THE APPLICATION OF SOME METHODS FOR COMPUTATION THE FLOWS FOR PROTECTION OF AQUATIC ECOSYSTEMS DOWNSTREAM OF RESERVOIR

TĂNASE ILEANA[1], RĂDULESCU DANIELA[2], GĂLIE ANDREEA [3]

ABSTRACT. The application of some methods for computation the flows for protection of aquatic ecosystems downstream of reservoir. The modification of the natural flow regimes by different water intakes degrades river ecosystems by erosion, by altering physical habitat and sediment supply rate. Providing a "flow for aquatic ecosystem" implies a flow regime designed to maintain a river in some environmentally acceptable conditions. All components of the natural hydrological regime have ecological significance. However, maintaining the full spectrum of naturally flows which occurring in a river is normally impossible due to water resources development and changes in land use in the catchments. Therefore, the flow protection of aquatic ecosystems should be seen as a compromise between developments within the river basin on the one hand and the maintenance of river ecology on the other. In Romania, providing the flow for the protection of aquatic ecosystems is a very important issue in the complex process of ecological restoration. According to the "Programme of Measures" chapter, presented within the River Basin Management Plans, "for increase of aquatic biodiversity besides the re-naturation of landscape, restoring the natural processes namely an adequate hydrologic regime for the water uses and aquatic species and a functional link between river and floodplain through changes to the water management systems operation is required". The paper shows the results for the application of some methods for computing the flows for protection of aquatic ecosystems downstream of a reservoir.

Keywords: flow for protection of aquatic ecosystems, protection and conservation of aquatic ecosystems, ecological restoration.

1. INTRODUCTION

International Water Management Institute in 2011 stated that: “water is an important part of any ecosystem, both qualitatively and quantitatively. Reduced water quantity has negative impacts on ecosystems. The environment has a natural self-cleaning capacity and resilience to water shortages, but when these processes are inhibited, biodiversity is lost, livelihoods are affected, and natural food sources for fish and other aquatic species are damaged. The high cleanup and rehabilitation costs are incurred”. Heightened water resources pressures world-wide have elevated the role of flow regimes in a sustaining aquatic ecosystem health (Snelder, Biggs, 2002).

[1] National Institute of Hydrology and Water Management, Bucharest, Romania, e-mail: liliana.tanase@hidro.ro

[2] National Institute of Hydrology and Water Management, Bucharest, Romania, e-mail: daniela.radulescu@hidro.ro

[3] National Institute of Hydrology and Water Management, Bucharest, Romania, e-mail: andreea.galie@hidro.ro

In 2003, David and Hirji stated that ”modification of river flows for human needs (such as dams and weir, extraction for agriculture and urban supplies) had significant negative environmental effects by reducing the total flow of many rivers and altering both the seasonality of flows and the size and frequency of floods. Therefore, must be balanced with the maintenance of essential water-dependent ecological needs. [….] At international level, there are a large conflict between water users and those who maintain some level of minimum flow for maintaining aquatic ecosystems. Flow reduction alters a number of habitat variables known to be important to aquatic invertebrates such as depth, velocity, temperature and fine sediment. In recent decades water managers have shown a growing acceptance that rivers are “legitimate users” of water”.

Maintaining or partially restoring important characteristics of the natural flow regime in order to maintain specified, valued features of the ecosystem is a tool for mitigate hydo-morphological impacts and an important mechanism to protect and enhance the status of aquatic ecosystems and promote a sustainable water use contributing to the achievement of European Union water policy goals (Sanz, Schmidt et all., 2012).

The Water Framework Directive aims at maintaining and improving the quality of aquatic ecosystems by achieving “good ecological status/potential”. Quantity and dynamics of water flow and river continuity are two hydromorphological elements supporting the biological elements that describe/characterize the ecological water status.

Flow dynamics in the design of restoration/mitigation measures is a key element in achieving the objectives of the WFD. To achieve these objectives, environmental flows must provide suitable habitat conditions to satisfy the needs of the different biological communities within the aquatic ecosystem, for maintain the biological integrity of the ecosystem.

