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Re–thinking Ecological Flow in Romania: A Sustainable Approach to Water Management and for a Healthier Environment

Cornel Ilinca * and Cristian Gabriel Anghel

Faculty of Hydrotechnics, Technical University of Civil Engineering Bucharest, 020396 Bucharest, Romania; cristian.anghel@utcb.ro
* Correspondence: cornel@utcb.ro; Tel.: +40–723–071–247

Abstract: The water resources and aquatic ecosystems are facing significant threats due unsustainable water management practices. To address this challenge in Romania, a sustainable approach to water management is necessary, re–thinking Ecological Flow. This article proposes rethinking the current approach to ecological flow in Romania by advocating for a more holistic and integrated approach that considers environmental factors. The objective of the article is to present a methodology regarding the establishment of ecological flow, which takes into account the natural variability of flows. Four ecological flow values related to flood, high water, medium water and low water hydrological regimes are defined. To establish them, the duration curve of average daily flows is used in conjunction with hydromorphological and biological indicators. The proposed methodology is applied compared to the existing methodology for the Uz river developed with hydropower use. The methodology represents a transition from the anthropocentric perspective to the sustainability perspective. The proposed methodology is easy to apply, with rigorously defined hydrological, hydraulic and biological criteria. This is a research topic addressed within the Hydrotechnical Faculty for the improvement of the Romanian legislation regarding the improvement of the ecological status of all water bodies.

Keywords: Ecological Flow; anthropogenic hydrological drought; duration curve;

1. Introduction

The good quality of water bodies are influenced by the modified hydrological Regime of the rivers, in the context of economic development overlapping with that of climate change.

The anthropization of rivers leads to the modification of the natural conditions of the habitats, affecting the aquatic ecosystem. What is worse is that species that require strict protection are threatened, threatened with extinction due to reduced flows downstream to all water uses (in particular abstraction, impoundment, flow regulation) [1]. Thus, the economic prosperity of human society negatively affects biodiversity.

A measure to reduce the impact on the aquatic environment is to ensure flows that provide optimal conditions for the aquatic ecosystem, imitating the variability of flows in a natural regime and improving the efficiency of the use of water resources. The solution to an effective implementation of the ecological flow is the socio–economically acceptable reduction of the use of water resources by increasing the efficiency of technological processes and turning to other alternative sources of energy, such as wind and photovoltaic.

In the European Union, concerns regarding mitigating the effects of altering the hydrological regime have focused on hydromorphological analysis and measures to reduce hydromorphological pressures, which have been transposed through the Water Framework Directive [2].

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

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In Europe, more hydrological methods are used to determine the ecological flow, the predominant one being the use of average monthly flows [1,3–9], and rarely used the duration curve of average daily flows [5,10–12].

In Romania, the ecological flow is implemented through HG 148/2020 [13], and as for the hydromorphological analysis, there are no official rules, only proposals [14].

Guidance Document No.31 [1] recommends an ecological flow that is variable, i.e., to imitate the natural variability of river flows over time, because this has an important role in ensuring the good ecological condition of water bodies, including biodiversity, an aspect known as "the natural flow paradigm" [15,16,17,18].

The ecological flow variability must be seasonal and "alike" because native aquatic and riparian biota are adapted to this variability [1,15].

According to Wei [19,20], the ecological flow calculation includes four categories, with the main methods presented in Figure 1. Their complexity increases in the order of enumeration.

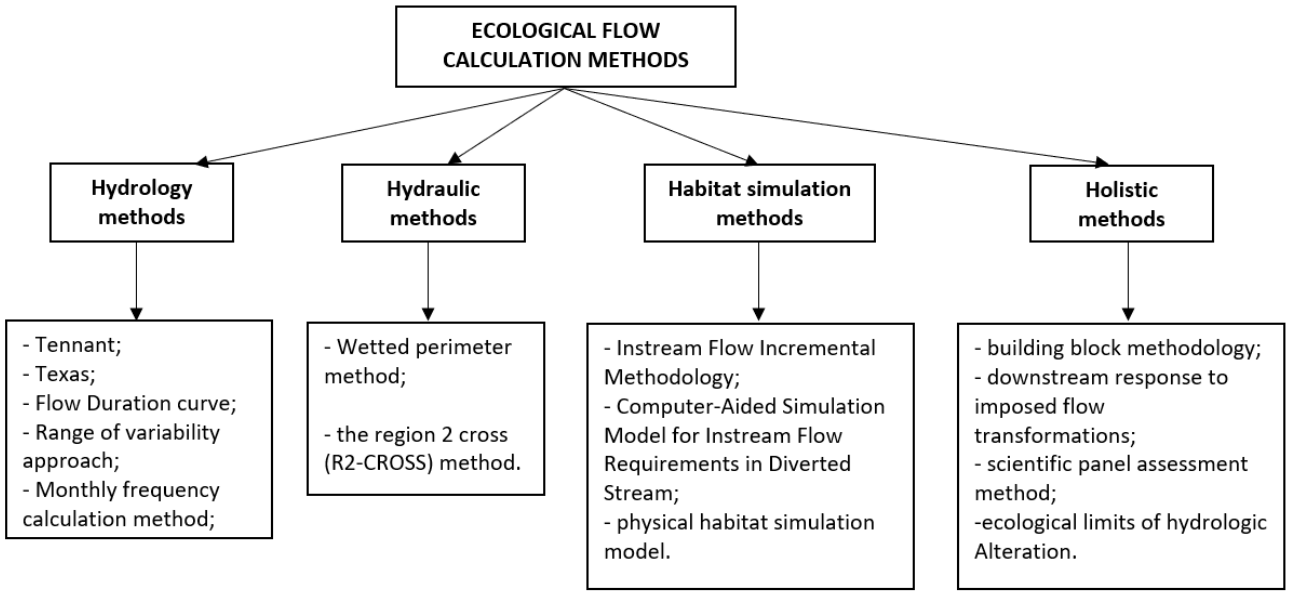


Figure 1. The categories of ecological flow calculation methods.

The hydrological method is preferred because it is simple. This is enhanced by using correlations with local physical–geographical conditions and critical periods of the ecosystem, usually in general. The hydrological method is a generalist method, so it becomes an inappropriate methodology for ecosystems that have particularities.

The hydraulic method is a method that generally defines the hydraulic parameters, such as wetted perimeter, depth and velocity required by the ecosystem. It is a very little used method and is often in tandem with other methods.

Habitat simulation methods are a very good alternative for particular cases, because generalization leads to the same problems as mentioned before.

Holistic methods represent the multitude of methods that take into account ecological, hydraulic, hydrological conditions and the requirements of human society, as a limiting factor.

