EVALUATION OF ECOLOGICALLY ACCEPTABLE FLOW FOR ALPINE STREAMS IN SLOVENIA

Authors: NATAŠA SMOLAR-ŽVANUT *, DANIJEL VRHOVŠEK

Limnos, Water Ecology Group, Podlimbarskega 31, 1000 Ljubljana, Slovenia

*Correspondence to: Limnos, Water Ecology Group, Podlimbarskega 31, 1000 Ljubljana, Slovenia. E-mail: natasa@limnos.si Phone: +386 1 505 74 72. Fax: +386 1 505 73 86.

ABSTRACT

Human influences on running water in the Slovenian alpine region are the reasons for treating and determination of Ecologically Acceptable Flow (EAF) for every section of the running water separately. EAF provision requires definition of the quantity and quality of water, which is needed to preserve the ecological balance in the running water and in the riparian zone. This means preservation of the structure and the function of the ecosystem, which it is reflected in diversity of species.
On the basis of hydrological, morphological and ecological criteria, hydrological and ecological methods in Slovenia are applied for the determination of EAF. Hydrological method is rapid to apply, but require hydrological data, an inventory of habitats, and ecological and morphological estimation. The application of ecological method demands the sampling of zoobenthos and periphyton in different habitats of the concerned sections of running water.
From 1992 more than 100 study sites in alpine streams and rivers have been examined for research and applications of the methods outlined above. This paper describes the criteria and methods used to determine EAF and experiences with their application in Slovenian alpine streams, with emphasize to the case study in the Soča River.

KEY WORDS: ecologically acceptable flow; alpine running waters; water abstraction; low flows

1. INTRODUCTION

Human influences on running water and in the riparian zone has ecological and economic consequences. The former exhibits a negative influence from the outset, the second shows the positive influence. The quantitative determination of Ecologically Acceptable Flow (EAF) is an extraordinary difficult task, because of direct confrontation between ecology and economy (Smolar and Vrhovšek, 1998). With increasing awareness of the environment, water abstractions in Slovenia are criticized and even demands for reduction of them are made. With the determination of EAF based on interdisciplinary approaches, a lot of criticisms subside.

In last 15 years, the problem of determination EAF has been tackled through the development of a number of different methods. Some approaches are available for determining minimum acceptable flows (Petts and Maddock, 1995): some apply hydrological methods (Schälchli, 1991, Mader, 1992) river assessment methods (Pehofer *et al.*, 1988, Statzner and Müller, 1989, Schälchli, 1991, DVWK, 1995, Smolar *et al*., 1998, Bernardo and Alves, 1999, Bonacci *et al*, 1999); and PHABSIM (physical habitat simulation model). The IFIM (Instream Flow Incremental Methodology) is implemented using PHABSIM (Johnson *et al.,* 1993, Stalnaker, 1995, Lamb, 1995, Gore and Hamilton, 1996, Maddock *et al*., 2001) and others utilize more detailed biological response simulations, e.g. CASIMIR (Jorde and Bratrich, 1998). The review of worldwide approaches for setting River Flows objectives were presented by Dunbar *et al*. (1998).
The rapid assessment methods based on hydrological and hydraulic calculations are applied less often when the demands of ecology, river morphology, forestry and other branches are considered more frequently.

2. DEFINITION OF EAF

The original definition of minimum flows in Slovenia on running waters was defined as a quantity of water, which enables the survival of water organisms. This formed the basis for granting permission according to specific regulations to ensure the availability of water supply for drinking and economic purposes (Uradni list SRS, 1976). This was insufficient for protection of the ecological balance in the river system, and from the point of view of the environment preservation and the diversity of organisms it was often even catastrophic. For this reason in 1994, the criteria for evaluating the provision of a quantity and quality of water to remain in the running water were selected (Vrhovšek *et al*., 1994).

