

Article

Definition of the Ecological Flow (Eflow) using the Indicators of Hydrological Alteration and IARI as an operative tool for water management

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Abstract: According to the Water Framework Directive, the Ecological Flow (Eflow) is assumed to be the minimum water discharge required to achieve and maintain the environmental objectives of “good quality status” in a natural water body. It is highly recognized that, the hydrological regime of natural flow plays a primary and crucial role influencing the physical conditions of habitats, which in turn determines the biotic composition and sustainability of aquatic ecosystems. Furthermore, the simple assumption to supply a minimum instream during dry periods is not enough any longer in order to protect the river environment. The recent hydro-ecological understanding states that all flow components might be considered as operational targets for water management, starting from base flows (including low flows) to high and flood regimes in terms of magnitude, frequency, duration, timing and rate of change. Several codes have been developed and applied on different case studies in order to define common tools to be implemented for the Eflow assessment. The study proposes the application of the Indicators of Hydrologic Alteration methodology (IHA by TNC) coupled to the valuation of the Index of Hydrological Regime Alteration (IARI by ISPRA) as an operative tool to define the ecological flow in each monitoring cross section to support the sustainable water resources management and planning. The case study of Agri River, in Basilicata (Southern Italy) is presented. The analyses have been carried out on monthly discharge data derived applying the HEC-Hydrological Modelling System at the basin scale using the daily rain data measurements obtained by the regional rainfall gauge stations and calibrated through the observed inlet water discharge registered at the Lago del Pertusillo reservoir station.

Keywords: Ecological flow, Indicators of Hydrologic Alteration, Index of Hydrological Regime Alteration, HEC-HMS,

1. Introduction

The recent evolution of the European and national regulatory framework, as well as the obligation to adapt and achieve the requirement of good quality in water bodies imposed by the Water Framework Directive (WFD 2000/60/EC) [1] needs the definition of the Ecological Flow (Eflow). The Eflow represents the amount, quality and timing, of water discharge required to sustain riparian and estuarine ecosystems as well as the human livelihoods and well-being depending on these [2]. Ecological flow can be defined as the minimum value of the discharge to be maintained in the river to ensure good (better optimum) conditions for the existing ecosystems; according to appropriate criterion based on the hydrological and environmental conditions respecting the biological balance.

The knowledge acquired in recent years in the field of hydro-ecology has highlighted the fundamental role of the hydrological river stages and their time variability, from drought up to flood, in relation to the life of river ecosystems in terms of maintenance, development and evolution of habitats, flora and benthos [3 - 8]. Thus, the Eflow might be assumed as the rate of natural discharge that should be left in the water body to maintain high value of water resources and water-related

ecosystems, according to the requirements of environmental protection [9]. Furthermore, the concept of Eflow evolved from the simple idea to determine the minimum water discharge needed for the existence of ecological species [10] to the complex view dealing with the possible implications on river ecosystem management in anthropogenic-stressed basins [11-13]. In other words, Eflow should represent the imposed conditions on river hydrology able to provide appropriate ecological functions under flow regulation restrictions induced by natural and/or anthropogenic stresses [14].

The European and Italian national frameworks to date, unfortunately, still note situations in which the current unavailability of specific measures and monitoring activities, requires the adoption and implementation of a transitional phase in which the "no deterioration" of the quality status of water body must be achieved and guaranteed. This condition might be determined on the basis of scientific methodologies arising from relevant international experiences, as suggested by the European Commission in the guidelines on ecological flow [15].

Several methods are reported in literature which were developed in the field of eco-hydrology for the assessment of ecological flow [16]. In a general overview, these methods can be classified in the three following groups [17-19]:

1 - Hydrological indicators and/or parameters, derived on the analysis of hydrological and hydraulic data arising from the monitoring activities without focusing on specific species or biotic communities.

2 - Habitat assessment and change forecasting, based on the principle that good habitat conditions for several species are the consequence of the interaction among water discharge, riverbed geometry, and vegetation allowing the proper depth/flow velocity ratio necessary for species in various age groups.

3 - Functional analyses through the analysis and understanding of functional relationships between hydrology and river ecosystem.

The methods for Eflow assessment should consider the natural variability of river flow by providing different flow components in order to obtain the best condition of freshwater ecosystems, habitats, and wetland species [20]. Thus, the assessment of minimum life inflow might not be subject only to economic criteria but following the general principles of sustainable development which allows socio-economic growth according to the simultaneous maintenance of natural balance [21-23].

