Surface waters vulnerability and Minimum Instream Flow assessment: an italian case study

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Abstract

The Italian laws D.L. 152/99 and D.L. 152/2006 define the general framework for safeguarding surface, ground and coastal waters by pursuing the objectives of preventing or containing pollution, restoring water quality, protecting waters used for special purposes, guaranteeing the sustainable use of available resources and maintaining the waters' natural ability to cleanse itself of impurities.
These objectives will be met through the use of a variety of instruments, including the guidelines of environmental quality and Protection Plans. However, before Protection Plans can be assessed, the qualitative and quantitative status of water bodies needs to be determined and information has to be acquired regarding the physical, natural, social and economic characteristics of the catchment basins in order to assess anthropic pressure and impact. This various set of investigative and planning activities constitutes a totally new approach to environmental policies regarding water resources in Italy.
A methodological approach has been developed in order to assess the vulnerability of surface waters and to define their environmental quality on the basis of an integrated analysis of the river's ecosystem, both qualitative and quantitative (Minimum Instream Flow). This procedure has been applied to the pilot watersheds of the Tusciano and Picentino rivers (Campania Region, Southern Italy), by means of a monitoring network. The proposed approach made it possible to provide an albeit preliminary assessment of the environmental quality status for the Tusciano and Picentino rivers.

Keywords: Surface water, Environmental status, Minimum Instream Flow, Habitat methods

1. Introduction

The Italian laws D.L. 152/99 and D.L. 152/2006 define the general framework for safeguarding surface, ground and coastal waters by pursuing the objectives of preventing or containing pollution, restoring water quality, protecting waters used for special purposes, guaranteeing the sustainable use of available resources and maintaining the waters' natural ability to cleanse itself of impurities.
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This paper will be focused to assess the environmental status of three rivers of Campania region (Southern Italy), particularly in terms of Minimum Instream Flow.

2. Minimum Instream Flow assessment

The assessment of Minimum Instream Flow (MIF) aims to safeguard the physical and hydrological characteristics of the river, the physicochemical characteristics of the water and the typical biocenotic communities in natural environmental conditions (Manciola et al, 1994, 2000; Menduni et al, 2006; Santoro, 1994).
Quantitative instream flow methods are generally divided into three major categories: historic flow regime, hydraulic and habitat methods.
Historic flow methods rely on the recorded or estimated river flow regime. The Tennant (1976) method -also known as the 'Montana' method- is perhaps one of the most widely known of these methods (Jowett, 1997).
Hydraulic methods relate various parameters of the hydraulic geometry of stream channels to discharge. The hydraulic geometry is based on surveyed cross-sections, from which parameters such as width, depth, velocity and wetted perimeter are determined. Variation in hydraulic geometry with discharge can be established by in situ measurements, prediction from cross-section data and stage–discharge rating curves, Manning's or Chezy's equations (Bovee, 1978), or calculation of water surface profiles (Jowett, 1997).
Habitat methods are a natural extension of hydraulic methods. The difference is that the assessment of flow requirements is based on hydraulic conditions that meet specific biological requirements rather than the hydraulic parameters themselves. When this is done for a range of flows, it is possible to see how the area of suitable habitat changes with flow.

3. The habitat methods

The most widely known method is the Physical HABitat SIMulation component (PHABSIM: Waddle T.J., 2001) of the Instream Flow Incremental Methodology (IFIM) (Bovee, 1978, 1982; Bovee et al, 1998).
Habitat suitability curves are the biological basis of habitat methods. Habitat suitability can be specified as seasonal requirements for different life stages, but this is not limited to aquatic organisms. Depth, velocity and width criteria for bathing, wading, kayaking, canoeing and other recreational pursuits have also been described. When considering multiple species, there can be conflicting habitat requirements with a decline in habitat for one species corresponding to an increase in habitat for another. The concept of habitat guilds or an 'indicator' species can be applied in these situations.
When using habitat methods, there are more ways of determining flow requirements than for either historic flow or hydraulic methods. The relationship between flow and the amount of suitable habitat is usually non-linear. Flows can be set so that they maintain optimum levels of fish habitat, retain a percentage of habitat at average or median flow, or set so that they provide a minimum amount of habitat defined either as a minimum percentage of water surface area or as a percentage exceedance value on the habitat duration curve. Flows can also be set at the point of inflection in the habitat/flow relationship. This is possibly the most common method of assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with this level of protection, it is a point of 'diminishing return' where proportionally more habitat is lost with decreasing flow than is gained with increasing flow. In some rivers, the relationship between flow and habitat for flow-sensitive species is linear, especially in the low flow range. In these cases, flow recommendations using percentage retention or exceedance for instream habitat are, in effect,

the same as recommendations of hydraulic and historic flow methods that specify a percentage or exceedance value for flow or wetted perimeter.
Habitat methods are more flexible than either historic flow or hydraulic methods. It is possible to examine the variation of the habitat utilized by many species and life stages throughout the year and to select flows that provide this habitat. However, this means that it is necessary to have a good knowledge of the stream ecosystem and some clear management objectives in order to resolve potential conflicting habitat requirements of different species or life stages.
Habitat methods are particularly suitable for 'trade-off' situations, where incremental change in habitat can be compared with the benefits of resource use. Habitat/flow relationships can be used to evaluate alternative flow management strategies and are part of the information base used in the process of choosing appropriate flow rules for river management (Jowett, 1997).
The PHABSIM Method is certainly innovative and more exhaustive compared to historic and hydraulic ones, but may present some applicative problems because theoretically the cross section of the river remains constant whereas in practice all the stream cross sections are changing in the time in particular those relating to small and mountain rivers.
This paper introduces a Microhabitat Method application to three rivers of Campania (Southern Italy) that have been monitored monthly for two years and that present remarkable variations of morphological and hydraulic characteristics as time goes by. Therefore it will possible to observe if the Method is reliable in these particular conditions.

4. Framework of the study area

The study area that has been chosen to investigate the environmental status of three streams of Campania - Tusciano, Picentino and Prepezzano - is under the auspices of the Destra Sele Water Authority. These rivers are geographically close, how Fig. 1 shows, and geological and geomorphological characteristics of their catchment basins are remarkably similar, but they have