It should be noted that the methods for calculating the ecological flow are diverse and their application can lead to deviations from the proposed objectives, due to attempts at simplification and generalization, often made by proposing inappropriate coefficients and referring to apparent conditions of the ecosystem [13].

The calculation of the ecological flow requires an exhaustive approach from hydrological data, generally sufficient, topographic data (reference sections, with the data necessary for the hydraulic calculation) to data related to the ecosystem (species and their

needs). This aspect makes any methodology from a simplified approach, generally easy to apply to a complex approach difficult to apply.

The methodology applied in Romania since 2022 [13] is a simple one based on unconvincing hydrological calculations. Reporting to the ecosystem was done by eliminating the current biodiversity studies, out of the desire to simplify and generalize the method. Environmental flow as it was defined in Romania until 2020, having a constant value, represented a pressure on water bodies because ensuring a constant value throughout the year leading to some ecological response like local extinction, threat to native species, reduced nutrients to floodplain plant species, etc [16,21,22,23].

The approach of a method for establishing the ecological flow must take into account the alteration of flow components: magnitude, frequency, duration [24,25].

The ecological flow must take into account the seasonal dynamics of the flows and must have four values corresponding to the hydrological regime, low flow, medium waters, high waters and floods and generally be greater than 25% of the multiannual average flow [26]. In general, for the area of Eastern Europe, a classification of hydrological regimes determined on the duration curve of average daily flows can be used. Thus wet condi−tions corresponds to the duration interval from 0 to 10%, moderately wet conditions corresponds to the duration interval 10%−40%, moderately conditions is associated with the duration interval 40%−60%, moderately dry conditions corresponds to the interval duration of 60%−90%, and dry conditions corresponds to the interval of duration 90%−100%. [27].

For the methodology proposed in this article, a similar classification was used, insisting on the influence of hydraulic regimes on hydromorphological indicators. Thus, there are four hydrological regimes, floods for the duration interval 0−0.274%, high water period for the duration interval 0.274%−5%, medium water period for the duration interval 5−30% and low water period for the interval duration 30%−100%. This classification allowed highlighting the optimal ecological conditions for biodiversity.

The new elements are presented, such as the definition of four hydrological regimes, namely floods, large waters, medium waters and small waters; using the duration curve of average daily flows to define hydrological regimes and corresponding ecological flow values; the holistic approach, integrating hydrology and river hydraulics with biodiversity; ensuring the daily variability of the ecological flow using hydrometric systems.

The article is organized as follows. The description of the existing and the new methodology for ecological flow in Section 2.1. The description of the existing and the new methodology for hydromorphological indicators, in Section 2.1. Case study by applying these methodologies on the Uz river, Romania in Section 3. Results, discussions and conclusions, in Sections 4 and 5.

2. Methodology

In this article, a methodology for determining ecological flows is proposed as a measure to reduce hydromorphological pressures, especially for highly modified water bodies and ensuring biodiversity.

The proposed methodology represents an improvement of the existing one, being practical, transparent and imitating the seasonal dynamics of flows. The methodology represents a holistic approach, with the determination of some values reported on the duration curve of average daily flows, take into account ecology and economy which to reflect the overall situation of river ecosystem and the water demand for of the utmost importance water users. Thus, the methodology represents an easy−to−apply hydrological synthesis with prospects for improving the environment in which we live.

2.1. The existing methodology

The existing methodology [13] is a hydrological method, which uses as basic data the multiannual average monthly flows of the last 30−50 years under natural conditions. Thus, at least one reference period that reflects changing climate will be included in the analysis.

The ecological flow has three distinct values, trying to imitate periods with a hydrological regime of small, medium and large waters, except for the flood period, which was not taken into account.

The calculation of the ecological flow is done for each month of the year according to the multiannual average monthly flow by applying some coefficients that take into account the altitude (mountain, hill, plain). The coefficients have four distinct values, namely, 0.20, 0.25, 0.30, 0.35, which are chosen according to the local physical−geographical and climatic conditions of the hydrographic basin in the calculation section, the location in a protected area and the characteristics of the ecosystem, the reproduction period of the ichthyofauna. The maximum values of the coefficients are chosen for areas that require a higher level of protection.

Based on the values of the monthly ecological flows, three distinct values are established for the hydrological regime. For the ecological flow of small waters, it is calculated using the maximum value between the average monthly minimum annual flow with the probability of exceeding 95% ($Q_{mam95\%}$ − minimum annual average monthly flow with 95% exceedance probability) and the lowest value among the monthly ecological flows. The average ecological flow value represents the median of the series of monthly ecological flows. The value of the ecological flow of large waters is given by the arithmetic mean of the first four values of the monthly ecological flows, ordered in descending order.

These three ecological flow values are correlated with the monthly hydrological forecast developed by the National Institute of Water Management (INHGA) of average monthly flow. The hydrological forecast is divided into five forecast classes as a percentage of the multiyear average monthly flow. Forecast classes are for > 100%; 80−100%; 50−80%; 30−50%; < 30%. Forecasts have a high degree of uncertainty, so for the months outside the ichthyofauna reproduction period, the ecological flows are reduced by a class of hydrological regime.

The main disadvantage of this methodology, in addition to the lack of a holistic approach, is the fact that it does not improve the ecological status of water bodies (especially for those located in protected areas), a fact highlighted by the analysis of the values of the ecological flows characteristic of the hydrological regime of small waters (representing a period of 8 months of the year), being generally much lower than the value of the healthy flow (which characterizes the situation before the emergence of the methodology). The methodology also does not take into account all four hydrological regimes that characterize water courses. Another disadvantage of this methodology is the reporting of the ichthyofauna biological component to non−updated materials and studies, completely ignoring the existing environmental studies, carried out regularly, which reflect the real situation of the ichthyofauna characteristic of watercourses in Romania. This aspect, with a generalized character, is also evident in the case study presented in this article. Also, the application of this methodology represents a disadvantage, the application being based on monthly hydrological forecasts, which are characterized by a high degree of uncertainty.

The relative advantage brought by the increase in the flow values for a period of 2−4 months of the year (depending on the hydrological forecast) is much reduced or non−existent in the case of run−of−the−river facilities, because they have an installation coefficient of at most 1.5− 2.5, so that in those periods higher flows were ensured even compared to the existing regulation. As for the dams, they remain in the previous situation (healthy flow), due to the exemption from the application through the analysis of disproportionate costs, so no improvement is made.

2.2. The proposed methodology

Considering the recommendations [1] and other specialized materials [28–30], it is recommended to impose a methodology with four ecological flow values, which imitate periods with hydrological regime.