Due to simplicity and straightforward application, hydrological and hydraulic methods are commonly used to compute Eflow, which is assumed depending on the given characteristic discharge observed in the water course. Meanwhile, hydraulic methods are supported by quantitative relationships between natural flows and habitats. These methods consider the effects of water flow variability on the habitat of main fish species referring to their optimal condition for living, reproduction, migration, and feeding.

The geometrical parameters, like wetted perimeter, maximum depth, or aspect ratio are generally used coupled to vertical and cross-sectional flow velocity distribution. Whenever no velocity data are available, expeditive entropy-based models might be used for the assessment of the vertical velocity profile in order to derive local velocity-gradients and, thus, bed shear stress [24, 25]. The hydraulic methods are suggested for use in catchment areas where hydrometric observations are not available, or for controlled cross-sections [26-30]. Furthermore, in the flow-habitat models the ecological flow is calculated from interactions between the water discharge and the riverbed morphology, rather than establishing the suitable habitat conditions corresponding to the local morphological conditions. The IFIM [31-33] is one of the most common methodology used to estimate the environmental flow as well as PHABISM [34, 35], HABIOSIM [36] and RSS [37].

In the present paper, the Indicators of Hydrological Alteration - IHA methodology [38-44] has been used coupled with the Hydrological Regime Alteration Index - IARI [45] in order to define the optimal value of the water discharge flowing in the water body able to warranty the acceptable sustainable water management for ecological integrity.

Furthermore, the rational of the study deals with cascade models starting from a classical rainfall-runoff model, like HEC- Hydrological Modelling System (HEC-HMS) for the assessment of the daily/monthly water discharge flowing in a generic control cross section along the water body, feeding the IHA. Then, in the different timing for the water stage the percentile corresponding to the

minimum discharge is assumed satisfying the boundary condition imposed by the respect of the reference value of the IARI for good status at least. This value is assumed as the Eflow for the corresponding cross section.

2. Materials and Methods

Study area – The Agri River Basin

The proposed analysis has been applied to all of the Lucanian river networks (Basilicata region - Southern Italy) but the present study refers to the case study of Agri River as a suitable example representing all the problems observed on the Lucanian river systems (Fig.1).

In detail, the study area consists of the Agri River basin. Agri River is one of the six major rivers of the Basilicata region, with a drainage basin area over 1715 km² and varying morphology from mountainous and hilly, in the medium-high upstream part, to low hilly and flat, in the downstream portion (Fig. 2).

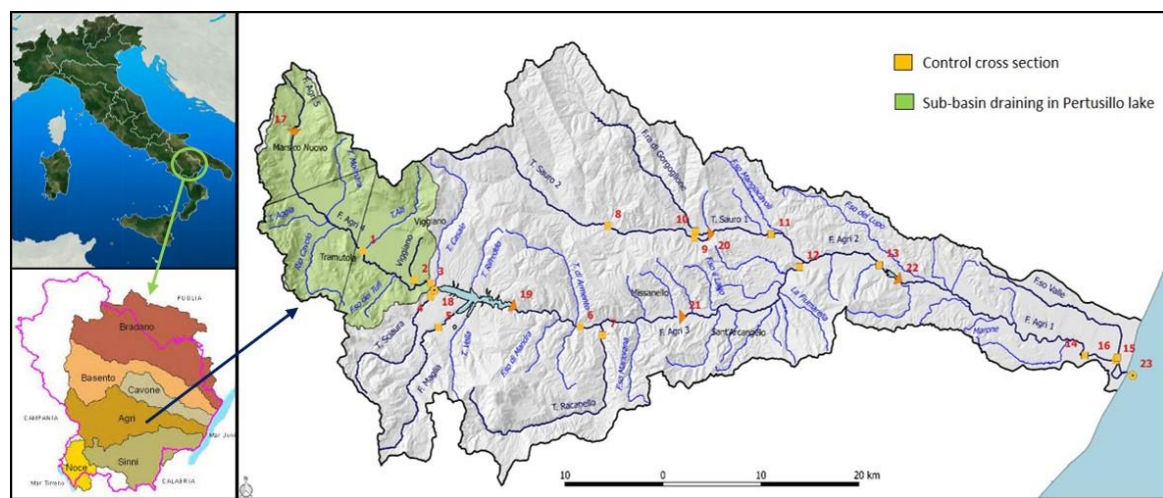


Figure 1 – The Study area of Agri River, the map of control cross section and example of sub-basin

The hydrographic network is substantially ramified, presenting a main stream of about 113 km long, whose mountainous reach with NNW-SSE trend, crossing the intermontane depression of the Alta Val d'Agri and then assuming a fairly regular W-E trend reaching the Ionian coast of Basilicata. The average annual rainfall is quite homogeneous along the basin, following the distributions aligned to the NW-SE ridge with a reference value of about 900 mm/yr (Fig. 3).