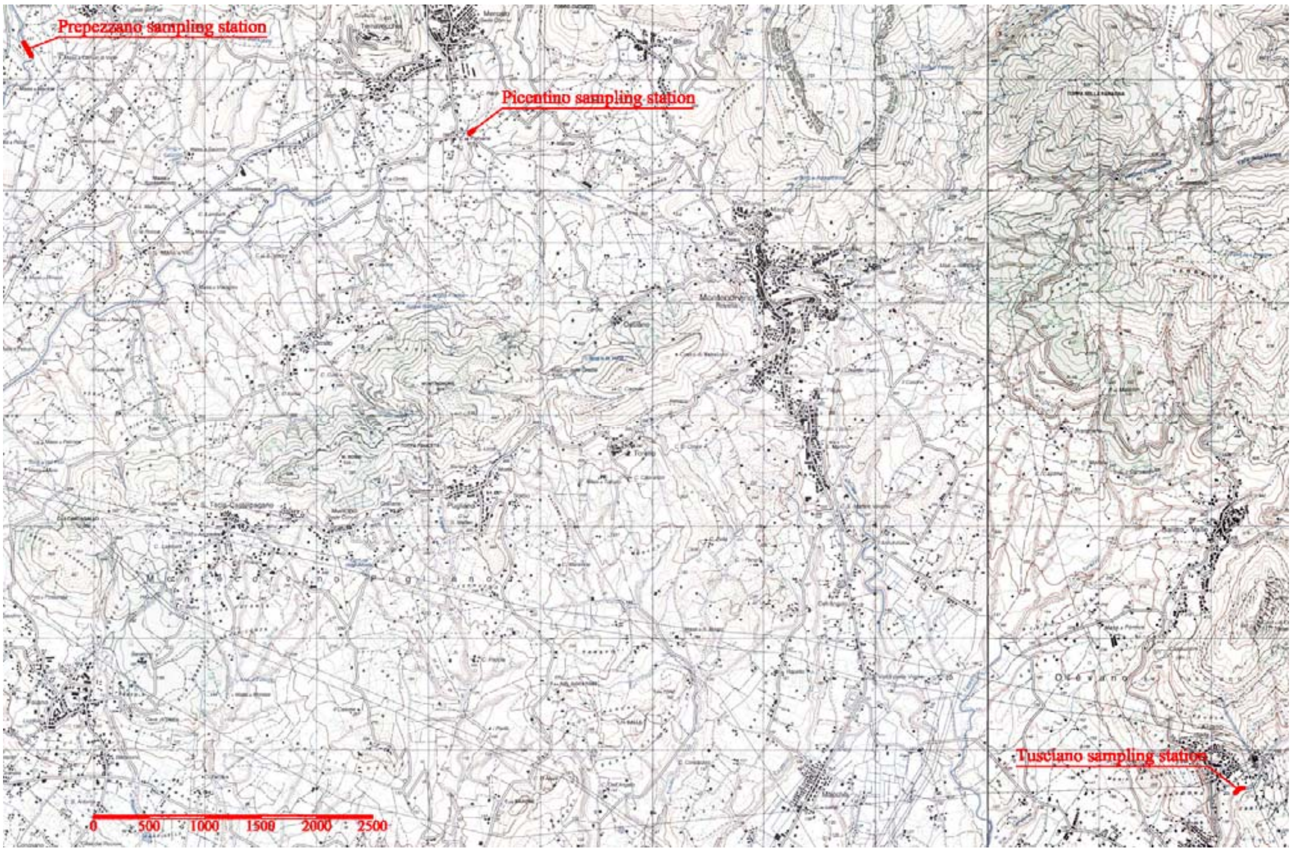

Fig.1 – The rivers territorial framework

different features in terms of main reach length, catchment area, average cross section sizes, etc. The Fig. 2 shows the rivers position in detail.

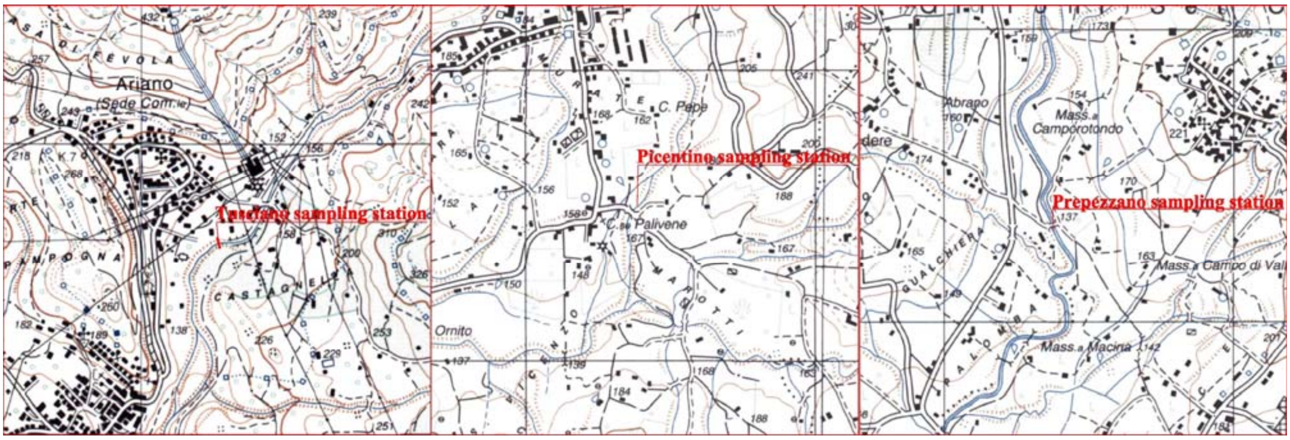

Fig.2 – The rivers territorial framework

Tusciano river (Fig. 3) is the most important one with a main channel 37 km long and a catchment area of approximately 240 km^2. The main tributaries are the Vallone Isca della Serra, the Cornea, the Vallimonio, the Lama, the Rialto and the main channel of the Sele (Giugni et al, 2002, 2004).

Fig.3 – A picture of Tusciano river section

The river Picentino, that rises in the Mount Accellica (1660 m a. s. l.), assumes typical connotation of Apennine waterways: a greater index of hierarchy, with many tributaries (Vallone Cerretelle, Rio Secco, Prepezzano) and assumes, further, a marked change in the slope and in the shape between upstream and medium-downstream reach.

The Prepezzano river is a tributary of Picentino, as already mentioned, and it is the smallest one of the three.

To ensure a reliable assessment of the environmental status, a monitoring network was setup comprising 3 sampling stations, as the Fig. 4 shows. Each station allows to measure physical, chemical, biological and microbiological parameters, the cross section sizes and the velocity (in three measure transects) in a sufficient number of points to calculate a value of discharge.

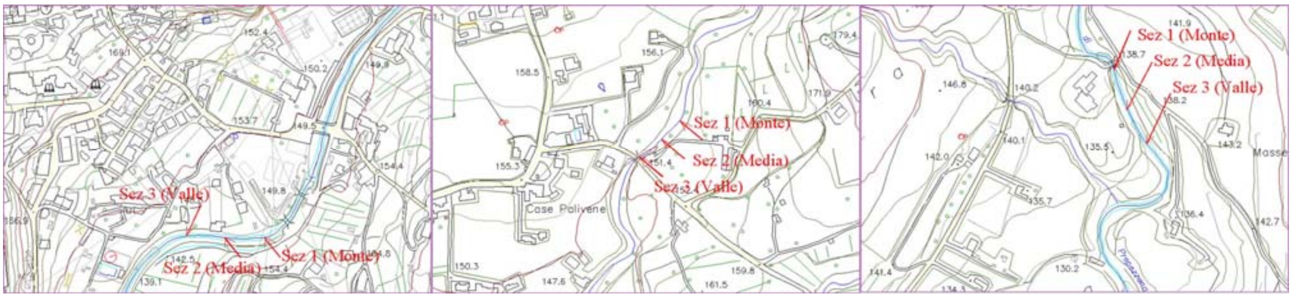

Fig.4 – Sampling stations distribution

The measures were carried out monthly for two years, thus allow to collect an extensive amount of data.
As far as the wildlife community of the rivers is concerned, it has been possible to observe the presence of a Salmonidae specie, the Salmo Trutta Fario, but it was not possible to carry out a field campaign to determine the experimental curves for the fish life in the river and so reference was made to suitability curves taken from the scientific literature (Fig. 5).