During the last five decades, it has been estimated that some 200 different generic methods have been developed to derive the “environmental flows” (Tharme, 2003). Hirji and Davis (2009) stated that: “different methods should be and are used for different purposes depending on the specifics of the case study and the type of issue to be addressed (water planning, monitoring, river restoration plan, etc.). However, no single environmental flow assessment technique suits all social, economic, hydrological, and ecological contexts within a country”.

In Romania, the Water Law establishes obligations on assuring of Environmental Flow but, there is no legally implemented formula for the environmental flow.

There are two terms defined within the law: sanitary/salubrious discharge and servitude flow.

Salubrious discharge (Q_{sal}) is the minimum discharge required for continuous flow, in a section on a watercourse, to provide/assure the natural life conditions for the existing aquatic ecosystems;

Servitude discharge/flow is the minimum flow required to be continuously supplied in a section on a watercourse, downstream a dam, consisting of the sanitary discharge and the minimum discharge necessary for the downstream water users. The same Water Law specifies that these flows are “minimum flows”, i.e. flows in extreme drought conditions of hydrological regime.

2. DESCRIPTION OF THE METHODS FOR COMPUTING THE AQUATIC ECOSYSTEM PROTECTION

Method 1

The method for computing the aquatic ecosystem protection flow / environmental flow (Radulescu, Galie, 2010) it was proposed in Hidrotehnica review. The method which computes flows for aquatic ecosystem protection is a dynamic method and it proposes a multiple and variable value for environmental flow assessment. The flow for aquatic ecosystems protection/environmental flow (Q_{aep}) varies between a minimum value (Q_{min}), represented by a minimum flow required in the riverbed for the survival of aquatic ecosystems (salubrious discharge) and a maximum value (Q_f), represented by the flow which generating flooding of the floodplain. Between the two values (minimum / maximum), flow of aquatic ecosystem protection varies relying on the natural hydrological regime in such a way to ensure necessary habitat for maintaining long-term development of the aquatic ecosystem (Table 1).

The variation flow between a minimum value and a maximum value depends on the natural hydrological regime, in order to perform maintenance and restoration of the natural shape and functions of the ecosystems.

The formula proposed is shown below:

$$Q_{aep,i} = Q_{\min} + Q_m + Q_f$$

Table 1 Values of Qaep depending on the natural hydrological regime
(Rădulescu & Gălie, 2010)

Case	Qmin	Qm	Qf	Coefficient values
$Q_{sal} \le Q < Q_{\min\_monthly\_mean}$	α Q_{sal}	-	-	α=1, β=0, γ=0
$Q_{\min\_monthly\_mean} \le Q \le Q_{mma}$	-	*β Qmonthly mean (i)*	-	α=0, β=0,10-0,20, γ=0
Q> Q_{mma}	-	*β Qmonthly mean (i)*	-	α=0, β=0,20-0,30, γ=0
Flooding (1-5 time/year)	-	-	γ Q*mma*	α=0, β=0, γ=≤2

Note: The values of Qaep must be always greater than the Qsal

For the computing salubrious discharge (Q*sal*), National Administration "Apele Romane" (Romanian water authority) currently uses a methodology (INHGA, 2012) developed by the National Institute of Hydrology and Water Management, which determines the minimum flow necessary to ensure the living conditions of the existing aquatic ecosystems (considered to be a flow for survival). The salubrious discharge is determined as average daily flow from the duration curve of the daily mean flows corresponding to 95% probability of occurrence.

The formula to compute the minimum environmental flow (salubrious flow) in Romania is the following:

$$EF = Q_{95\%} \text{ from } DCDF$$

where:

$Q_{95\%}$ = the minimum daily mean discharge with 95% probability of exceeding and

DCDF = the duration curve of the average daily flow

Method 2

The assessment of the results obtained by the Q_{aep} method application will be done by comparing with three characteristic values/limits for assessing habitat quality for fish set by the Montana method (Tennant, 1976). These limits are 10% from mean annual flow for poor quality (survival), 30% from mean annual flow for moderate habitat and 60% from mean annual flow for optimum habitat conditions.