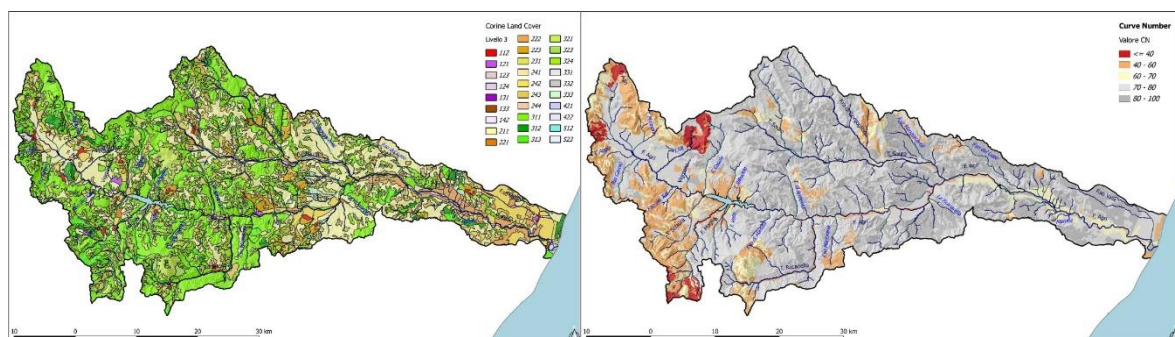


Figure 2 – Corine Land Cover and Curve Number maps of Agri River basin

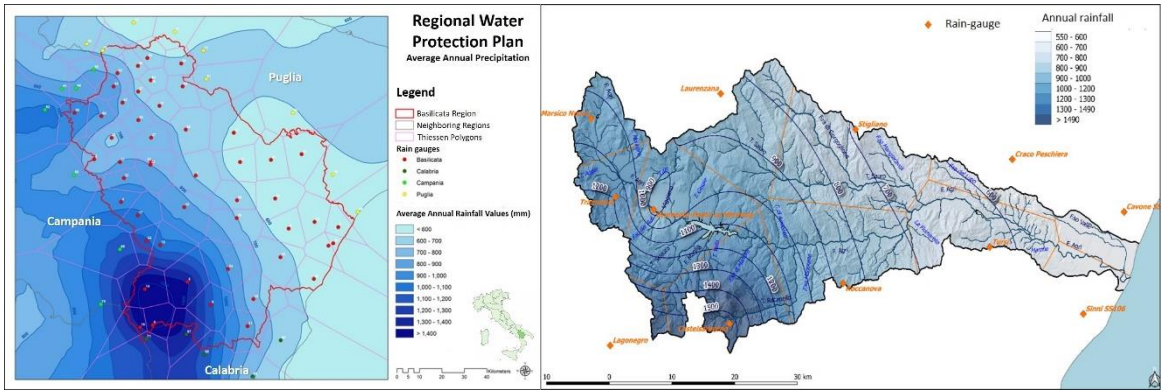


Figure 3 – Rain-gauge network, the average annual regional rainfall and Agri River basin maps

Methodology

The evaluation of the hydrological regime alteration of a watercourse, both in terms of characterization and quantification, is a problem still not fully solved, leaving significant degrees of arbitrariness for decision makers, and depending on direct and indirect assessments of hydrological functional scenarios.

Observing the international background, several methodologies have been developed for evaluating the alteration of the hydrological regime as summarily reported in Table 1 [46].

Table 1. List of international methodologies for hydrological regime alteration.

Method	Acronym	Country	Reference
The Indicators of Hydrologic Alteration	IHA	USA	Richter et al. (1996; 1997) [38, 39]
Indice di Alterazione del Regime Idrologico	IARI	Italy	Ispra (2011) [45]
Dundee Hydrological Regime Alteration Method	DHRAM	Scotland	Black et al. (2005) [47]
Hydrologic Index Tool	HIT	USA	Henriksen et al. (2006) [48]
Hydrology Driver Assessment Index	HAI	South Africa	Kleynhans et al. (2005) [49]
HIDRI- Protocolo 3	QM - HIDRI	Spain	Munné et al. (2006) [50]
Histogram Matching Approach	HAI	Taiwan	Shiau and Wu (2008) [51]
Indices de Alteracion Hidrologica en Rios	IAHRIS	Spain	Martínez Santa-María et al.(2008) [52]

All the procedures mentioned in Table 1, are generally based on the comparison between an undisturbed condition and altered condition, both characterized by the value assumed by several descriptive parameters for different aspects of the hydrological regime.