EAF provision requires definition of the quantity and quality of water, which is needed to preserve the ecological balance in the running water and in the riparian zone. This means preservation of the structure and the function of the ecosystem, which it is reflected in diversity of species (Vrhovšek *et al*., 1994). The EAF is the quantity of water, which enables the survival and reproduction of water organisms in different hydraulic habitats (Smolar-Žvanut, 2000).

The diversity of hydro-morphological types of running waters in Slovenia (karst, lowland and alpine running waters) and great biological diversity demand special treatment and determination of EAF for each individual section of the river system.

3. THE BASIS FOR DETERMINATION OF EAF IN THE SLOVENIAN ALPINE REGION

On the Slovenian alpine running waters, there are water abstractions mostly for drinking water, energetic use and fish farming. Most localities of the existing and planned water abstractions are in small river basins where no information about the quantity of water exists. Because of specifically hydro-geological conditions in particular sections of

running waters, first of all, low-flow values should be determined by means of simultaneous measurements of water flows in the low flow period (Burja *et al*, 1995).
Because of the hydro-morphological and biological diversity of Slovenia it is imperative that the affected sections should be inventoried and the species diversity and ecological balance should be protected before large intervention by man in the river systems occurs. By environmental impacts the knowledge of structure and function of the ecosystem is indispensable (Vrhovšek & Smolar, 1997). Such a notion of EAF, of course, requires that each part of the running water is treated individually and that EAF is determined with interdisciplinary co-operation (Vrhovšek *et al*., 1994).

The basic starting points for selecting the criteria for evaluation EAF were, (Smolar *et al*., 1998) that the state of Slovenia has to preserve and protect running waters, their habitats with flora and fauna with special attention to rare and endangered plant and animals species respectively, i.e. in the groups important for the preservation of the ecological balance. For each change of quality and quantity of water in the river system a new determination of EAF is required. In future, the EAF should also be determined for sources of pollution (polluters).

4. CRITERIA AND METHODS FOR DETERMINATION OF EAF

On the basis of hydrological, hydraulic, morphological and ecological criteria in the section concerned, hydrological and ecological methods are applied. The application of both methods and the mode of proceeding in the determination of EAF were defined (Vrhovšek *et al*., 1994).

The starting points for the determination of an EAF according the **hydrological method** are basic hydrological and hydraulic parameters such as mean annual flow, mean minimum flow, minimum flow, etc. In cases where there are no hydrological data, it was suggested that for new water abstractions, hydrological observations should be carried out for two years, especially in the minimal flow periods. In some cases a special analysis of flow in the months of low flow is required and a flow duration curve is constructed. In addition to the hydrological data, ecological data (the ecological estimation of the existent situation), an inventory of habitats and hydro-morphological estimation are needed by the hydrological method for determination of EAF.
In the application of **ecological method** for the determination of EAF, samples of zoobenthos and periphyton on the chosen sampling points in the affected river sections are carried out. The number of sampling points in the profile depends on the breadth of the riverbed, structure of the habitats and the water velocity. In the affected section, hydrological and morphological measurements are made; at the sampling points the river depth, local velocities and the size of substrata are measured. The inventory and diversity of water organisms, the changes in biomass of the periphyton are determined, as well as an inventory constructed of macrophytes, flora and fauna of riparian zone. On the basis of the analysis, the existing situation is described. Depending on the quantity, length and duration of water abstraction, and the characteristics of the running waters, the research can be reduced or extended.
Because of seasonal dynamics of organisms and different flows during the year, the analysis should be performed during the whole year in different seasons according to

seasonal appearance of water organisms. The frequency of sampling is higher in the low flow periods, when the effect of water abstraction on water organisms is higher. The EAF is determined according to biotic and abiotic parameters, which are critical with respect to the EAF, where the ecological balance is still preserved. Decision about the EAF is accepted at a workshop according to the results of experts.