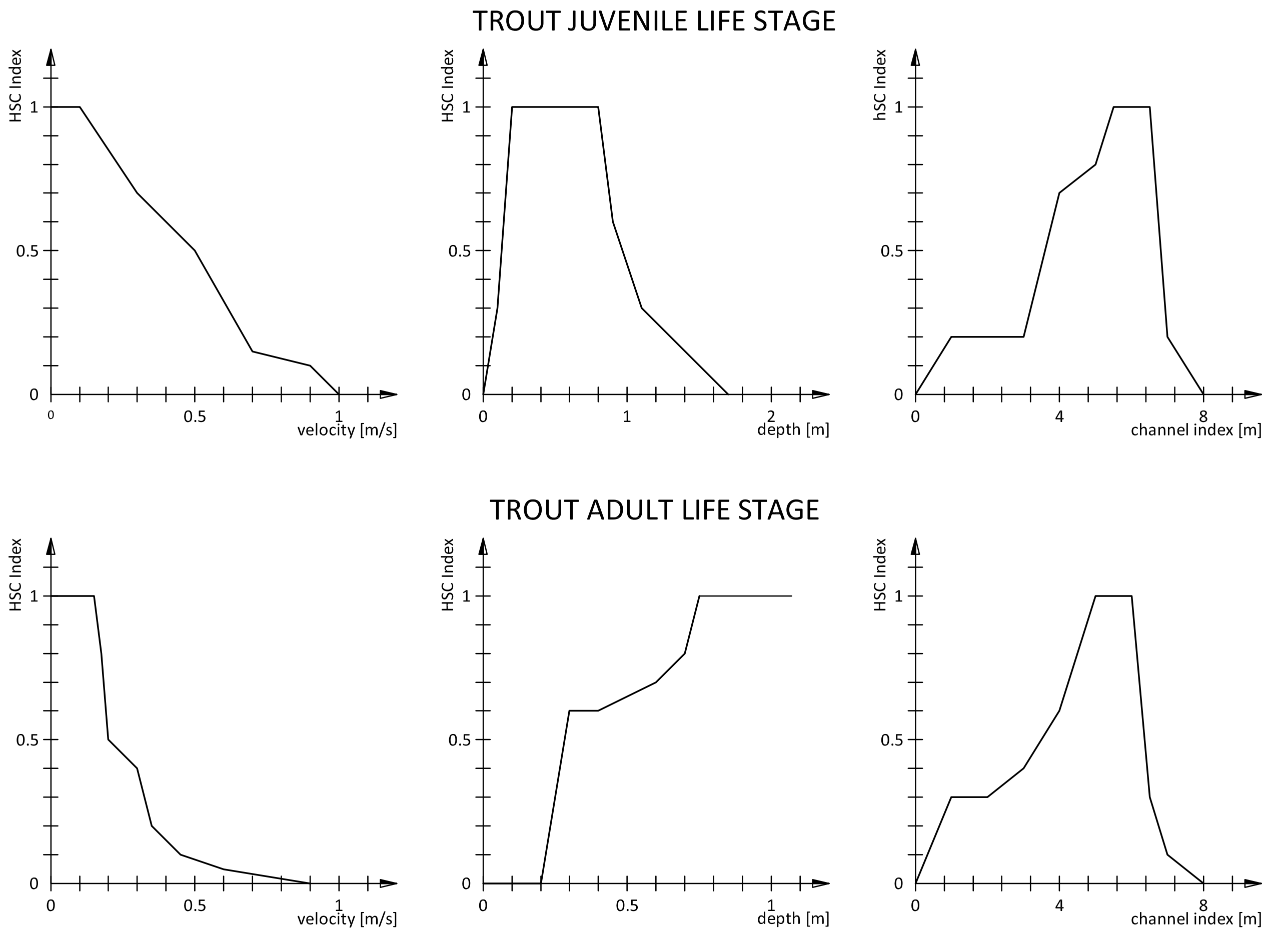

Fig.5 – Trout suitability curves relating to adult and juvenile life stages.

5. Application of Microhabitat Model to cases study

In order to assess Minimum Instream Flow, reference has been made to the hydro-biological approach based on the search for environmental conditions suitable for the development of one or more representative species of the river’s wildlife (biological indicator) using in situ measurement

techniques, such as depth and velocity and characteristics of the bottom substrate, to determine the above mentioned environmental conditions and hence define an habitat quality index as a function of the flow.
The application of Microhabitat Model to estimate the MIF was carried out by the software PHABSIM V.1.2 (Waddle, 2001) that allows to calculate, among other things, the values of Weighted Usable Area (WUA) relating to flows (Q). The WUA represents an index of wealth of the target specie. As it was mentioned before, for each transect the cross section was monthly surveyed and the velocity in many points was measured.
For the Microhabitat Model, the input data are given about each transect but it is possible to have a concise result relating to the river on the whole.
It has been observed that there is a remarkable variation of the cross section as time goes by; in Fig. 6 some different bed profiles of the same transect (Tusciano river; T3 transect) are shown and we can see that the width, the depth and the regularity of the bed significantly vary in time. That could involve serious problems because if the river cross section changes then the result obtained for a specific discharge in terms of WUA curve, for example, could be uncorrect for different configurations. To this aspect will be given subsequently more extended treatment.

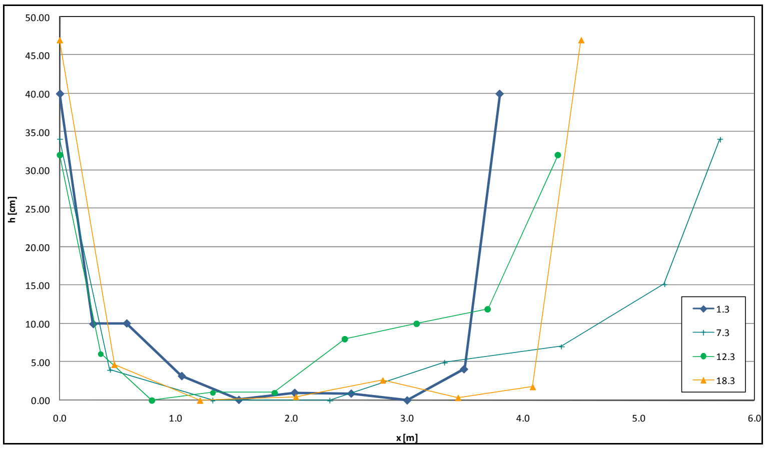

Fig.6 – Surveyed cross sections (Tusciano river, section 3)

A significant input in the model is represented by the habitat suitability. Some investigations have shown the presence of trout in the streams so we have considered, in the model, the suitability curves relating to this aquatic specie in two different life stages: adult and juvenile. The suitability curves, adopted in the model, were first displayed (Fig. 5).
Subsequently the software PHABSIM calculated WUA (Weighted Usable Area) for each stream in relation to discharge values. For example the next figures shows the final WUA(Q) curves, each one for a specific measured configuration, for the juvenile and adult trout relating to Tusciano (Figg. 7, 8), Picentino (Figg. 9, 10) and Prepezzano stream (Fig. 11, 12).
The curves trend is substantially the same varying the time, showing that the variation of cross section characteristics doesn’t influence remarkably the phenomena.
Each curve has a bell-shaped trend so, for each one, we can easily find the value of discharge relating to peak of WUA (optimal flow Q_{opt}).