In particular, ISPRA (2011) [45] proposes the implementation of the combined use of "Indicators of Hydrologic Alteration" (IHA) and the "Hydrological Regime Alteration Index" (IARI), as a useful tool for assessing changes in the hydrological regime of a watercourse induced by anthropogenic pressures such as dams, diversions, hydroelectric plants, or any other type of action affecting the naturalness of the river system [53, 54].

The analysis of the hydrological regime alteration of a watercourse, indeed, might be carried out at a cross-section of the watercourse on the basis of the IARI methodology, which provides a measure of the deviation of the hydrological regime, assessed on a daily or monthly scale, compared to the natural datum corresponding to the absence of any anthropogenic pressure.

Furthermore, the IHA can be calculated using parametric (mean/standard deviation) or non-parametric (percentile) analysis starting from the time series of water discharge. The IHA parameters and their influence on the ecosystem are attributable to five main hydrological groups, HG, [38, 39]:

- Group 1: the monthly condition of the watercourse;

- Group 2: minimum and maximum flow conditions at 3-7-30-90 days, zero flow days and base flow rates;
- Group 3: the extreme conditions of the watercourse and the number of days with the same flow rate;
- Group 4: frequency and duration of high and low impulse flows;
- Group 5: the frequency of variability of the flow rate.

and five different types of environmental flow components, EFC, as following:

- Type 1, Minimum flow rate: represents the dominant condition in most water courses and represents the base flow;
- Type 2, Extreme drought: present during drought periods, with very low levels of flow if not completely zero, to which correspond conditions of particular criticality for some types of organisms and could be a source of life for other species;
- Type 3, High flow rate pulses: include any flow rate increase, such as significant rain periods, which are necessary and important for the relief of ecosystems at minimum flow rates;
- Type 4, Small floods: these promote the mobility of aquatic fauna usually confined to swamps, ponds and shallow wetlands that usually correspond to poorly accessible habitats;
- Type 5, Major floods: which corresponds to a reorganization of the biological and physical structure of a stream.

The entire range of flow conditions represented by the EFC components (globally 33 parameters), must be maintained in order to ensure river ecological integrity.

The IARI is determined from the flow data, by comparing the "altered" flow rates with the corresponding natural flow rates, as indicated by the ISPRA [45] according to the following criteria:

- 1) provide a quantitative measure of the deviation of the observed hydrological regime from the natural one that would occur in the absence of anthropogenic pressures;
- 2) take into account the general and widespread scarcity and/or absence of data;
- 3) be able to use all available hydrological information;
- 4) use tools, methods and results already available from the competent entities that carried out the hydrological and water balance in the water protection plans;
- 5) be easy to implement and calculate with the usual calculation tools.

The procedure has the following characteristics:

- a) is defined at successive levels of in-depth analysis;
- b) is defined primarily on the basis of the monthly average flow rates to take into account the effect of seasonality and to use the results of the water balance of the protection plans;
- c) is defined differently for river sections with or without flow measurement instrumentation;
- d) is derived from the IHA method and the statistics used in the procedure can be easily calculated with the corresponding open-source software IHA.

With regard to the reference values for the IARI, it is useful to point out that, conventionally, the following ranges are adopted:

- $0 \leq \text{IARI} \leq 0.05$ excellent
- $0.05 < \text{IARI} \leq 0.15$ good
- $\text{IARI} > 0.15$ no good

Thus, the procedure for the assessment of the status of the hydrological regime through the determination of the IARI, is divided into three phases (Figure 4):

1. Phase 0 - preliminary analysis: An analysis of the basin-scale pressures shall be carried out in order to identify the detectable conditions in the considered section by selecting one of the following conditions:
 - no or negligible pressure on the hydrological regime, it can be assumed that it is unchanged;
 - significant or not negligible pressures leading to impacts that cannot be assessed a priori, a necessary assessment must be made on an objective basis.
2. Phase 1- calculation of the index: if in Phase 0 the identified conditions do not show the absence of impact on the hydrological regime due to pressure, the quantitative assessment of the alteration is carried out through the calculation of the IARI index.

3. Phase 2- direct evaluation or consultation: this step is accessed whenever the results obtained in Phase 1 reveal critical elements. In such a case, a detailed analysis essentially based on the qualified information given by experts is provided in order to explain the causes and to confirm or not the exposed criticalities.