The methodology is based on the tributary flow input and the return to the water course of a fraction of it according to the hydrological regimes, thus ensuring a better variability compared to the situation with a constant value for long periods of the year (8 months). The advantage of the proposed methodology is that the variability of ecological flows does not depend on seasonal periods, but takes into account the hydrological regime of tributary flows. Thus, during the period of low water (usually associated with the July–February period by the existing methodology), periods of medium, high or even floods can be recorded, so instead of ensuring a constant value during this period, a variable flow depending on the tributary flow according to hydrological regimes.

Figure 2 shows the flow chart of the proposed methodology for determining ecological flows.

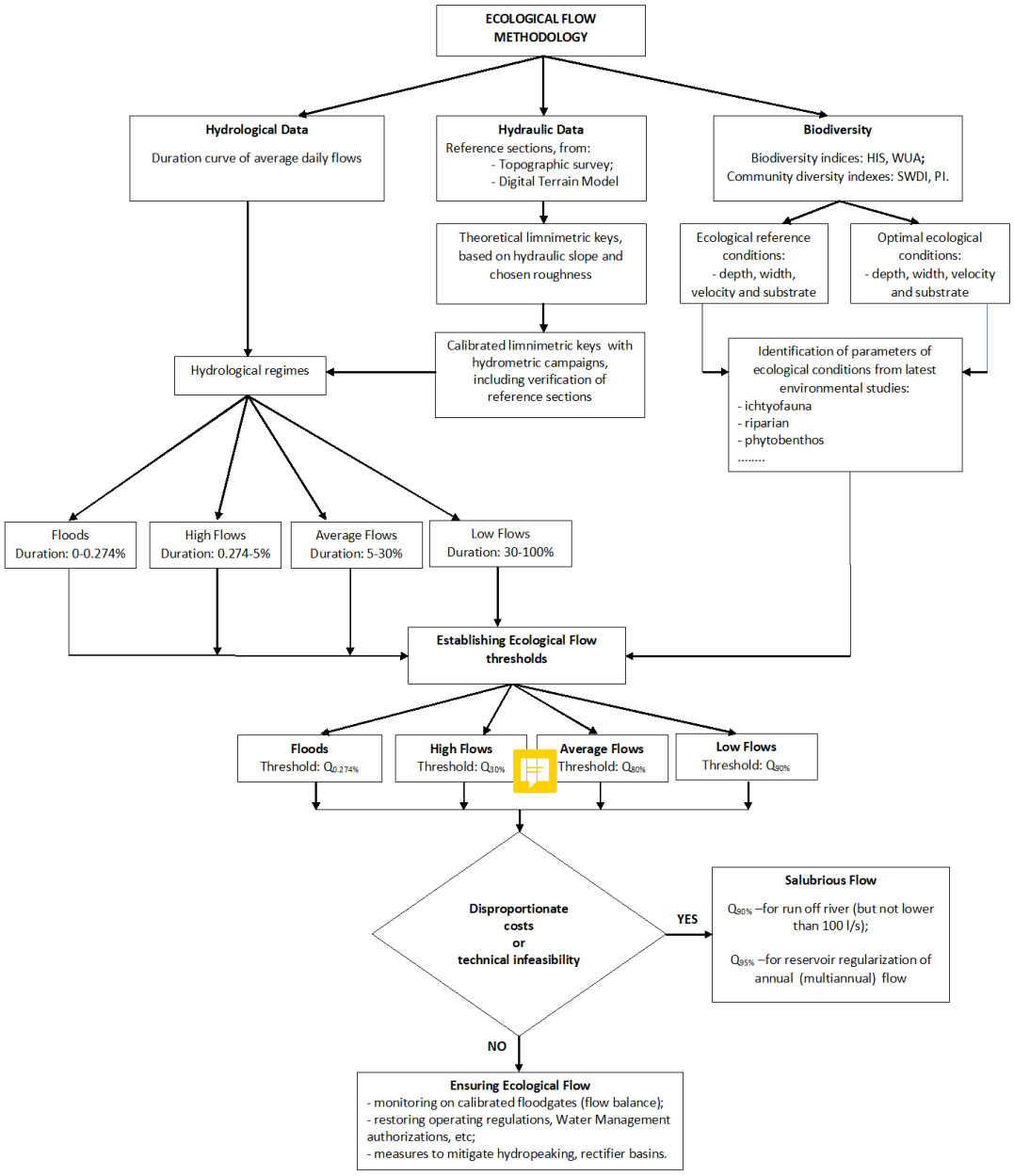


Figure 2. The flowchart of the ecological flow calculation.

where HIS represent the Habitat Suitability Index; WUA is the Weighted Usable Area index [31–35] and SWDI is the Shannon–Wiener diversity index [36–38]; PI represent the Pielou index [36–39].

The proposed methodology uses the duration curve of average daily flows, from the last 30 years, under natural conditions. The principle behind the choice of average daily flows is that it describes more accurately the hydrological characteristics of the body of water. The variation with daily frequency of flow is also important for biological processes because native aquatic and riparian biota are adapted to this variability.

The methodology was carried out using the holistic method (hydrological–hydraulic–biological) but with the establishment of thresholds, duration and flows, correlated with the annual hydrological regime. The analysis was based on rivers with varied catchment areas and physical–geographic characteristics, as well as biological characteristics from updated environmental studies.

Hydrological data are based on the chronological series of average daily flows transformed into duration curves of average daily flows expressed in modulo flows ($k = Q_{day}/Q_m$).

Figure 3 shows part of the analyzed duration curves characteristic of some watercourses with varied morphometric elements.

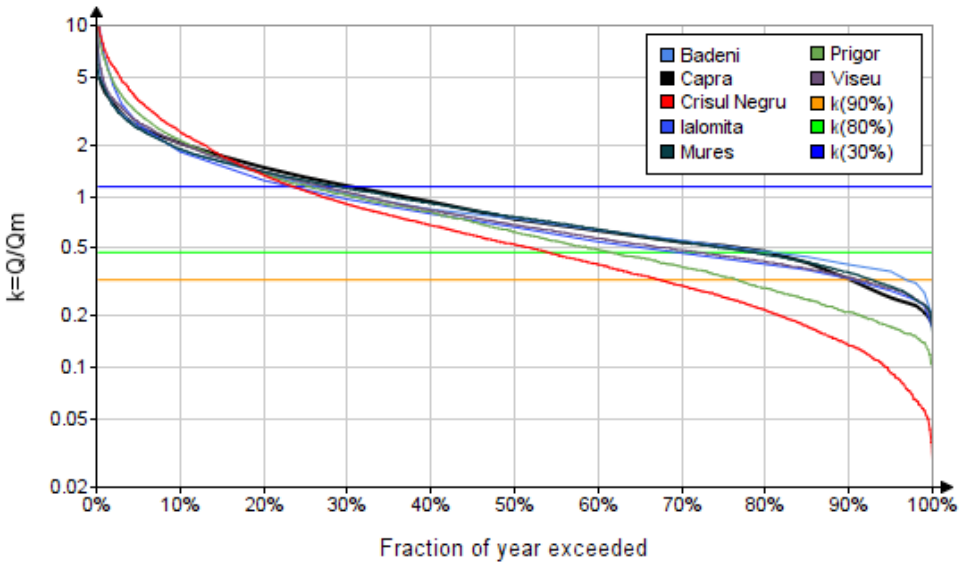


Figure 3. The different Duration curves of daily flow.

