat (flow velocity, water depth and lurking places) preferred by the individual fish species. They express the main abiotic factors, i.e. the physical habitat preferred by the given species and their life period.

Criteria curves may be obtained by means of three methods. The first one is the DELPHI method, which resides in estimating the occurrence of the respective fish species, especially adult and juvenile fish, depending on the given factor without measuring the relevant parameters in the field. The second one is the IFIM method based on the quantification of the specifically determined numerical data obtained by measurements in the field. The third method includes the application of the respective criteria curve obtained from other locations. With respect to the considerable laboriousness, staff, time and financial demands related to the IFIM method (Mattas *et al.* 1998; Slavík, Mattas D. 1995) criteria curves, developed by the staff of VÚV T.G.M. Prague on the basis of data obtained from Czech rivers, were used. An example of the criteria curves for the brown trout is given in Figure 5.

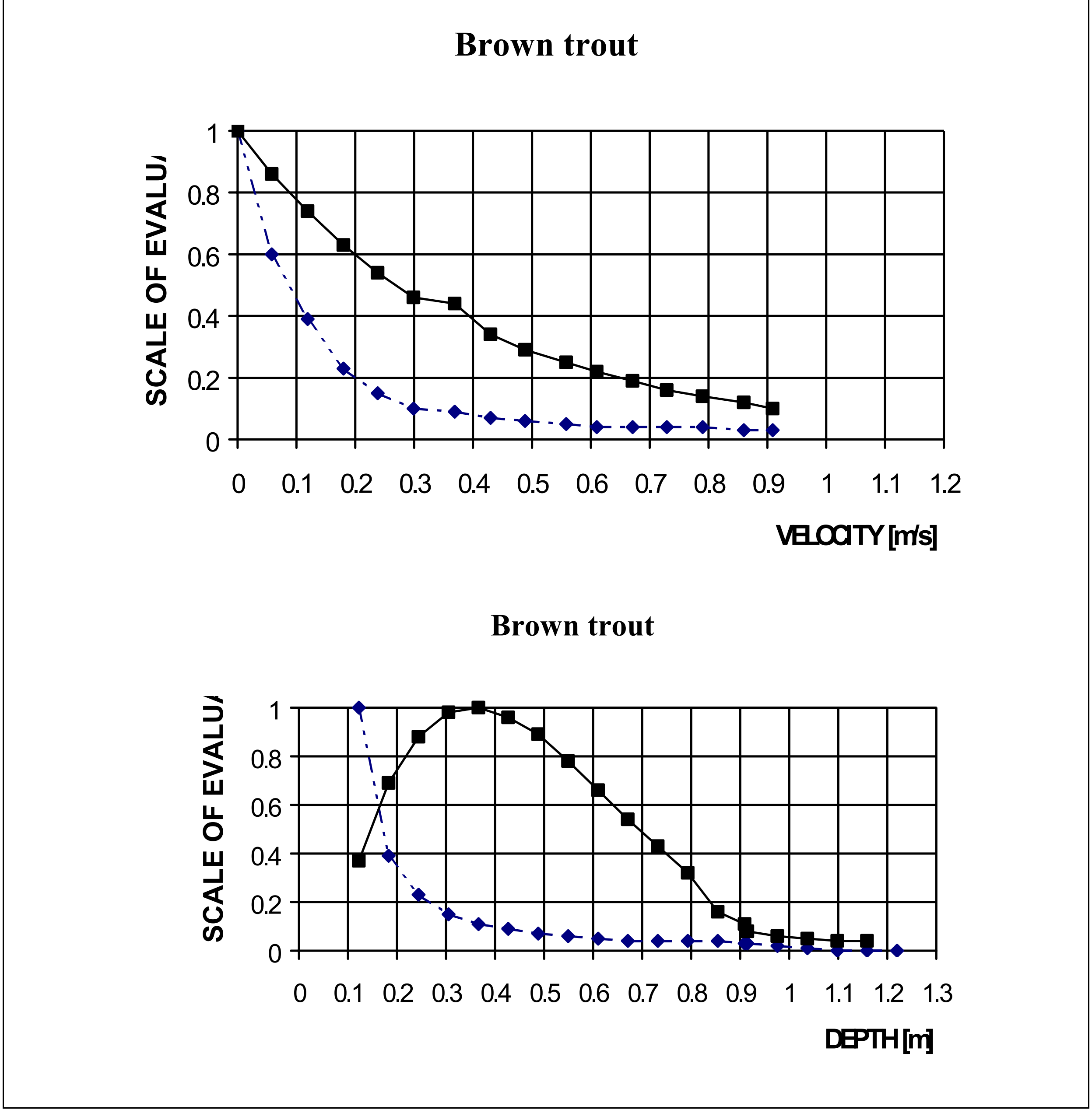


Figure 5. Depth and velocity criteria curves for the brown trout

It is necessary to stress that the criteria curves for the same fish species in the same river vary depending on whether the fish are juvenile or adult. Generally, it holds true that juvenile fish prefer lower flow velocities and smaller depths in a dissected environment, while it is the other way round in the case of adult fish. In other words – the young fish inhabit primarily the littoral area and places near the banks, while adult fish are to be found further away from the banks and in deeper places with a higher flow velocity. Moreover, the same fish species demonstrates different demands on the environment in various rivers. Hence, also in this case the information on a fish species obtained from one river does not have to apply to the same species in another river. This unambiguously leads to the conclusion that a general determination of MQ is out of question and it has to be determined for each possible river individually on the basis of specific data and information on the qualitative and quantitative composition of the ichthyic fauna, in relation to the actually measured values for the microhabitats in the given river.