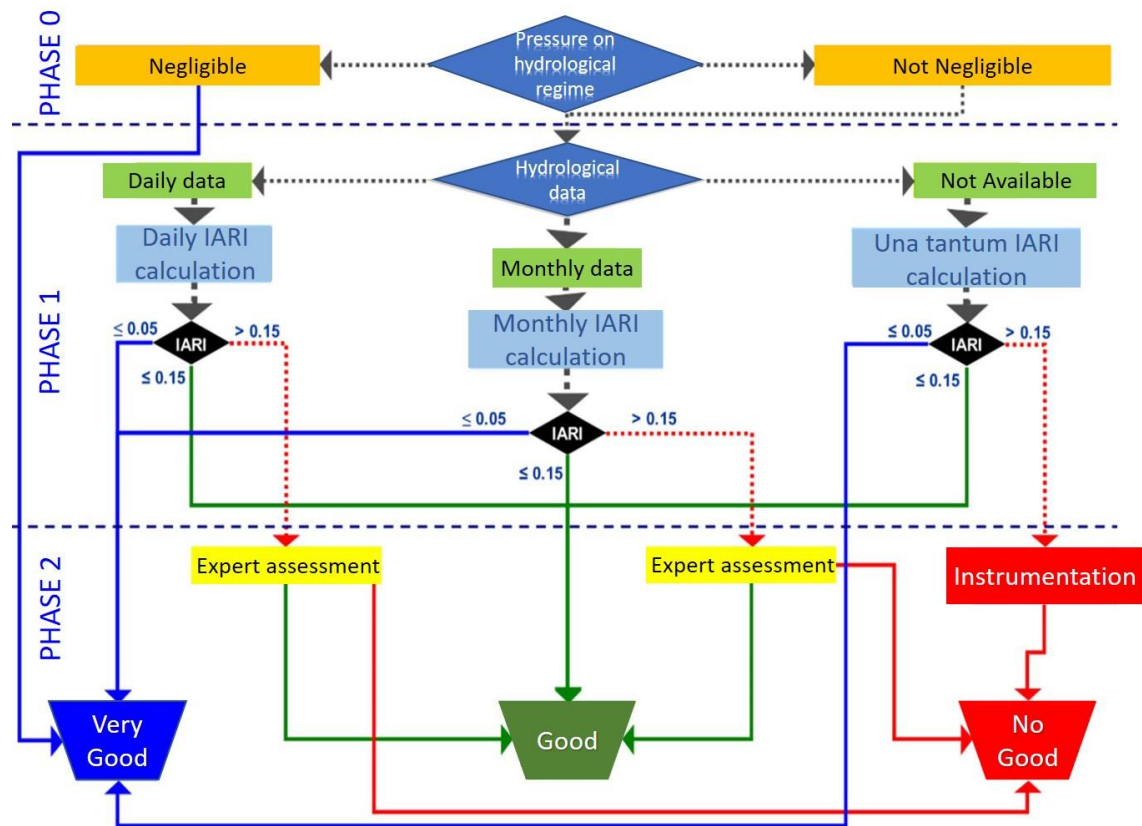


Figure 4 - IARI evaluation procedure (ISPRA, 2011)

In detail in each control cross section, based on the monthly time series relating to the "undisturbed" condition, the 25-th and 75-th percentiles, $X_{N0.25,i}$ and $X_{N0.75,i}$, must be computed per each i -th IHA parameter (i.e the monthly flow discharge)

Subsequently, for each i -th parameter, the characteristic value, $X_{i,k}$, corresponding to k -th reference period in which the altered condition occur, i.e. in the present case corresponds to the value of monthly flow rate assumed as the monthly ecological flow.

Furthermore, through the comparison between the value $X_{i,k}$ and the $X_{N0.25,i}$ and $X_{N0.75,i}$, the term $p_{i,k}$ is calculated according to the procedural scheme reported in the following equation:

$$p_{i,k} = \begin{cases} 0 & \text{if } X_{N0.25,i} \leq X_{i,k} \leq X_{N0.75,i} \\ \min \left(\left| \frac{X_{i,k} - X_{N0.25,i}}{X_{N0.75,i} - X_{N0.25,i}} \right|, \left| \frac{X_{i,k} - X_{N0.75,i}}{X_{N0.75,i} - X_{N0.25,i}} \right| \right) & \text{if } X_{i,k} < X_{N0.25,i} \text{ oppure } X_{i,k} > X_{N0.75,i} \end{cases} \quad (1)$$

where:

- i refers to the i -th IHA parameter;
- k is the reference period;
- $X_{i,k}$ is, the characteristic value of the i -th parameter corresponding to k -th reference period in which the altered condition occur;
- $X_{N0.25,i}$ is the 25-th percentile of the i -th IHA parameter in the natural condition (unaltered condition);
- $X_{N0.75,i}$ is the 75-th percentile of the i -th IHA parameter in the natural condition (unaltered condition).