Table 1 shows the morphometric elements of the rivers shown in Figure 3.

Table 1. The morphometric characteristics of the analysed rivers.

River	Watershed area (F_{BH})	Average altitude (H_m)	Multiannual average flow (Q_m)
	[km²]	[m]	[m³/s]
Viseu	1555	1020	34.6
Crisul Negru	3750	351	30.3
Mures	27056	618	186
Capra	79.4	1625	2.72
Prigor	141	729	1.71
Badeni	27.6	1438	0.455
Ialomita	6233	494	33.8

Based on the analyzed duration curves, the characteristic durations of the hydrological regimes specific to Romania were established, namely the regime of small waters, medium waters, large waters and floods.

The duration of the low water regime was established as being in the range of durations with a probability of 30%−100%. The 30% limit was established taking into account that the values of the multiannual average flow are in the range of 25%−35%, on the duration curves of the daily average flows, choosing the duration of 30%, which represents the middle of the range.

The duration of the average water regime was established as being in the range of durations with a probability of 5%−30%. The choice of the threshold with a duration of 5% was made on the grounds that it generally corresponds to a value of three times the average multiannual flow, considered characteristic of periods of high water [40−42].

The duration of the high water and flood regime was determined to be characteristic of the duration with probability < 5%. The duration of high waters is characterized by high flows with relatively long periods, and the duration of floods is characterized by very high waters with relatively short periods. Thus, it was necessary to impose a duration threshold delimiting these two sub−regimes. The threshold was set as the duration with the probability of 0.274%. This, following the research carried out within the Faculty of Hydrotechnics regarding the improvement of the norm for the delimitation of the minor bed, corresponds to the duration of the bankfull discharge, this being the main hydrological component for the lateral connectivity of water bodies. Thus, the duration of the high−water regime is between the thresholds of 0.275−5%, respectively the flood regime with the duration < 0.274%.

For reference sections for biological and hydromorphological processes, hydraulic data are determined and consist of cross sections with hydraulic slope and associated roughness. Based on these, limnimetric keys are made which are later calibrated following hydrometric measurement campaigns. The 2D modeling results, i.e., water flow depths and velocities for each flow threshold value, were correlated with habitat suitability criteria [43].

For the synthesis of the hydromorphological results, correlations with linearizable power functions (Leopold and Maddock) were used in the technical reports for the synthetic characteristics of the minor bed (width B, average depth H, velocity V) [44−46].

$$B(Q) = a \times Q^b \tag{1}$$

$$H(Q) = c \times Q^f \tag{2}$$

$$V(Q) = k \times Q^m \tag{3}$$

The relations are logarithmized for linearization, thus the coefficients a, c, k and the exponents b, f, m are obtained by the method of least squares with the flow and depth vectors as calibration data, with the condition that the product of the coefficients is one, respectively the sum of the exponents to be one. The depth function of flow is thus more simply defined for the water depth range from thalweg to bankfull. The coefficients a, c and k depend on the roughness of the bed and the hydraulic slope of the river, and the exponents b, f and m depend on the shape of the bed.

Another solution is to use numerical computation using the inverse of the function defining Chezy's relation, which requires iterative numerical computation.

The proposed methodology focuses on ensuring optimal conditions for biodiversity, also reflected by the hydromorphological indicators that represent a data centralization solution for decision−making.

Biodiversity is the most important characteristic of water bodies. Reference ecological conditions (depth, width, speed and temperature) and optimal ecological conditions are defined according to recent ichthyofauna and environmental studies. The parameters of the ecological conditions are chosen based on the updated mandatory environmental

studies (Ichthyofauna, riparian, phytobenthos, etc.) for the reference sections of the reference water bodies established following the analysis.

Following the multi−criterial analysis (hydrological, hydraulic and biodiversity), the ecological flow thresholds associated with the four hydrological regimes are established. Natural hydrological regimes are modified by flow sampling affecting river lengths. Thus, the proposed methodology optimizes the water requirement for uses with the water requirement for ensuring biodiversity. The modified hydrological regime will not in reality approach in terms of durations and magnitudes of the flows of the natural hydrological regime, but it will preserve for shorter durations the important characteristics of the natural hydrological regime. In the proposed methodology, four duration intervals are defined for the duration curve of average daily flows for the hydrological regimes of deficit waters, medium waters, high waters and floods.

Thus, for the hydrological regime of small waters, the ecological flow threshold corresponding to the probability of exceeding was chosen $Q_{90\%}$ from the curve of the duration of average daily flows. This has a constant value during the hydrological regime of small waters (30%−100%). The choice of the flow threshold took into account the values of the hydromorphological indicators (depth, width, speed), optimal for biodiversity.

During the hydrological regime of medium waters, the value of the ecological flow corresponds to the flow with the $Q_{80\%}$ probability from the duration curve of average daily flows. This flow has a constant value throughout the period characteristic of the hydrological regime of medium waters (5%−30%). In establishing it, the particularities of the biodiversity component were taken into account, especially the reproduction period of the ichthyofauna. This period was established based on updated environmental studies. It should be noted that during this period a compromise is made between water management and biodiversity, so instead of a flow close in magnitude to the average flow, a flow with a value of approximately 30% is accepted Q_m.

The hydrological regime of large waters is characterized by an ecological flow corresponding to the flow with the probability of 30% from the duration curve of average daily flows ($Q_{30\%}$). This value is constantly ensured throughout the hydrological regime of large waters (0.274%−5%). The value of the ecological flow is approximately Q_m, so below the characteristic values of the hydrological regime of large waters that vary from Q_m to approximately $3 \times Q_m$.

Regarding the hydrological regime characteristic of floods, the discharge threshold was established as the bankfull discharge value. Following the researches within the Faculty of Hydrotechnics, in which it is desired to improve the existing regulations for the delimitation of the minor river, bankfull discharge corresponds to the discharge with the probability of $Q_{0.274\%}$ from the duration curve of the average daily discharges.