EAF should be determined according to ecological methods described in the cases below (Smolar *et al*., 1998):

- If the running water is in a preserved or legally protected area
- If there are rare, endangered or protected species of flora and fauna in the running water or in the riparian zone
- If the spawning grounds are endangered by water abstraction
- If the water abstraction is irreversible
- If the inventory of habitats, the field work or ecological estimation require the application of further ecological method
- If the public interest demands multi designation of the running water.

In other cases the EAF is determined by hydrological method.

The values of EAF vary for different seasons. Because of the need to maintain a balance in the running water and in the riparian zone, the natural dynamics of high flow should be preserved (Smolar *et al*., 1998). Special attention in determination of EAF in Slovenia is aimed at ensuring sufficient quantity and quality of water, as well flow dynamics that there is no excessive growth of the benthic periphyton and biomass.
In the running waters where there is a water abstraction or the water regime is changed, the EAF has to be assured in all periods irrespective of the quantity and the duration of water abstraction. In the case of increasing a water abstraction or where the flow regime downstream from a dam is changed, a new value of EAF should be determined. The value of EAF is not a constant value but has to be dynamically adapted at particular locations along the river. The dynamics have to be included in the operating strategy of the water user.

5. APPLICATION OF DETERMINATION OF EAF IN THE SLOVENIAN ALPINE RUNNING WATERS

From 1992 on more than 100 study sites in the Slovenian alpine region the EAF have been examined according to hydrological and ecological method. The values of EAF were determined mostly for existing water users, where the tolerance-limit of the user economy was considered. In the running waters where hydroelectric power plants have existed for many years, high changes in the EAF are questionable. In such cases the concept of EAF in Slovenia is, that ecology and economy have their tolerant limits, within it is possible to find a compromise solution for determination of EAF.
During the determination of the EAF the results demonstrate that most water users abstract too large quantities of water in low-flow periods. We required the increasing water flow in the riverbed and an improvement of conditions for organisms in the water and in the riparian zone. This means that especially in the low-flow periods smaller quantities of water may be abstracted from the running waters.

For the most of the small hydroelectric power plants the EAF was determined according to hydrological method, while for the large hydroelectric power plants (on the rivers Sava Bohinjka, Sava Dolinka and Soča), the value of EAF was determined according to ecological method. If it was possible the experiment with increasing the flow downstream the dam was done and evaluation of habitats at different flows were made.

5.1. Case study: the Soča River

The Soča River is one of the most beautiful rivers in Slovenia, well known for present of fish *Salmo marmoratus* and rafting opportunities. Downstream the pollution increasing and 71 km from its source is the first dam on the Soča River. The Soča River as a source of hydropower was already considered interesting at the time of Austro-Hungarian Empire. In 1998 the re-construction of the Doblar and Plave power plants began. Joint design flow for the Plave I and Plave II power plants will be 180 m^3s^{-1}, the same as the design flow for the Doblar I and Doblar II power plants. The abstraction section from the Doblar Dam to the Doblar hydro power plant is 4320 m long, and that from the Plave Dam to the Plave hydro power plant is 7950 m long.
Downstream of the dam Doblar, the measured discharge during low flow is usually 0.20 m^3s^{-1}, the value of the EAF determined according ecological method was 1 m^3/s. Flow through the gate of the dam Plave was 0.5 m^3/s until 2001, according to the water management operating license for the Plave power plant. With the purpose of improving ecological status of the river, EAF was determined at a quantity of 2.5 m^3s^{-1}. The reason for such an increase in the EAF downstream of both of dams were the results of applied studies, which show qualitative and quantitative hydrological, biological, and physicochemical changes downstream of the dams. Results of hydrological analyses show substantial changes in the hydrological regime (Table 1) and predominance of gravel deposits with a considerable proportion of coarse grains downstream of the dams.

Table 1. Hydrological parameters for the Soča River for the period 1961-1995 for water regimes with and without water abstraction for hydro power plant.