In other words, if the value of the parameter $X_{i,k}$ falls within the band delimited by the percentiles 25% and 75%, the term $p_{i,k}$ is assumed to be zero, corresponding to a condition of ordinary fluctuation, otherwise it is equal to the minimum distance, normalized on the amplitude of the interval, from the limits of the band. IARI is therefore defined as the average of the values assumed by the terms $p_{i,k}$. In order to identify the groups of elements which have the greatest influence on the alteration of the regime, also to plan any intervention measures, the IARI is estimated for each group and the average was then calculated as reported in the following Eq. 2 based on the number of parameters belonging to the generic group $j=1,2,\dots,5$.

$$IARI_k = \frac{1}{33} \sum_{j=1}^5 n_j \left(\frac{1}{n_j} \sum_{i=1}^{n_j} p_{i,k} \right) = \frac{1}{33} \sum_{i=1}^{33} p_{i,k} \quad (2)$$

In this framework, the Eflow is considered as the hydrological alteration induced in the water body. Thus, the hydrological Eflow arises from the assessment of the levels of acceptability of Indicators of Hydrological Alteration (IHA) and the determination of the Hydrological Regime Alteration Index (IARI), at a generic river cross section.

The methodology, therefore, defines the ecological flow as the i -th percentile of the distribution of the average monthly flows which provides a value of IARI corresponding to a "good" level at least. Whenever, no time series of water discharge are available, and a rain-gauge network is present, a classical catchment rainfall-runoff modelling can be used. In the present study the HEC-Hydrological Model System was employed using a suitable rainfall time series available from the regional civil protection gauge network. The HEC-HMS simulates the complete hydrologic processes of river catchment systems, and includes several traditional hydrologic analyses such as infiltration, unit hydrographs, and hydrologic routing [55 - 57].

Following such an approach, the concept of ecological flow goes far beyond the commonly reductive idea in which the minimum ecological flow rate corresponds to a fixed percentage of the average annual flow rate. The Eflow, indeed, represents the monthly water discharge inducing acceptable alteration on the hydrological regime ensuring the functionality of the water body.

The methodology is immediately spatially scaling and applicable to a generic cross section of any watercourse.

3. Discussion and results

Since the main objective of the above-described procedure is to detect any changes in the hydrological regime induced by the adoption of the Eflow, a crucial aspect is the definition of the reference condition for the hydrological regime corresponding to the "unaltered" condition. Therefore, ISPRA (ISPRA, 2011) suggests that this condition should be identified from a series of daily/monthly flow rates that can be taken as "natural" at least for 15 years, in order to ensure a sufficiently reliable hydrological evaluation.

Omitting the detailed analysis and the numerical aspect of the briefly above mentioned, the proposed methodology has been applied to all the rivers of Basilicata, in order to assess the monthly hydrological Eflow to be guaranteed in each control section identified in the "Plan for monitoring surface water bodies" of the Basilicata Region. The case study of Agri River is discussed further below.

In detail, the following steps are made for the first assessment of the hydrological Eflow (Fig. 5)

1. collection of the hydrological data of the river under investigation: precipitation values observed at the available rain stations and the flow data observed at the measuring sections along the water course (minimum 15 years);
2. hydrological analysis and implementation of the HEC-HMS at the basin scale for the evaluation of regionalization laws and to compute the average flow rates on a fixed time basis (monthly, annual);