Thus, during the period of hydrological drought, it is prohibited to take the flow, this corresponds to a related flow threshold value lasting 90% of the Flow Duration Curve (FDC), and the period of high water for the reservoir (Large Dams) is improved by controlled discharges at characteristic flows minor beds.

The application of the values of ecological flows must take into account the provisions and recommendations of the specific European legislation, regarding the disproportionality of costs and technical infeasibility [1,13].

The Romanian legislation [13] provides that, if, following the analysis of disproportionate costs, the ecological flows are not implemented, the initial regulatory conditions are kept, namely the maintenance of the healthy $Q_{95\%}$ flow.

It is thus necessary to introduce an additional condition, namely that, if following the calculations of disproportionate costs, the implementation of the ecological flow is not possible, the step−by−step increase of the healthy flow to $Q_{90\%}$ for run off river and $Q_{95\%}$ for reservoir regularization of annual (multiannual) flow. In the case of run off river power plants with or without pondage, during the period of high−water flows and floods they

discharge, thus implicitly ensuring the flow of high water without restrictions. The phased application involved the assumption by the whole society of increasing the efficiency of water use and thus reducing its consumption in favor of increasing river flows. This can be done through successive stages over the 6−year periods of the water management plans of increasing flows by $1\% \times Q_m$ every 6 years, thus reaching the proposed values in a 30−year period.

Additional measures will be imposed to reduce hydropeaking by building rectifier basins or abandoning the operation of the weightage.

The monitoring necessary for the implementation of the ecological flow will be carried out with the help of limnimetric keys in the upstream and downstream sections of the water intakes or even through the limnimetric keys of the catchments. The identification of the hydrological regimes is done by the readings on the calibrated limnimetric keys in the upstream sections, and the ecological discharge corresponding to the hydrological regime will be ensured by checks on the calibrated limnimetric keys in the downstream section. Currently, daily readings are taken per meter and flow balance to ensure healthy flow for all water uses, so the procedure for ensuring and monitoring ecological flow is easy to implement.

3. Case Study

The Uz River is the right tributary of the Trotus River, from the hydrographic basin of the Siret River (cadastral code XII).

It is located in the eastern part of Romania, on the territory of Harghita and Bacau counties, between the geographical coordinates 46°19'39.0"N 26°02'51.2"E and 46°21'55.5"N 26°30'54.4"E (Figure 4).

The Uz River has a length of 50 km, a watershed area of 469 km², an average altitude of 972 m, an average slope of 17‰, a sinuosity coefficient of 1.26.

As main tributaries we find Başca (cadastral code XII −1.69.22.3) and Bârzăuţa (cadastral code XII −1.69.22.5), both right tributaries [47].

As protected sites, we find the site ROSCI0327 Nemira−Lapos.

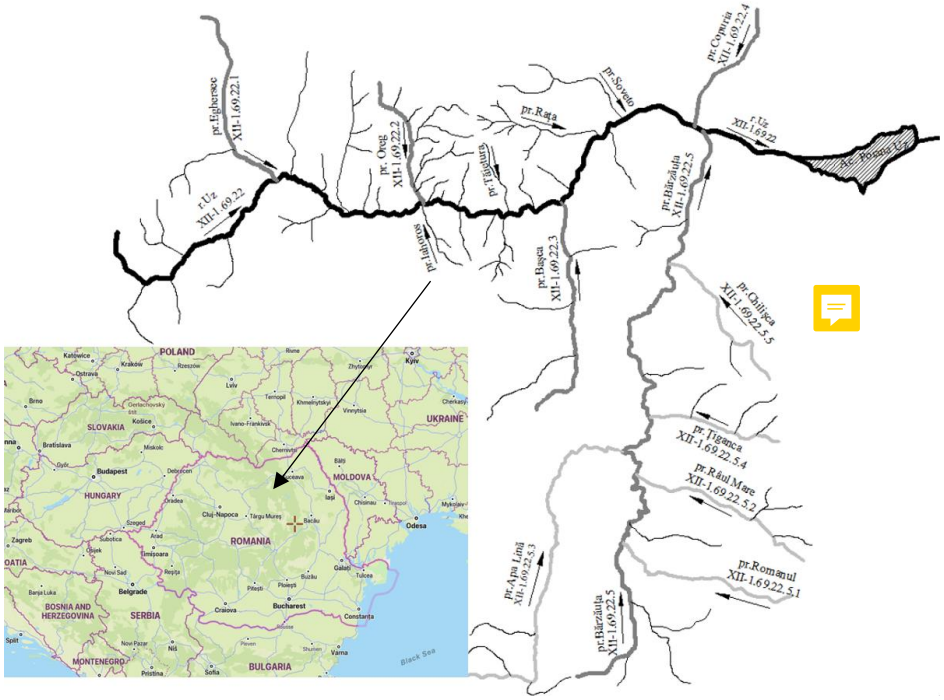


Figure 4. The location of the Uz watershed and stream networks.

On the site of the Uz river and its two main tributaries, a hydropower facility consisting of 5 Tyrolean−type water catchments and 6 small hydro power plants is provided.

Immediately upstream of the confluence with the Trotus river, we find the Uz Valley gravity dam, with a height of 84 m and a reservoir of 98 million cubic meters, having as water uses the supply of drinking and industrial water, including the supply of a small hydropower plant.

The main morphometric characteristics of the river are presented in Table 2 [48].

Table 2. The morphometric characteristics.

River	Length [km]	Average slope [‰]	Sinuosity coefficient [–]	Average altitude, [m]	Watershed area, [km²]
Uz	50	17	1.26	972	469
Oreg	6	29	1.3	1124	12
Başca	10	27	1.32	1123	25
Copuria	6	113	1.12	1001	10
Bârzăuţa	26	22	1.31	1091	156
Apa Lina	15	17	1.22	1030	48

In the location, the zonal relationship for calculating the average specific flow as a function of the average altitude is given by the relationship: $q_m = 5.382 \times 10^{-5} \times H_m^{1.753}$.

The duration curve of average daily flows was obtained from the time series of average daily flows at the Uz Valley reference hydrometric station, for a period of 40 years. From the duration curve expressed in flow rate, the ecological flow values corresponding to the four hydrological regimes were obtained.

Table 3 presents the threshold values of the ecological flows corresponding to the hydrological regimes.

Table 3. The Threshold values of ecological flows.

Flows from the duration curve of average daily flows			
$k_{0.274\%}$	$k_{30\%}$	$k_{80\%}$	$k_{90\%}$
9.37	1.01	0.297	0.207

From the point of view of the Romanian legislation regarding river typology, the Uz river belongs to the RO01 typology, being part of the mountain typological class. According to this typology, the fish species that should be found in the location are brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*) and chub (*Squalius cephalus*). But in reality the ichthyofauna of the site is represented by the bullhead (*Cottus gobio*), Petenyi's barbel (*Barbus petenyi*), brown trout (*Salmo trutta*), minnow (*Phoxinus phoxinus*) and stone loach (*Barbatula barbatula*). Among these species, 2 species are protected at European level (*Cottus gobio, Barbus petenyi*). *Cottus gobio* has protection status according to [48,49]. *Barbus petenyi* has protection status according to [48,49,51].