The Montana Method (also known as Tennant) is a simplistic approach that defines environmental flow values as percentage of the average daily discharge or mean annual flow. At 10% of the average flow (the mean daily flow, averaged over all years of record), fish were crowded into the deeper pools, riffles were too shallow for larger fish to pass, and water temperature could become a limiting factor. A flow of 30% of the average flow was found to maintain satisfactory widths, depths and velocities. Thereby, 10% from mean annual flow are considered as absolute minimum flow, 30% from mean annual flow are recommended for to sustain a good habitat, while 60-100% from mean annual flow is expected to provide optimal habitat conditions (Table 2). Also natural flushing events (200% from mean annual flow) are recommended (Richter et. all, 1997) the choice of a maximum flow was based on the theory that prolonged large releases would result in severe bank erosion and degradation of the downstream aquatic environment.

Table 2. Critical minimum flows required for fish, wildlife and recreation in streams identified by Tennant (1976)

% of mean annual flow		
Description of flows	***Dry season***	***Wet season***
Flushing or maximum	200% of the mean annual flow	
Optimum range	60 - 100% of the mean annual flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	0 - 10% of the mean annual flow	

3. THE DATA USED FOR METHODS APPLICATION

The above-described methods to compute Environmental Flows are applied on the Olt River Basin in a location downstream of dam in order to find out how much water should be released from reservoirs. For statistical computation, data series, for the period 1950-2011 (INHGA), are used. The environmental flows are computed in a cross-section downstream of Frumoasa dam (Fig. 1) on the Frumoasa River. Both methods for environmental flow assessment use the natural flow regime.

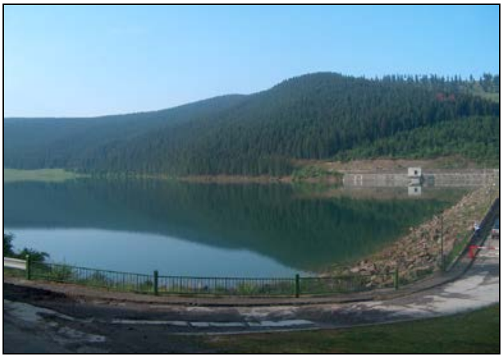

Fig. 1. Frumoasa reservoir (Olt River Basin)
(source: Wikipedia.com)

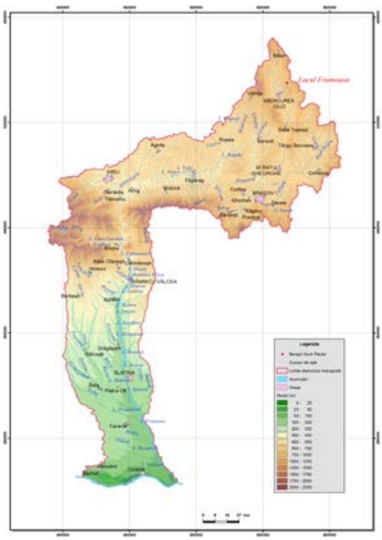

Fig. 2. The geographical features of the Olt River basin and the locations of the analyzed dam

The Frumoasa River is a small river in the Olt river basin, located in the Ciuc Depression. Frumoasa Dam (1986) is located at an altitude of 836 m on the river Frumoasa (figure 2), 2.5 km upstream from the village Frumoasa and 12 km from Miercurea Ciuc city. Frumoasa reservoir was built to water supply Miercurea Ciuc city and Frumoasa, Nicolesti, Fitod, Lelicieni localities. The reservoir is situated in Natura 2000 protected sites - *Frumoasa - ROSCI0085, ROSPA0043 and RO0000 105 "Ciucului Depression and Mountains"* (Olt River Basin Management Plan, 2009). The water body *"Frumoasa downstream of Frumoasa dam - Racu river confluence"* has a "moderate ecological potential" due to the discharge deficit downstream of Frumoasa dam. To achieve the "good ecological potential" must be ensured a properly flow on this water body (Olt River Basin Management Plan, 2009).