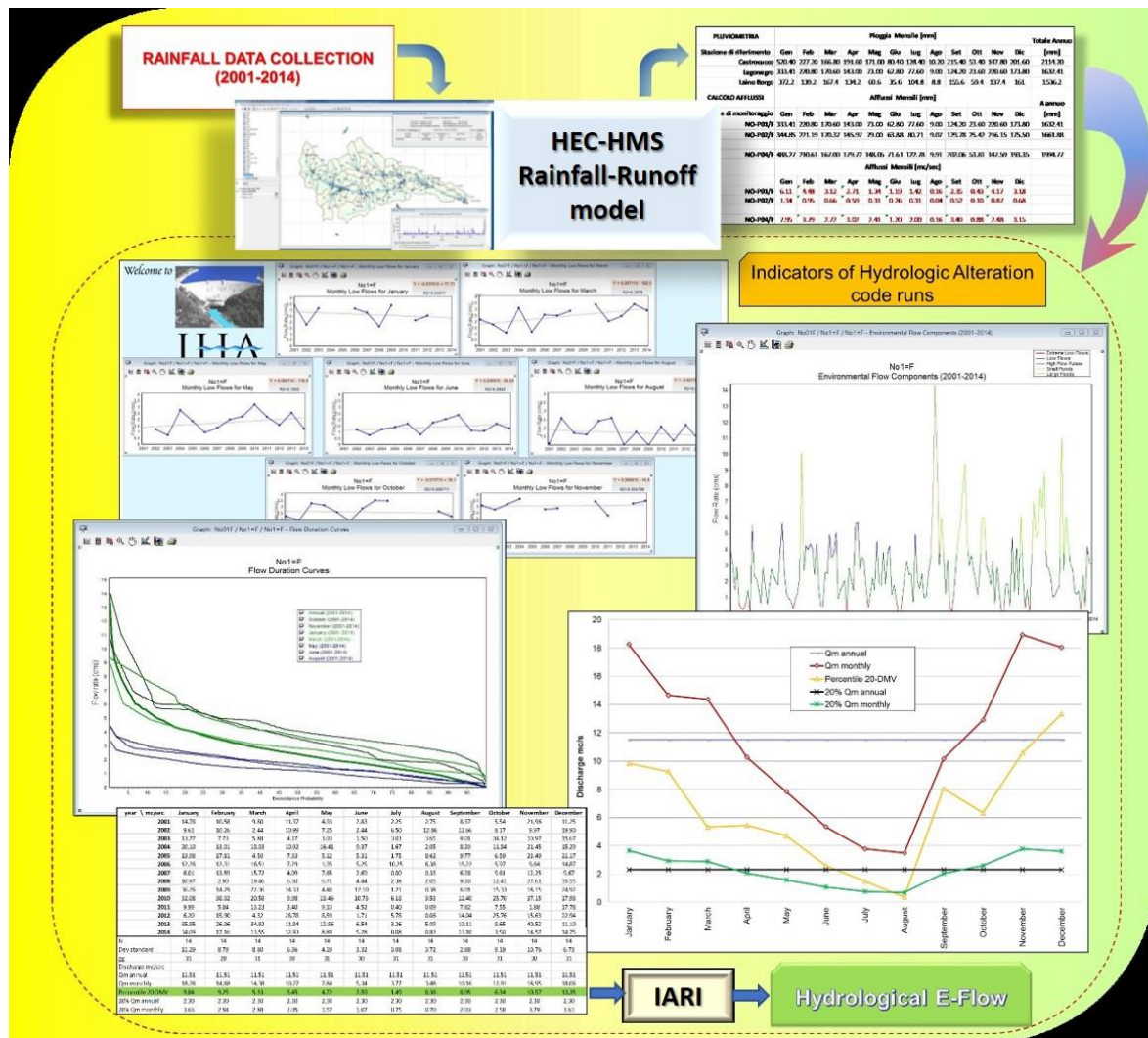


Figure 5 – Logical procedure for the Hydrological Eflow assessment

Tables 2 and 3 report the reconstructed and observed data respectively, referred to the Pertusillo Lake control cross section selected along the Agri river. The Pertusillo Lake, indeed, represents the gauged section corresponding to the inlet of the reservoir in which the water discharge is measured by the Management Authority.

The measures are generally collected daily in order to provide a daily inflow/outflow water storage balance.

The data reported in the tables are referred to the average monthly discharge computed by HEC_HMS and the observed ones to the control cross section.

The significance and the validation of the reconstructed data was evaluated using two criteria: the root mean square, E_{RMS} , and mean absolute percentage error, E_{MA} , expressed as follows:

$$E_{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\frac{(X_c)_i - (X_o)_i}{(X_o)_i} \right)^2} \quad (3)$$

$$E_{MA} = \frac{1}{n} \sum_{i=1}^n \left| \frac{(X_c)_i - (X_o)_i}{(X_o)_i} \right| \quad (4)$$

where X_o is the observed value, and X_e is the value estimated by the application of HEC-HMS. The tests were applied to the data set for the same period 2001-2007, obtaining 0.26 and 0.35 for E_{RMS} and E_{MA} respectively, which represents an acceptable result. Moreover, Figure 6 shows the comparison between the compute and observed average monthly discharge at the Pertusillo Lake cross section presenting a good correlation with $R^2=0.9836$.