Figure 5 shows the five species of fish found in the site; information obtained in 10 years of specialized studies [52].



(a) Cottus gobio.



(b) Salmo trutta.



(c) Phoxinus phoxinus.



(d) Barbatula barbatula.



(e) Barbus petenyi

Figure 5. The existing species in the site.

Regarding the critical periods characteristic of these species, they are highlighted in table 4.

Table 4. Critical periods of fish species found in the site.

Species name	Breeding period											
	months of the year											
	1	2	3	4	5	6	7	8	9	10	11	12
Cottus gobio												
Barbus petenyi												
Salmo trutta												
Phoxinus phoxinus												
Barbatula barbatula												

On the site of the Uz river and its two main tributaries, a hydropower facility consisting of 5 Tyrolean−water intake and 6 small hydro power plants is provided.

The maximum height of the water intake is 1.45 m, all sections being provided with fish ladders for ichthyofauna with increased mobility (*Barbus petenyi, Salmo trutta, Phoxinus phoxinus, Barbatula barbatula*) and lateral passages specially designed to ensure optimal conditions for sedentary ichthyofauna with low mobility such as *Cottus gobio*.

4. Results

To observe the differences regarding the ecological flow calculated by the new methodology and the existing methodology [13], the river Uz was chosen, which has a run−of−river hydropower arrangement with five water intakes and 6 small hydro power plants (SHPP), which represents a model of good practices regarding reducing the impact on the environment.

Thus, at the initiative of the ichthyofauna specialists [53,54], with the beneficiary's help, alternative passages to the fish ladders were made to ensure the mobility of sedentary fish species.

The existing enviromental flows (salubrious flow) until 2023 represented 21%–26% of Q_m, which were constantly ensured, regardless of the hydrological regime.

According to the legislation in force, for the July–February period, the ecological flow is constant and represents 13% of Q_m, practically half of the salubrious one. This is a consequence of inadvertently choosing the ecological flow value as the maximum of two values from two different data sets, namely the minimum annual average monthly flow with 95% excess probability and the lowest value of the monthly ecological flows, which represents a fraction of the average monthly flows.

For the forecast of average monthly flows below 80%, in the March–June period the ecological flow is 28.5% of Q_m. This period was established on the basis of non–updated ichthyofauna studies [55] as the breeding period of the potential fish fauna.

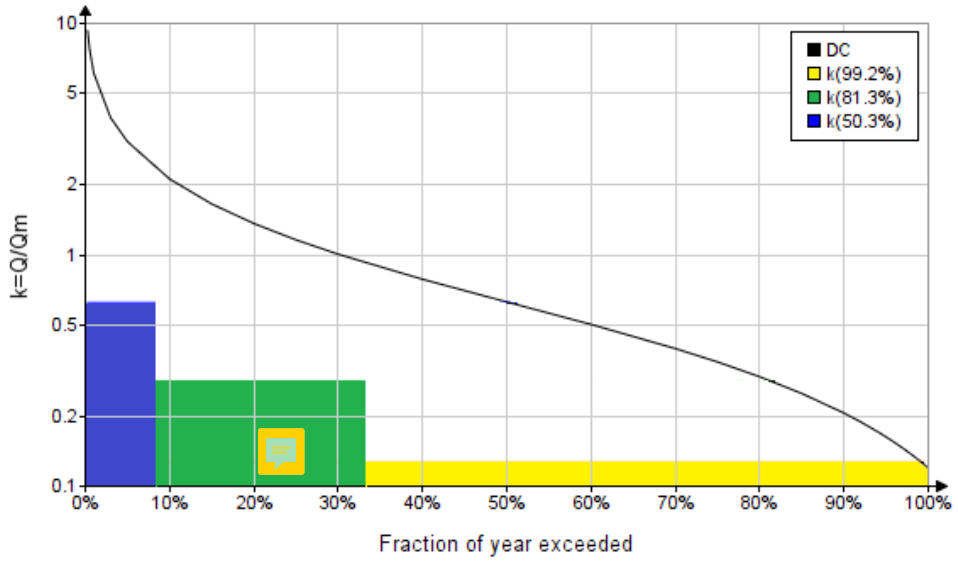
In the INHGA studies, it is wrongly stated that the fish fauna is represented only by brown trout, grayling and chub species. In reality this is represented by *Cottus gobio*, *Barbus petenyi*, *Salmo trutta*, *Phoxinus phoxinus*, *Barbatula barbatula*.

For the forecast of average monthly flows above 80%, the ecological flow increases only for the month of March to 62% of Q_m.

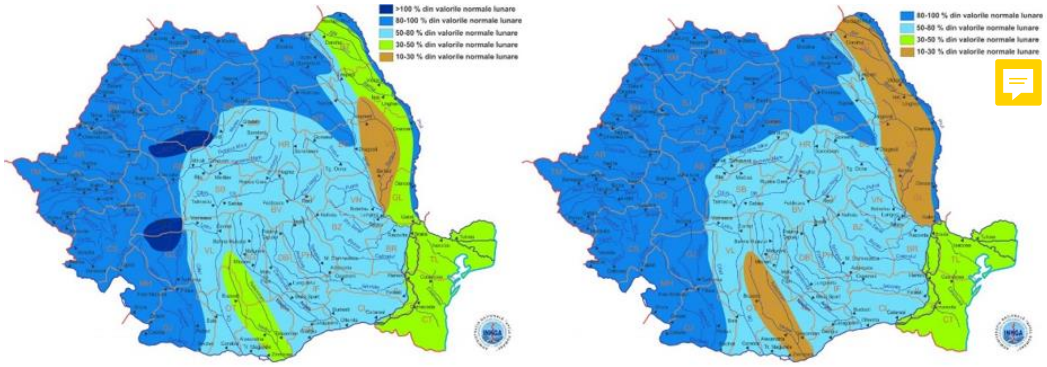
It is observed that regardless of the fact that in the autumn months the hydrological regime is often medium and/or large waters, the flow remains at 13% of Q_m.

A big disadvantage of the methodology [13] is that it does not ensure the variability of the flows depending on the hydrograph, and imposes a seasonal variability with the period of eight months without variability and with lower flows compared to the existing situation, namely lower values than those of the hydrological year normal.

Figure 6 shows the duration curve and a model of forecast maps.