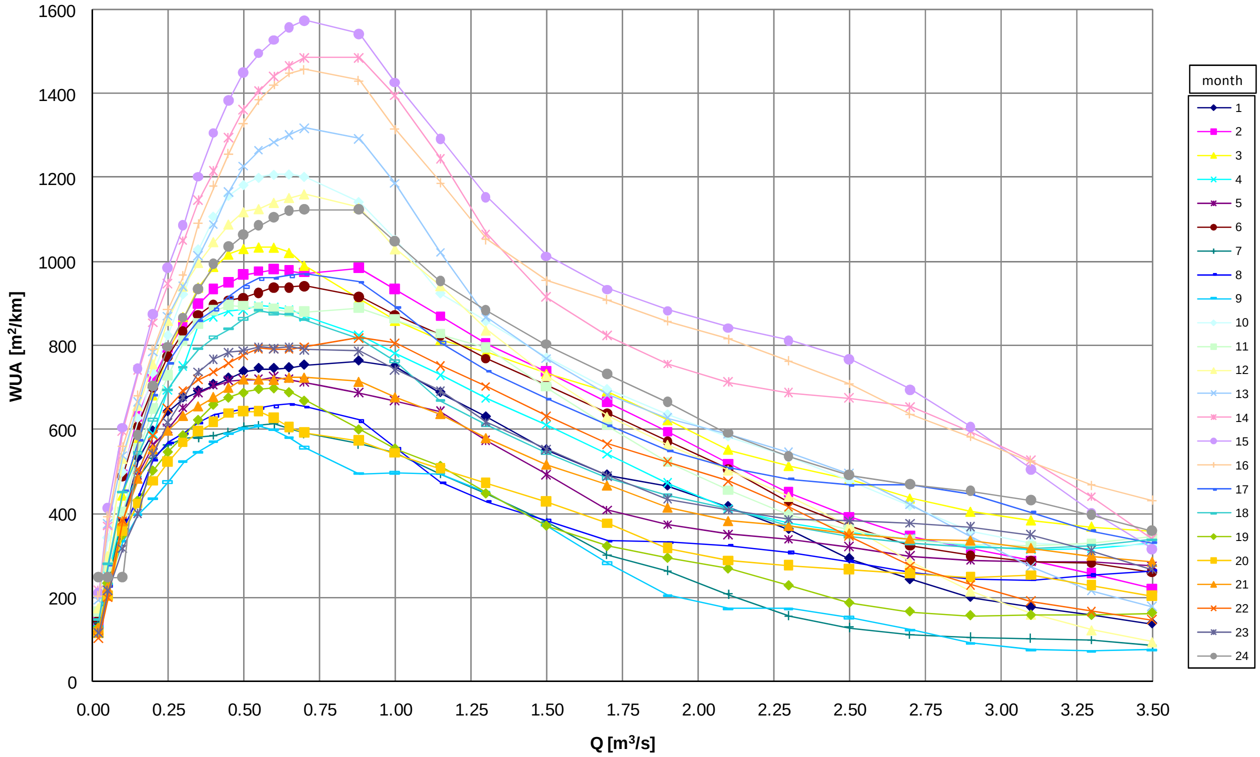

Fig.7 – WUA vs. discharge relation for juvenile trout relating to Tusciano river.

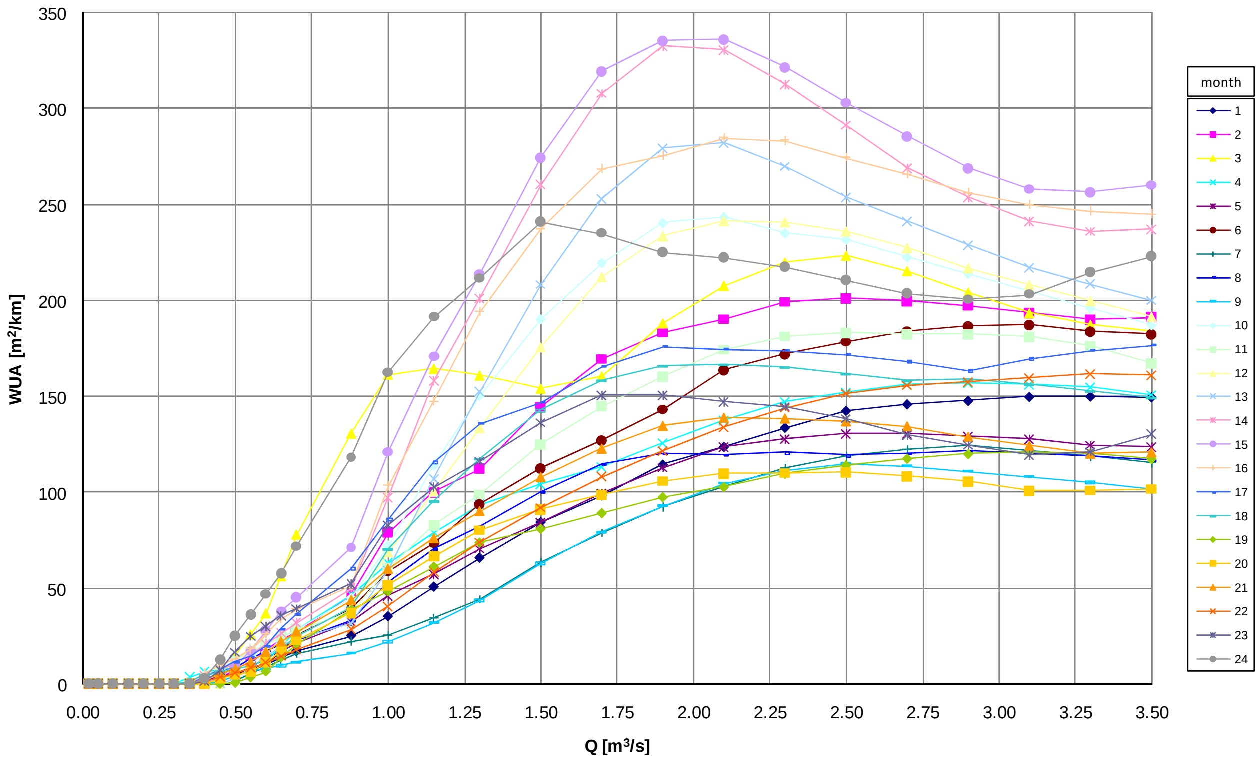

Fig.8 – WUA vs. discharge relation for adult trout relating to Tusciano river.