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

The relation between the depth, velocity and water level area was quantified by means of two methods:

1st Method. By 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 next difference is that the depth and velocity values are multiplied individually by parameters from the criteria curves for the individual fish species, while when applying the 2nd method these values are multiplied by one value, which is the intersection of the depth and velocity with a common weight.

2nd Method. This method that was developed by the authors of this paper, was developed especially as a reference method for the verification of standard models, therefore accuracy was the main criterion. The modelling of the habitat accessibility degree 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, which is substantial, are suitable for the verification of other models, therefore this method will be hereinafter mentioned as a reference model. The measurement and hydraulic modelling results are not evaluated two-dimensionally, but as a three-dimensional contour plan, which was used for the evaluation of velocity field and water depth intersection areas at a specific flow. The intersection areas were corrected by the parameters of the criteria curves with the same weight. The area of the intersection areas was determined by the AutoCAD programme. Thus for each depth zone the percentage of velocity intervals was evaluated with respect to the total water level area of the reference section. An example of this relation for reference section No. 1 of the Nitra River at a discharge of 0.6 $m^3.s^{-1}$ is depicted in the histogram in Figure 6. This histogram together with the criteria curves for the individual fish species constitute the basis for the evaluation of the weighed usable area. The evaluation of the habitat quality is based on the assumption that the accessibility degree of the physical habitat of the selected target fish species may be characterised by a function defined as WUA. An example of the WUA evaluation is given in Figure 7.