(a) The Duration curve of average daily flows.



(b) The forecast map model.

Figure 6. The Duration curve of average daily flows with the threshold values resulting from HG 148/2020 and a forecast map model.

Table 5 presents the situation of ecological flows according to HG148 [13].

Table 5. Ecological flows according to HG148.

Class of forecast	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
>100%			0.29	0.62	0.29				0.13			
80-100%												
50-80%												
30-80%												
<30%												

The proposed methodology imitates the natural hydrograph in certain periods, resulting in variable flows depending on the hydrological regime, thus eliminating the shortcomings of the existing methodology, which has ecological flows with fixed monthly thresholds.

The value of the ecological flow for the hydrological regime of low waters is 21% of Q_m, compared to 13% of the existing methodology.

The value of the ecological flow for the hydrological regime of medium waters is 30% of Q_m, noting that this value will also be found in the July−February period.

For the hydrological regime of high waters, the value of the ecological flow is a value close to the multiannual average flow, and for the period in which floods are recorded, the ecological flow is approximately 9.4 of Q_m, thus ensuring the lateral connectivity.

Figure 7 shows the graphic representation of the duration curve of average daily flows with the highlighting of the ecological flow threshold values for the four duration intervals characteristic of hydrological regimes in natural regime.

A shift of the duration curve is observed from the 90% duration with lower values to also ensure water uses, but with much higher values also in important periods compared to the existing methodology.

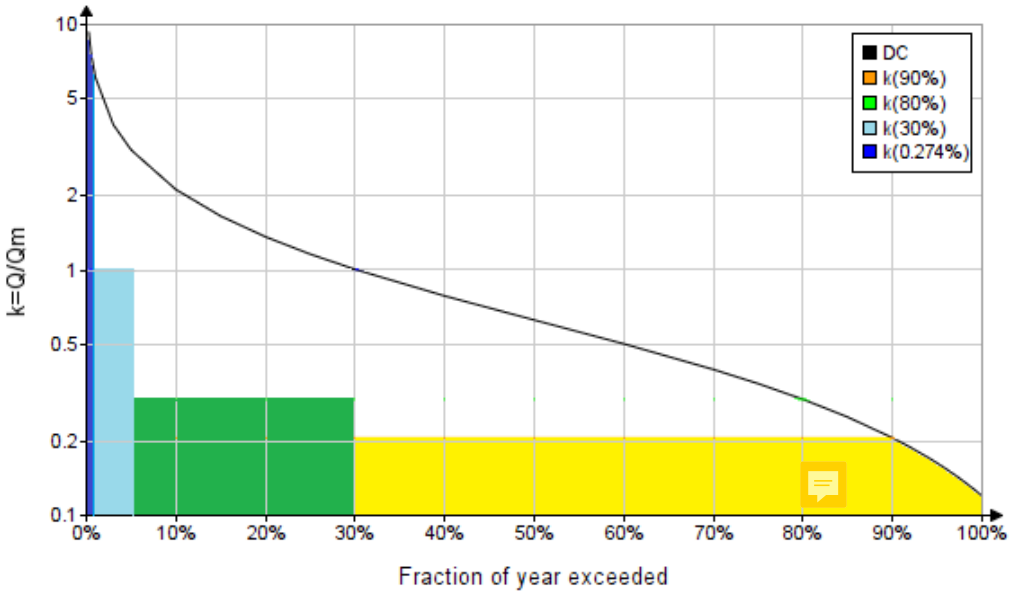


Figure 7. The duration curve and threshold values for the proposed methodology.

The proposed methodology analyzes daily flows (inflow) through monitoring and thus establishes daily flow variations, imitating nature, if necessary, especially for periods of high water and floods, where the most frequent changes are.

Figure 8 shows a simulation of ecological flows for the year 2018 using the existing method and the proposed method.

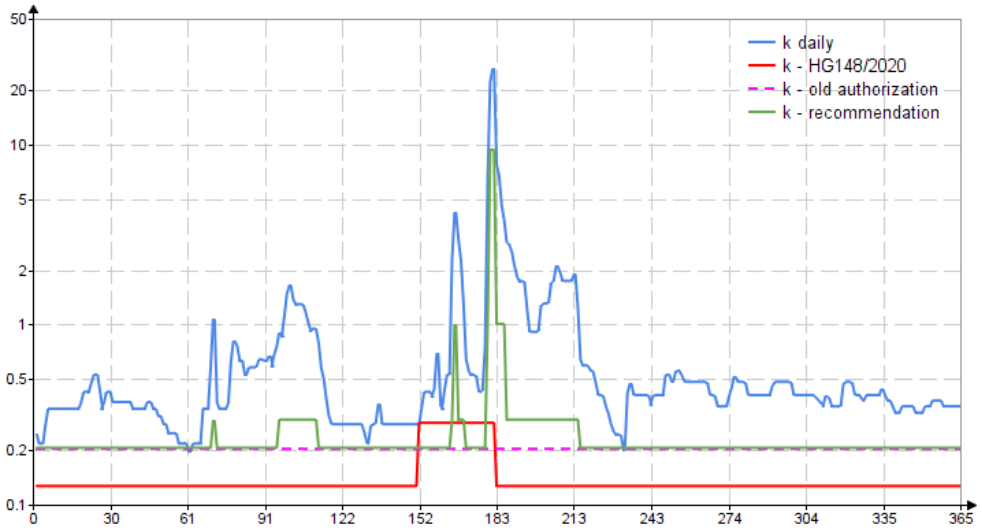


Figure 8. The time series of the module of average daily flows and the resulting values for the ecological flows of the presented methodologies.

The returned volumes downstream of captures are 18% of the 2018 stock for the old methodology, and the returned volume for the new methodology is 37%.

Compared to the multi−year average stock for the old methodology, the returned volumes are 14% and for the new methodology they are 29%.

In the case of a salubrious flow, the returned volume from the average multi−year stock would have been 21%.

5. Discussions

The implementation of ecological flow in Romania could have been a response to infringement cause no. 2015/4036 − water − micro−hydropower plants in Romania [56] regarding the incorrect application of [2] and [38], in the approval process of micro−hydropower plants in Romania.

The methodology described in HG 148/2020 [13] represents one step forward and two steps back, being only an opportunistic approach to an important topic in water management with "zero" environmental contributions. This does not improve the ecological status of water bodies. Before 2020, the salubrious flow (Q_{sal}) was used in Romania, with a constant value, which was defined as the flow with the probability of exceeding 95% of the duration curve of average daily flows ($Q_{95\%}$). The ecological flow (Q_{ec}) according to HG 148 [13] is a variable flow with three values depending on the hydrological regime and the hydrological forecast. The characteristic value of the hydrological regime of low waters, for 8 months of the year, is generally much lower than the salubrious flow value. This aspect represents a real threat to the good ecological condition of water bodies, including hydromorphological indicators. The most important criticism is the reduction of flows for a very long period of at least eight months a year, especially for rivers in natural protection areas. The advantage of increasing the flow values in 2−4 months per year depending on the hydrological forecast is non−existent for run of the river facilities.