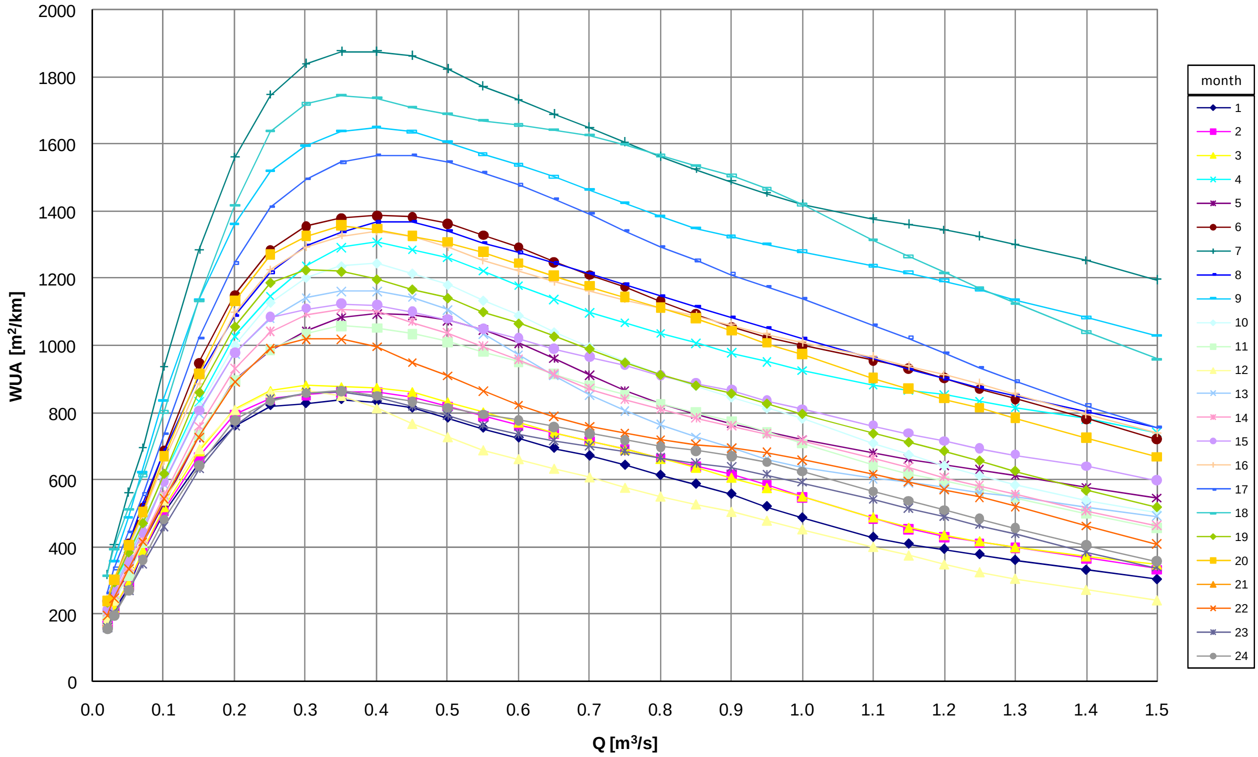

Fig.9 – WUA vs. discharge relation for juvenile trout relating to Picentino river.

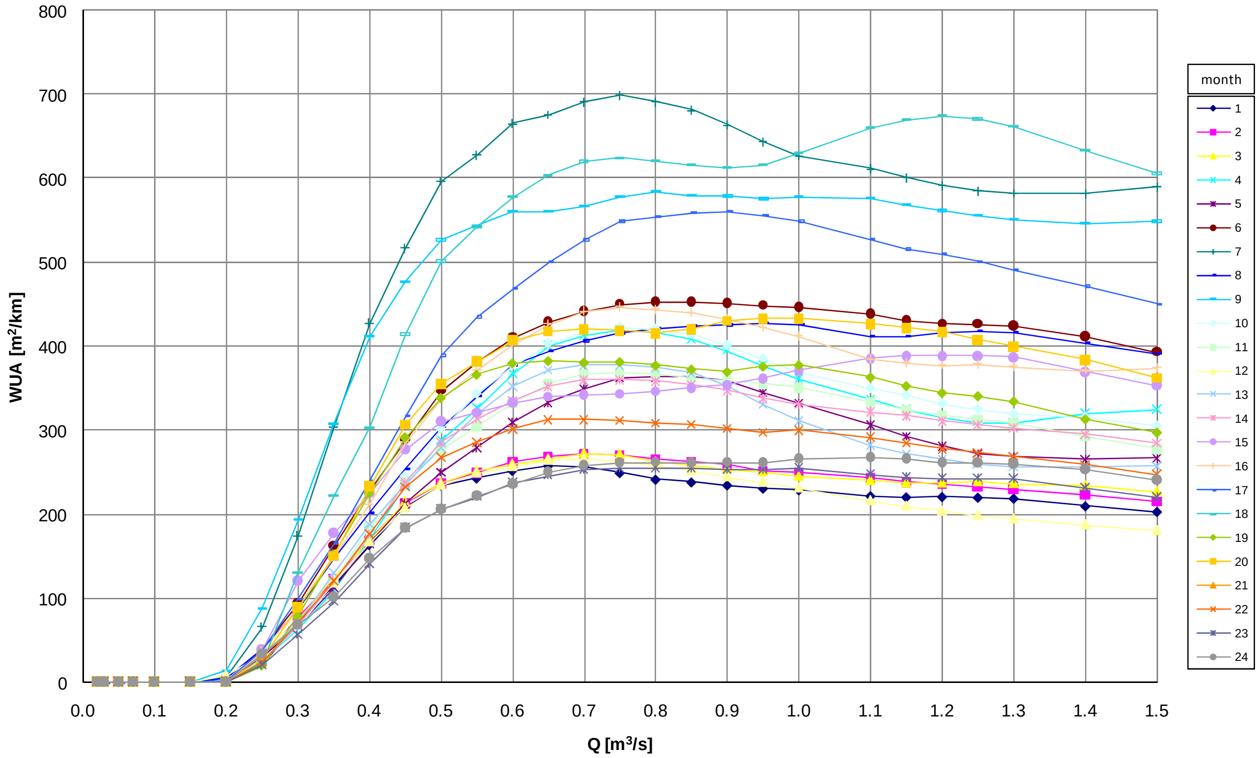

Fig.10 – WUA vs. discharge relation for adult trout relating to Picentino river.