4. THE RESULTS OF THE METHODS APPLICATION

The results of the environmental flow calculated using the methods described above are presented in the table 3 and figure 4. In this study case, the values of coefficient (β) were considered 0.15 respectively 0.30 (Method 1).

Table 3. Required data and the results of applying the methods

Date and results	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	***Jul***	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Q monthly mean	0.175	0.200	0.395	0.697	0.577	0.503	0.474	0.346	0.265	0.228	0.201	0.191
Q mean multiannual (Q_{mma})	0.354											
Q salubrious (Q_{sal})	0.08											
Q minimum monthly mean	0.020	0.035	0.125	0.175	0.139	0.094	0.066	0.080	0.072	0.072	0.082	0.050
Qaep (method 1)	**0.090**	**0.090**	**0.119**	**0.209**	**0.173**	**0.151**	**0.142**	**0.090**	**0.090**	**0.090**	**0.090**	**0.090**
10% Q_{mma} (method 2)	**0.035**											
30% Q_{mma} (method 2)	**0.106**											
60% Q_{mma} (method 2)	**0.212**											

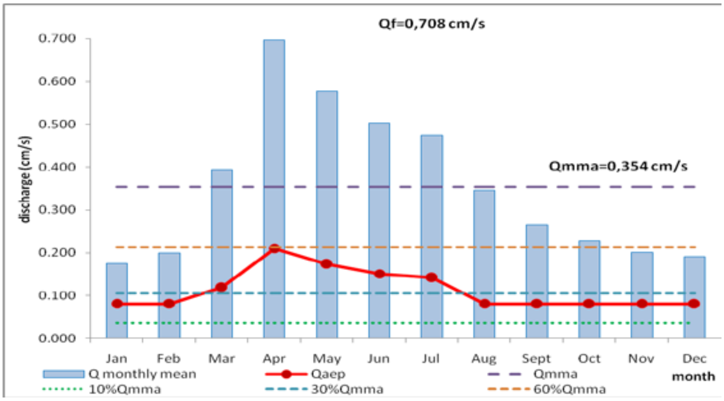

Fig. 3. Charts highlighting the results of the methods application

5. CONCLUSIONS

The environmental flow is defined as flow providing habitat necessary to maintain long-term development of the aquatic ecosystem. This flow must show a variation between a minimum value, being the necessary flow in the riverbed for the survival of aquatic ecosystem, and a maximum value, that generates river flooding depending on the natural hydrological regime, in order to perform maintenance and restoration of the natural shape and functions of the ecosystems.

The method 1 presented in this paper is a dynamic method because it calculates not only a single value for flow, but multiple values which assuring the variability of the flow which is similar to natural pattern of the flow. As seen on the chart and taking into account the method 2 (Montana), the values of environmental flows resulting from the application of the method are always situated above the thresholds values of 10% from mean annual flow considered proper for survival of habitat (absolute minimum flow). Most of the environmental flow values (that coincide with drought period) are between the 10% and 30% from mean annual flow, threshold values recommended by Tennant to sustain a good quality for habitat. The other values vary between 30% and 60% from mean annual flow, threshold values recommended by Tennant to sustain the optimal habitat. In April (when the maximum value of the monthly flow in natural regime is recorded), the method 1 reaches the value of 60% from mean annual flow, value considered adequate for providing optimal habitat (good conditions for reproduction and migration) by Method 2. The Method 1 follows closely the pattern of the natural hydrological regime, therefore, the natural characteristics of the river flow being kept.

PERSPECTIVES

In the future, the method will be developed taking into account the requirements for achieving the Water Framework Directive objectives (such as the good ecological status/potential (GES/GEP), the good quantitative status or groundwater body (GWB), or the conservation objectives of protected areas).

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