An example of the analysis was the situation of several sites ROSCI0122 Făgăraș Mountains, Crișul Negru, etc., designated for the conservation of *Romanogobio uranoscopus*, which has the reproduction period from May to June [55], or *Barbus petenyi* and *Sabanejewia balcanica*, which have the reproduction period in the months of May −August [55]. In the eight−month period of the existing regulation, the reduction of flows for a long duration of the reproduction periods, but also of the pre−development periods, represent the conditions for moving to a high probability of extinction. Existing legislation considers only part of the reproductive period as critical, completely ignoring the larval period.

Table 6 presents a situation, on a number of 10 rivers, of the ecological discharge compared to the salubrious one.

Table 6. Ecological flows vs. salubrious flow.

River/Section	Stereo 70 coordinates		Q_{sal}	Q_{ec}	Relative decrease
	X	Y	[m³/s]	[m³/s]	[%]
Uz, S1	588177	535287	0.187	0.100	47
Uz, S2	591789	535387	0.250	0.131	48
Baska	594435	533770	0.055	0.034	38
Uz, S4	594186	535746	0.351	0.183	48
Uz, S5	596901	538721	0.457	0.220	52
Barzauta	598123	533676	0.375	0.211	44
Vistea	467134	480336	0.202	0.107	47
Sâmbăta	483838	460648	0.138	0.058	58
Vișișoara	481882	461806	0.078	0.036	56
Porumbacu	462540	457880	0.152	0.122	20
Călinești	441401	433684	0.152	0.113	26
Taia	375799	447525	0.114	0.098	14
Ausel	377447	448071	0.251	0.189	25

It is possible to observe a decrease in the flow's characteristic of the hydrological regime of low waters (8 months of the year), this being the most vulnerable period for biodiversity.

Moreover, government authorities that prepare ecological flow studies, prepare studies that approve new water−consuming and polluting uses (intensive fish farming), thus increasing the degree of deterioration of rivers in areas already affected by other uses.

The methodology proposed in this article uses updated environmental studies, requested by the governmental environmental agencies in Romania. Reporting to the duration curve of average daily flows was chosen as the implementation method, so it is easy to apply and understand by water users. The methodology proposes a phasing of the increase in salubrious flows for those who claim disproportionate costs.

The proposed methodology has the advantage that it is variable for wet year, normal year and dry year, compared to the existing methodology that does not differentiate between wet year and normal year.

Lateral connectivity is ensured by imposing a flow rate greater than bankfull discharge, compared to the existing methodology that does not foresee downstream flows higher than 0.7 of Q_m, resulting in downstream river sectors of water accumulations with annual and multiannual regularization to be condemned to a perpetual regime of law waters, well below the multiannual average flow.

5. Conclusions

The existing methodology regarding the determination of ecological flows in Romania is based only on hydrological methods, representing a regression compared to the situation before its appearance, not bringing a real improvement of water bodies, especially those located in natural protected areas.

The methodology proposed in this article represents a holistic approach, based on a complete and complex analysis and research carried out in the Faculty of Hydrotechnics regarding the development of a regulation to replace the existing legislation for determining the ecological flows on water courses in Romania.

In this article, the methodology was applied, compared to the existing methodology, on the Uz river, which is arranged (from upstream to downstream) with six small hydropower plants in the cascade, as well as with the dam and the reservoir Uz Valley.

The main conclusions are summarized as follows.

(1) The proposed methodology has a holistic approach, the calculation methods presented are simple, concise and unambiguous.
(2) From the point of view of the hydrological component, the methodology respects and ensures the natural variability of flows, being characterized by four hydrological regimes: floods, high waters, medium waters and law waters. The methodology uses the duration curve of average daily flows, which has a higher degree of confidence than the duration curve of average monthly flows, regarding the hydrological regime on the rivers.
(3) The biodiversity component is of particular importance, in the development and application of the methodology, taking into account both the potential and the capacity to sustain biodiversity, as well as the existing and regularly conducted environmental studies for the majority of rivers in Romania, which clearly highlight the real situation of biodiversity on the rivers and the mandatory measures to support it.
(4) The application and monitoring of ecological flows is done in real time depending on the hydrological regime, based on the limnimetric keys, calibrated with hydrometric measurement campaigns, of the hydrotechnical constructions evacuators.
(5) The opportunity to apply ecological charges is made following the analysis of disproportionate costs, thus taking into account the recommendations of the European Guide No. 31. If the analysis results in disproportionate costs (thus maintaining the salubrious flow), the methodology proposed in this article provides for increasing the salubrious flow from $Q_{95\%}$ to $Q_{90\%}$ (but not less than

100 l/s) for the run of river, and for the reservoir regularization of annual and multiannual flow, the salubrious flow will still be increased to $Q_{95\%}$. These increases will be made once every 6 years with 1% of the multi−year average flow until the target values are reached.

(6) (6) Additional measures are required to reduce hydropeaking by creating rectifier basins or abandoning the exploitation of weightage. This is a measure specific to the hydropower sector.

Author Contributions: Conceptualization, C.I. and C.G.A.; methodology, C.I. and C.G.A.; software, C.I. and C.G.A.; validation, C.I. and C.G.A.; formal analysis, C.I. and C.G.A.; investigation, C.I. and C.G.A.; resources, C.I. and C.G.A.; data curation, C.I. and C.G.A.; writing—original draft preparation, C.I. and C.G.A.; writing—review and editing, C.I. and C.G.A.; visualization, C.I. and C.G.A.; supervision, C.I. and C.G.A.; project administration, C.I. and C.G.A.; funding acquisition, C.I. and C.G.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

HG (in Romanian)	Government Decision
Q_m	multiannual average flow
$Q_{p\%}$	flow with exceedance probability of p%
$Q_{mam95\%-}$	minimum annual average monthly flow with 95% exceedance probability
Q_{day}	average daily flow
Q_{sal}	salubrious flow
Q_{ec}	ecological flow
INHGA	National Institute of Water Management
HIS	Habitat Suitability Index
WUA	Weighted Usable Area Index
SWDI	Shannon−Wiener diversity Index
PI	Pielou Index
F_{BH}	Watershed Area
H_m	Average Altitude
FDC	Flow Duration Curve
SHPP	Small Hydro Power Plant
l/s	liters per second
m^3/s	cubic meters per second

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