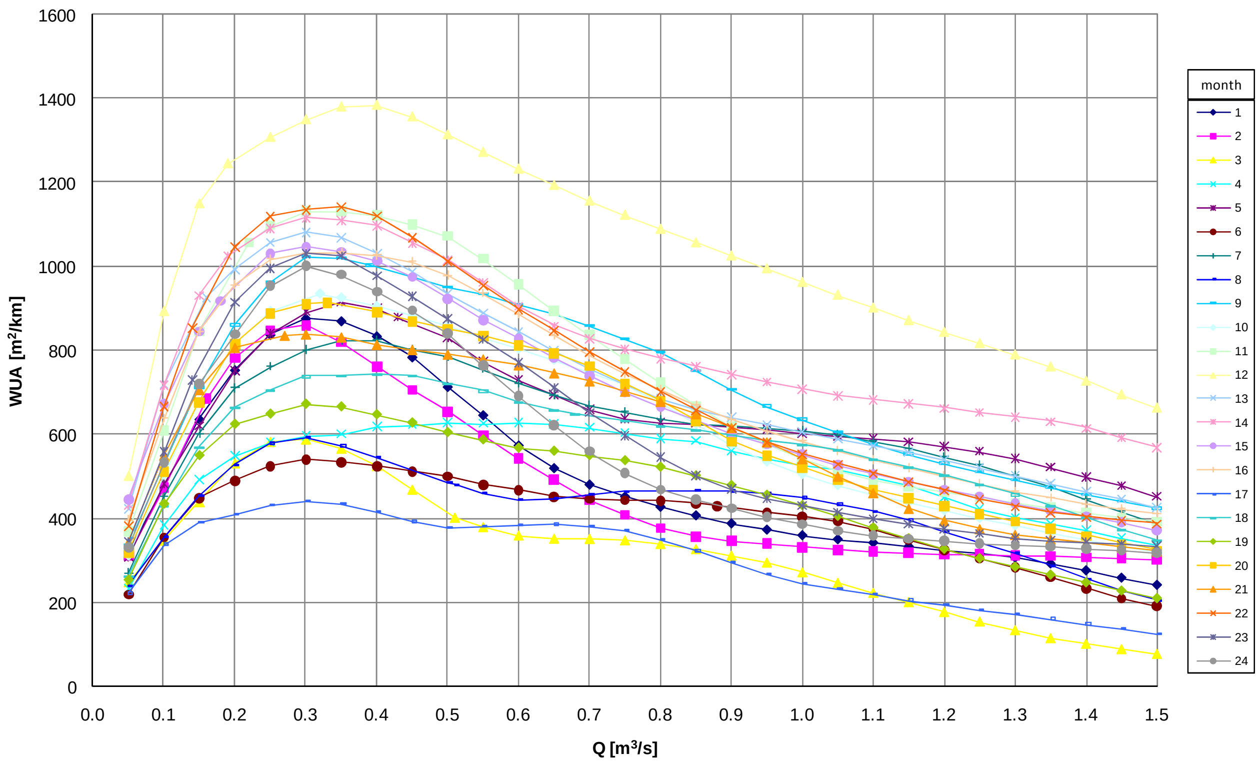

Fig.11 – WUA vs. discharge relation for juvenile trout relating to Prepezzano river.

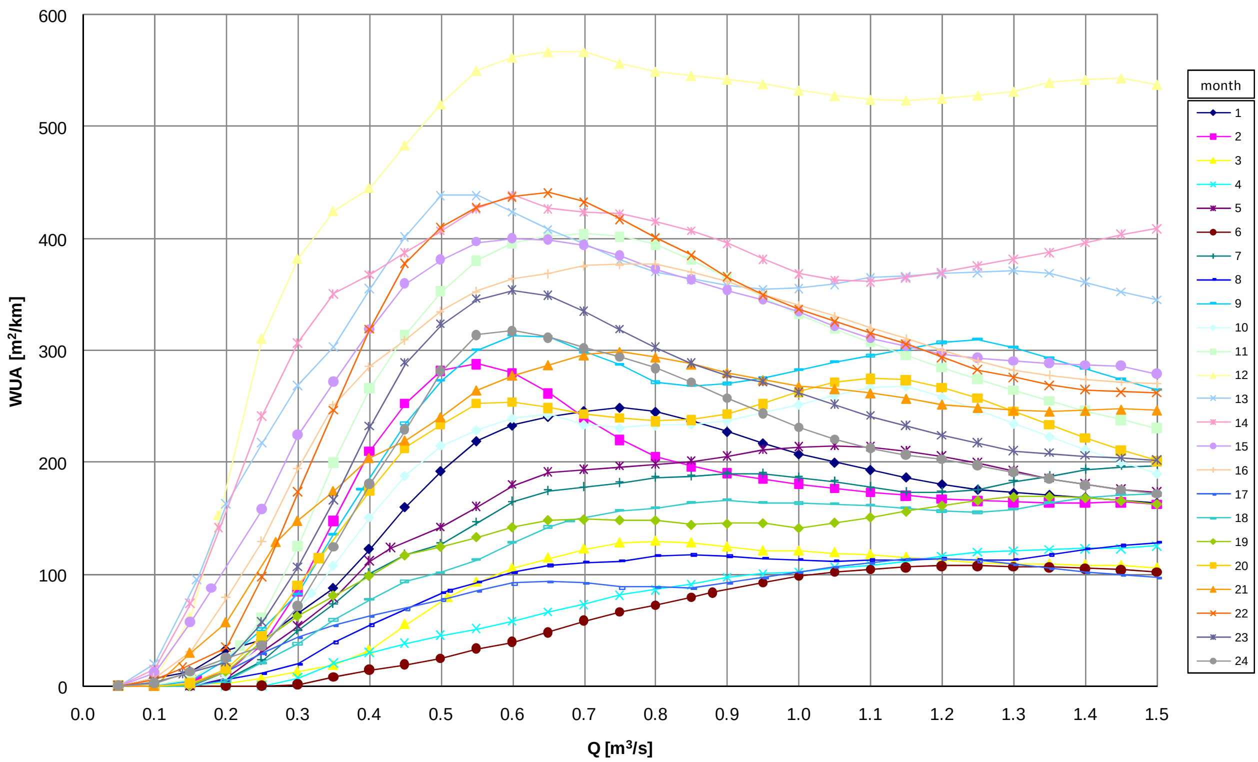

Fig.12 – WUA vs. discharge relation for adult trout relating to Prepezzano river.

Subsequently it was possible put all the optimal flow values relating to specific river in only one graph to obtain the optimal discharge vs time relation.
The following figures (Figg. 13, 14, 15) show, for each measure station, the relationship, for adult and juvenile life stage, between optimal flow and time (in months). As we can see the trend of the

curves is more or less constant; that is especially true for juvenile life stage and a little less for adult one.
The following table 1 shows the results in terms of mean value of optimal flow (Q_{opt}) and of relative standard deviation.

	Tusciano		**Picentino**		**Prepezzano**	
	j. l. s.	**a. l. s.**	**j. l. s.**	**a. l. s.**	**j. l. s.**	**a. l. s.**
Q_{opt} [m^3/s]	0.610	2.350	0.368	0.778	0.333	0.783
dev.st [-]	0.080	0.511	0.041	0.125	0.053	0.243

Tab. 1 – Q_{opt} mean value and relative standard deviation value for each river and each life stage.