Hydrological cross-section	F (km^2)	sQs (m^3s^{-1})	sQn (m^3s^{-1})	nQn (m^3s^{-1})	Q_{300} (m^3s^{-1})	Q_{347} (m^3s^{-1})
Soča River downstream of the Doblar Dam -without abstractions	1254	80.6	16.03	10.0	27.47	20.08
Soča River downstream of the Doblar Dam - with abstractions	1254	22.5	0.13	0.12	0.64	0.25
Soča River downstream of the Plave Dam -without abstractions	1345	86.2	17.8	10.5	29.70	21.22
Soča River downstream of the Plave Dam -with abstractions	1345	33.1	1.0	1.0	1.41	1.12

Legend: F = catchment area, sQs (mean flow) = the average of mean daily flows for every year in the considered period, sQn (mean minimum flow) = the average of minimum flows for every year in the consider period, nQn (minimum flow) = the minimum flow in the considered period, Q_{300} = flow lasting for 300 days a year, Q_{347} = flow lasting for 347 days a year.

Due to the abstractions, the physicochemical composition of water downstream of the dams was not determined by conditions in the upper reaches of the river but by tributaries downstream of the catchment area. Summer temperatures were 7 ºC higher in

comparison with the reference site. Constant flow and rare occurrence of high waters downstream of the dams' changes diversity of periphyton and high periphyton biomass were measured here (average value of ash free dry mass was 40 gm^{-2}), compared with reference sites upstream of the dams (average value of ash free dry mass was 15 gm^{-2}) (Smolar-Žvanut, 2000).

6. CONCLUSIONS

In the last 10 years there has been strong efforts to improve ecological characteristics of the Slovenian alpine running waters. One important step of alpine river basin management is the determination and assurance of an EAF. Because of changes of hydrological and ecological conditions, and pollution in the running water, monitoring of the value of EAF should be undertaken. The EAF should be determined at the outset, before the proposals for the water development project are complete and the final decision on the construction is reached. The water should be abstracted only on the sections of the running water where this is ecologically and economically acceptable. The actual possibility of water potential should be respected and natural factors incorporation into the management of the environment.

7. REFERENCES

Bernardo JM, Alves MH. 1999. New perspectives for ecological flow determination in semi-arid regions: a preliminary approach. *Regulated Rivers: Research and Management* **15:** 221-229.

Bonacci O, Kerovec M, Roje-Bonacci T, Mrakovčić M, Plenković-Moraj E. 1998. Ecologically acceptable flows definition for the Žrnovnica river (Croatia). *Regulated Rivers: Research and Management* **14:** 245-256.

Burja D, Smolar N, Muck P, Vrhovšek D. 1995. Osnove določanja ekološko sprejemljivega pretoka (The basis for ecological acceptable flow determination). In *Proceeding Mišičev vodarski dan 1995*: Maribor; 67-71.

Dunbar MJ, Gustard A, Acreman MC, Elliot CRN. 1998. *Overseas approaches to setting River Flow Objectives. R&D Technical report W6-161,* Environment Agency and NERC; 83.

DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau). 1995. Merkblätter zur Wasserwirtschaft, Gesichtspunkte zum Abflufl in Ausleitungsstrecken von Wasserkraftanlagen: Bonn; 155.

Gore JA, Hamilton SW. 1996. Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems. *Regulated Rivers*: *Research and Management* **12:** 459-469.

Johnson IW, Elliott CRN, Gustard A, Armitage PD, Ladle M, Dawson FH, Beaumont WRC. 1993. *Ecologically Acceptable Flows, Assessment of Instream Flow Incremental Methodology*. National Rivers Authority: Bristol; 25.

Jorde K, Bratrich C. 1998. Ecological evaluation of Instream Flow Regulations based on temporal and spatial variability of bottom shear streass and hydraulic habitat quality. In *Advances in River Bottom Ecology,* Bretschko G, and Helešic J (eds). Backhuys Publishers: Leiden; 47-63.