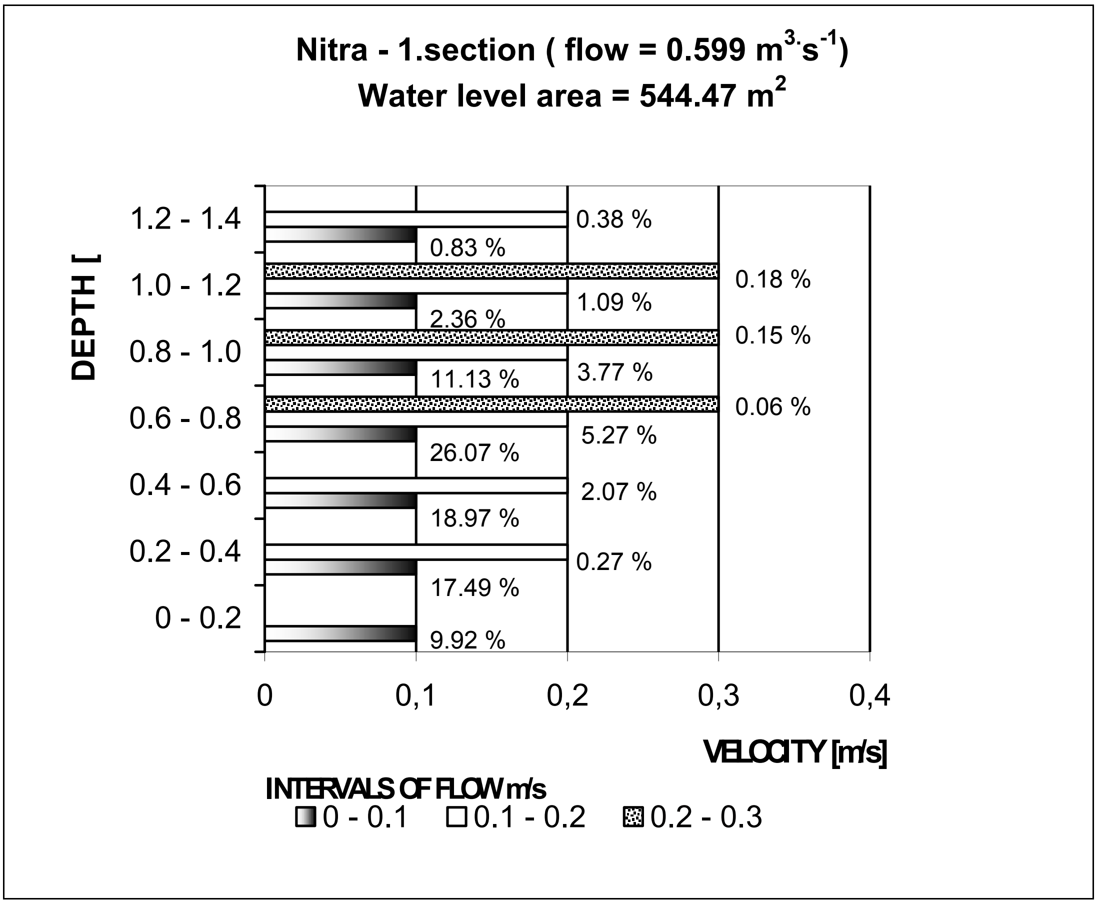


Fig. 6 Histograms expressing the relation between the depth, velocity and water level area for reference section No. 1 at a discharge of 0.6 $m^3.s^{-1}$

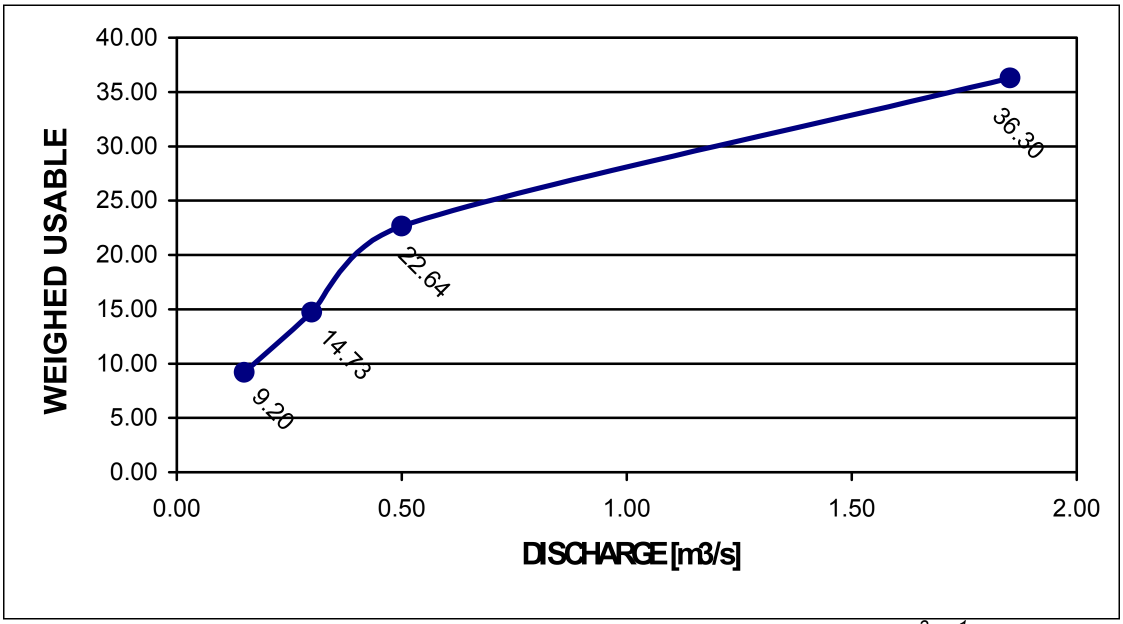


Figure 7. The weighed usable area (WUA) as a function of discharge [$m^3.s^{-1}$] in reference section No. 2 for the brown trout

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

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

WUA values obtained by both methods vary. It is necessary to remind, that the WUA value represents the qualitative depiction of the biota development in the water course depending on the discharge, morphology or other parameters, therefore the WUA development trend, which is maintained, is decisive. This is also documented by Fig. 8, which depicts the evaluation of the WUA curve by both methods, whereby the RHABSIM model values are corrected – reduced by the average difference between the results obtained by both methods. It may be anticipated, that in the case of small water courses with considerable differences in the velocities and depths, larger differences in the trend could occur; in this case it is useful to verify or confirm the trend even by the reference method. The aforementioned results in the fact that the evaluation by the RHABSIM method is objective and we recommend detailed evaluation on the basis of the methodics characterized in item 2 only in controversial cases