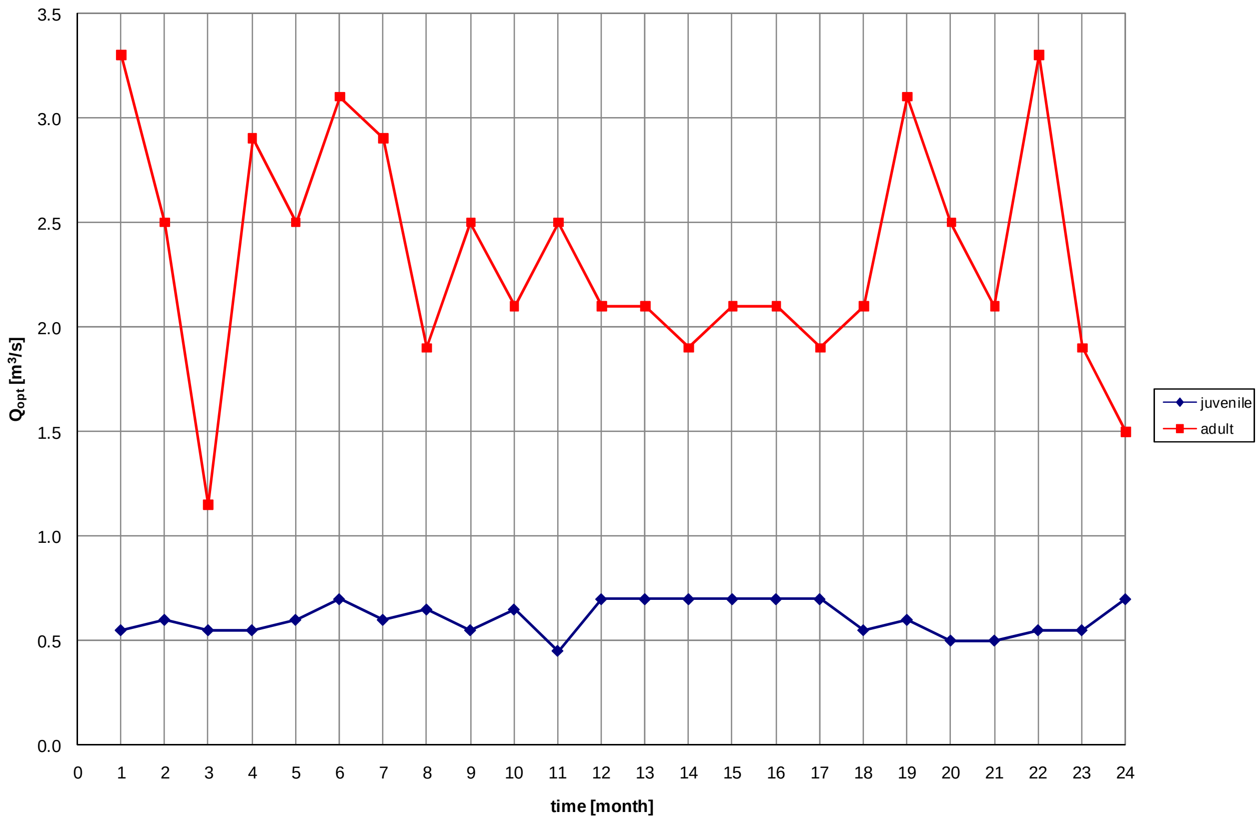

Fig.13 – Optimal Flow vs. time relation for Tusciano river.

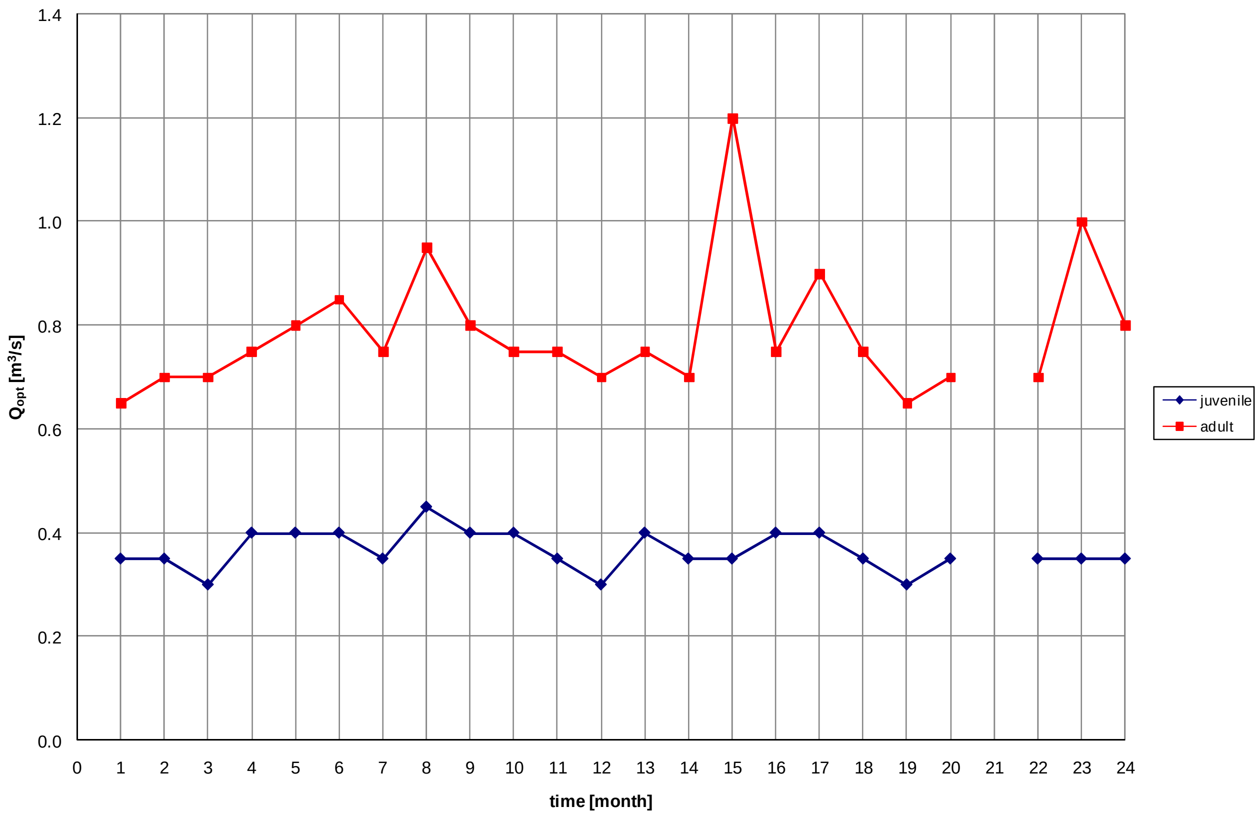

Fig.14 – Optimal Flow vs. time relation for Picentino river.