Kokol J. 1994. Varstvo in gospodarjenje z vodami v Sloveniji (Protection and management with waters in Slovenia). In *Okolje v Sloveniji (Environment in Slovenia),* Lah A (ed). Tehniška založba Slovenije: Ljubljana; 362-374.

Lamb BL. 1995. Criteria for evaluating state Instream-Flow programs: Deciding What Works. *Journal of Water Resources planning and Management* **121** (3): 270-274.

Maddock IP, Bickerton MA, Spence R, Pickering T. 2001: Reallocation of compensation releases to restore river flows and improve instram habitat availability in the Upper Derwent catchment, Derbyshire, UK. *Regulated Rivers: Research and management* **17:** 417-441.

Mader H. 1992. Festelgung einer Dotierwassermenge über Dotationsversuche. *Dissertation*. In *Wiener Mitteilungen, Wasser Abwasser Gewässer,* Band 106: Wien; 375.

Pehofer HE, Margreiter-Kownacka M, Pfister P, Ritter H, Rott E, Saxl R. 1988. *Restwasserfordernisse aus limnologischer Sicht, Fallstudie Gebirgbach (Alpbacher Ache, Tirol)*. Bundesministerium für Land- und Forstwirtschaft: Wien; 200.

Petts GE. and Maddock I. 1995. Flow Allocation for In-river Needs. In *The Rivers Handbook. Hydrological and Ecological Principles, vol. 2,* Calow P, and Petts GE (eds). Blackwell Scientific Publications: Oxford; 289-307.

Schälchli U. 1991. Morphologie und Strömungsverhältnisse in Gebirgsbächen: ein Verfahren zur Festlegung von Restwasserabflüssen. In *Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie*. ETH, Band 113: Z¸ rich; 113.

Smolar N, Vrhovšek D. 1998. Experiences at the application of ecologically acceptable flow in Slovenia. In *Proceeding International Symposium on Water Management and Hydraulic Engineering*, Petraš J. (ed). Faculty of Civil Engineering: Zagreb; 103-108.

Smolar-Žvanut N, Vrhovšek D, Burja D. 1998. Criteria for Evaluation of Ecologically Acceptable Flows in Slovenian Streams. In *Proceeding XIXth Conference of the Danube countries on Hydrological Forecasting and Hydrological Bases of Water Management,* Gereš D (ed.). Hrvatske vode: Zagreb; 379-385.

Smolar-Žvanut N. 2000. *Vloga perifitonskih alg pri določanju ekološko sprejemljivega pretoka v tekočih vodah (The role of periphytic algae in determination of ecologically acceptable flow in running waters). Unpublished PhD Dissertation*, University of Ljubljana, Biotechnical Faculty: Ljubljana; 172.

Stalnaker CB. 1995. Evolution of Instream Flow Habitat Modelling. In *The Rivers Handbook. Hydrological and Ecological Principles, vol. 2,* Calow P, and Petts GE (eds). Blackwell Scientific Publications: Oxford; 276-286.

Statzner B, Müller R. 1989. Standard hemispheres as indicator of flow characteristics in lotic benthos research. *Freshwater Biology* **21**: 445-459.

Uradni list SRS. 1976. Uredba o ureditvi določenih vprašanj s področja voda (Decree on legal regulation in the field of water). *Uradni list SRS (Official gazette of Socialistic Republic of Slovenia)* **22**: 1321-1323.

Vrhovšek D, Martinčič A, Krušnik C, Kosi G, Burja D, Muck P, Smolar N, Pogačnik Z. 1994. *Kriteriji za zagotovitev dopustnih najnižjih pretokov v Sloveniji (The criteria for acceptable minimum flows in Slovenia). Final report,* Water management Institute: Ljubljana; 131.

Vrhovšek D, Smolar N. 1997. Pomen bioloških parametrov pri določanju ekološko sprejemljivega pretoka vode (Importance of biological parameters in determination of ecologically acceptable flow). In *Proceeding Mišičev vodarski dan 1997*: Maribor; 28-33.