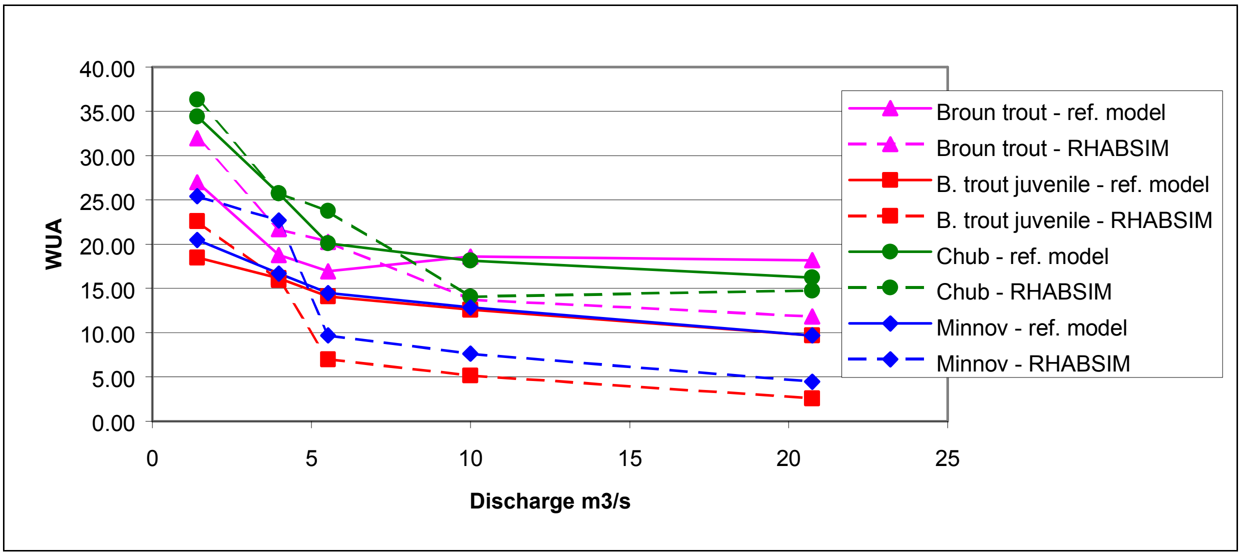


Fig. 8 Comparison of WUA trends evaluated by both methods

16. Results and discussion

When applying the described method it is necessary to bear in mind that fish are characterized by a great variability, just as all living organisms. There are limits though that determine their habitats and their behaviour in these habitats, but these are quite extensive and do not enable to make an unambiguous decision. This also leads to the conclusion that the MQ values can in no case be designed in a general manner, but have to be determined individually for each river.

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

- The number of reference sections should be representative of the habitats existing in the section in question. (In the course of the project the reference sections were complemented several times and in one case – the Kysuca River – the reference sections were abolished and new ones were determined.) We recommend that the reference sections and the percentage of represented habitats be selected on the basis of the tachometric survey of the section of interest and be specified in the field together with ichthyologists.

- The collection of hydraulic and ichthyologic 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; ichthyologic survey (or ichthyologic measurement) is not necessary for this measurement.
- The RHABSIM method objectively features the WUA development trend; the evaluation based on the methodics characterized in item 2 is appropriate only in controversial cases.
- We recommend to evaluate WUA by the RHABSIM model, especially for the hydraulic module, which is optimised for modelling in the area of minimum discharges, but also for trouble-free communication of the individual modules.

Based on the first research results we may state, that in spite of the fact that only a limited number of factors of the environment (dissection of the riverbed, velocity field, river bed grain-size distribution, ichthyologic survey) were evaluated, the method represents a new qualitative stage in determining the effect of the discharge and river bed nature (including technical work done within the river regulation) on biological alteration in the aquatic area. The critical value of biotic changes was so far characterised in Slovakia as a function of the discharge and hydrological characteristics.

17. Summary

The measurements made in the reference sections of the Nitra River demonstrated that the relation between the fish population and characteristics of the habitat gives a true picture of the changes induced by the topography of the riverbed (for instance by river regulations) and by the discharge. The main advantage of the IFIM method is that it quantifies biological changes in the river as a function of the WUA and discharge through fish, which are bioindicators of the environmental quality. In this way quantitative data for experts on the biotic and abiotic environment may be obtained. These experts can then establish the minimum flow parameters in a more objective manner.

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