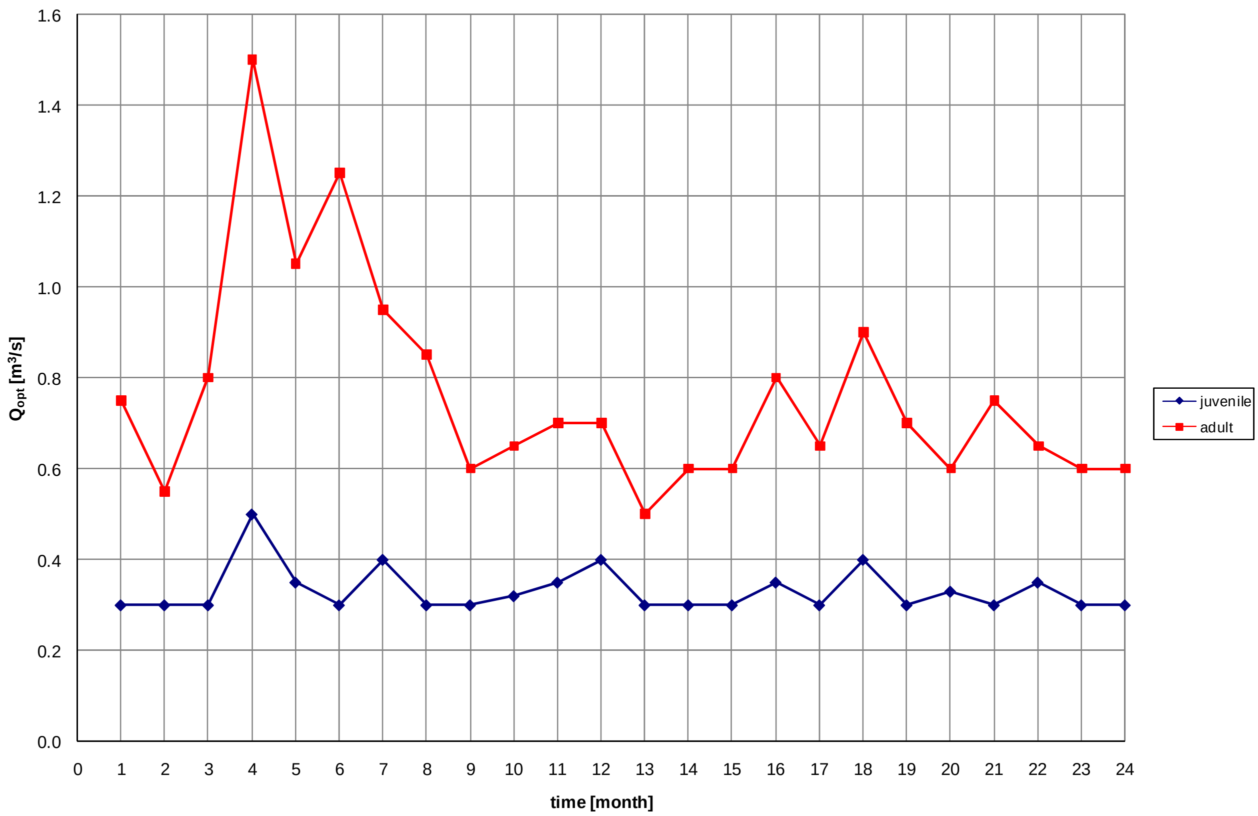

Fig.15 – Optimal Flow vs. time relation for Prepezzano river.

The Minimum Instream Flow, which is obviously much lower than the optimal flow, should on the other hand be determined by assessing the consequences on biological indicators of a gradual reduction in the Weighted Usable Area (WUA) corresponding to the optimal flow WUA(Q_{opt}).
Calculations carried out to this end have yielded the Q values reported in table 2, which were assessed with reference to values of 80% and 40% of the WUA(Q_{opt}).

	Tusciano		**Picentino**		**Prepezzano**	
	j. l. s.	**a. l. s.**	**j. l. s.**	**a. l. s.**	**j. l. s.**	**a. l. s.**
$Q_{80\%}$ [mc/s]	0.272	1.611	0.183	0.503	0.160	0.513
$Q_{40\%}$ [mc/s]	0.085	1.050	0.072	0.359	0.046	0.335

Tab. 2 – Values of the $Q_{80\%}$ $Q_{40\%}$ for each river and each life stage.

Finally can be interesting and useful to get the values of unit discharge relating to Q_{opt}, $Q_{80\%}$ and $Q_{40\%}$ that are obtained dividing these values by the surface of the each specific river catchment basin relating to the cross sections considered to estimate the discharge.
The follow table 3 shows for each river the value of basin surface S, and the values of unit flow q relating to juvenile life stage and adult one.

	S [km^2]	**juvenile life stage**			**adult life stage**		
		q_{opt} [l/s·km^2]	**$q_{80\%}$ [l/s·km^2]**	**$q_{40\%}$ [l/s·km^2]**	**q_{opt} [l/s·km^2]**	**$q_{80\%}$ [l/s·km^2]**	**$q_{40\%}$ [l/s·km^2]**
Tusciano	95.7	6.37	2.84	0.89	24.56	16.83	10.97
Picentino	29.64	12.42	6.17	2.43	26.25	16.97	12.11
Prepezzano	27.7	12.02	5.78	1.66	28.27	18.52	12.09

Tab. 3 – Values of the q_{opt}, $q_{80\%}$ and $q_{40\%}$ for each river and each life stage.

Conclusive remarks

Results obtained by the application of Habitat method on rivers Tusciano, Picentino and Prepezzano shows that the Method provides reliable results even for watercourses characterized by significant changes in the cross section.
With particular reference to the values of the Minimum Instream Flow of the monitored waterways, it can also observed:

- regarding the target species at juvenile life stage, the unit optimal flow q_{opt} was significantly greater for the rivers Picentino and Prepezzano (approximately 12 l/s·km^2) than Tusciano (6 l/s·km^2). This difference remains marked even after taking into account a reduction of WUA, since for Picentino and Prepezzano the $q_{80\%}$ is approximately 6 l/s km^2 (vs. 3 l/s·km^2 of river Tusciano), whereas the $q_{40\%}$ is around 2 l/s km^2 (vs. 1 l/s·km^2 of Tusciano);

- regarding, instead, the target species at the adult life stage, the unit optimal flow q_{opt} was very similar for all the waterways investigated (approximately 25÷28 $l/s \cdot km^2$). This trend is unchanged considering $q_{80\%}$ (approximately 17÷18 $l/s \cdot km^2$) or, also, $q_{40\%}$ (approximately 11÷12 $l/s \cdot km^2$);
- the value of q_{opt}, $q_{40\%}$ and $q_{80\%}$ calculated for the target species at adult life stage are significantly higher than the corresponding values for the juvenile one.

Further studies are in progress about the assessment of Minimum Instream Flow for the waterways taken into consideration, correlating the values provided by the software Indicators of Hydrological Alterations (IHA) with an index of environmental status of waterways, eg. Extended Biotic Index - EBI (Ghetti, 1995, 1997).

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