Table 2. – Reconstructed water discharge data for the control cross section of Pertusillo Lake

Reference Cross Section	PR01 - Pertusillo Reservoir						Monthly Water Discharge (mc/s)					
	January	February	March	April	May	June	July	August	September	October	November	December
2001	8.43	7.54	6.99	7.24	4.17	2.39	2.42	1.20	2.71	4.78	2.97	7.18
2002	8.31	6.98	5.40	8.42	5.96	2.50	2.73	3.55	5.47	6.58	8.16	10.40
2003	10.05	6.19	7.51	5.15	4.11	2.60	3.38	1.06	2.48	5.16	8.69	8.55
2004	11.63	10.94	8.86	7.12	7.52	3.16	2.59	0.94	4.36	4.90	7.30	11.90
2005	6.24	4.93	11.08	3.70	4.35	1.89	2.09	2.82	3.81	5.61	11.71	16.04
2006	6.63	9.39	8.59	5.89	1.66	2.89	2.72	2.73	3.90	0.96	3.63	8.27
2007	4.12	10.19	6.54	5.32	5.22	3.30	0.23	0.40	1.73	5.28	6.75	5.85
2008	4.37	10.61	1.92	4.65	2.84	2.56	2.51	0.66	3.98	5.05	11.38	10.96
2009	20.01	18.39	7.78	15.23	6.46	1.74	2.23	2.90	3.55	6.03	8.02	11.40
2010	11.17	15.33	16.35	8.14	11.92	3.84	2.62	1.28	2.01	4.60	10.02	9.25
2011	6.03	15.41	5.18	5.58	7.10	2.70	1.21	1.48	3.09	4.16	5.38	8.47
2012	6.28	6.11	13.22	12.52	5.31	1.16	1.93	0.41	3.52	5.94	8.21	9.23
2013	17.38	17.12	14.90	4.39	5.81	4.27	2.29	2.53	2.53	5.23	6.27	13.94
2014	12.62	6.46	9.21	11.05	5.44	3.78	2.62	0.68	4.42	3.15	8.63	6.58

Table 3 – Observed water discharge data for the control cross section of Pertusillo Lake

Reference Cross Section	PR01 - Pertusillo Reservoir						Observed Monthly Water Discharge (mc/s)					
	January	February	March	April	May	June	July	August	September	October	November	December
1987	11.35	16.57	8.00	6.60	3.74	2.73	1.77	1.23	1.50	2.45	3.33	5.32
1988	8.10	9.17	13.71	6.17	3.55	2.27	1.26	0.55	1.90	2.19	7.43	9.87
1989	3.03	8.57	9.94	5.93	3.74	2.00	1.19	0.87	1.07	3.65	4.53	8.03
1990	3.26	3.39	3.10	13.30	3.90	1.43	0.48	0.42	0.73	2.26	4.70	21.52
1991	10.81	13.50	6.77	17.33	8.10	1.87	1.26	1.52	2.07	3.13	15.07	5.39
1992	5.26	4.03	3.39	5.80	3.07	1.77	1.00	0.39	0.67	2.68	5.87	7.23
1993	6.29	3.46	11.65	6.43	4.19	1.03	0.26	0.06	1.13	2.36	4.43	12.13
1994	15.00	18.43	6.58	10.27	7.16	0.70	1.42	0.61	0.63	2.39	4.00	3.74
1995	7.81	5.89	12.06	11.70	8.42	2.20	1.87	2.00	2.57	1.94	2.53	7.26
1996	6.71	15.41	16.94	13.83	7.61	3.20	1.48	0.61	2.83	9.55	19.30	20.84
1997	15.65	8.86	6.03	6.03	5.52	1.40	1.10	1.48	1.17	4.16	12.43	12.16
1998	9.65	15.82	6.42	7.07	8.71	1.90	0.58	1.61	3.33	6.26	5.30	10.29
1999	8.16	12.14	11.61	10.87	5.36	1.63	1.07	0.45	1.97	2.58	7.63	10.48
2000	5.52	8.79	6.39	6.13	2.84	0.97	0.23	0.03	1.27	3.52	4.10	8.68
2001	11.90	6.43	6.97	7.27	3.39	2.70	2.52	2.42	4.67	2.10	2.63	4.13
2002	5.71	4.36	4.00	7.23	3.13	1.37	2.90	1.55	2.77	3.42	8.33	7.94
2003	21.94	13.04	7.55	5.13	1.87	1.33	2.71	1.13	1.47	6.13	3.70	8.74
2004	9.10	10.83	9.65	9.73	10.39	3.93	1.23	1.00	2.13	2.61	6.23	9.26
2005	9.52	13.71	10.29	11.07	6.26	3.63	1.55	1.81	3.43	2.84	6.53	15.55
2006	14.35	13.86	12.65	9.57	4.84	3.13	3.13	2.36	2.67	2.23	2.03	5.87
2007	6.10	7.75	15.06	9.87	4.16	2.83	0.55	0.55	1.13	3.00	5.00	10.00

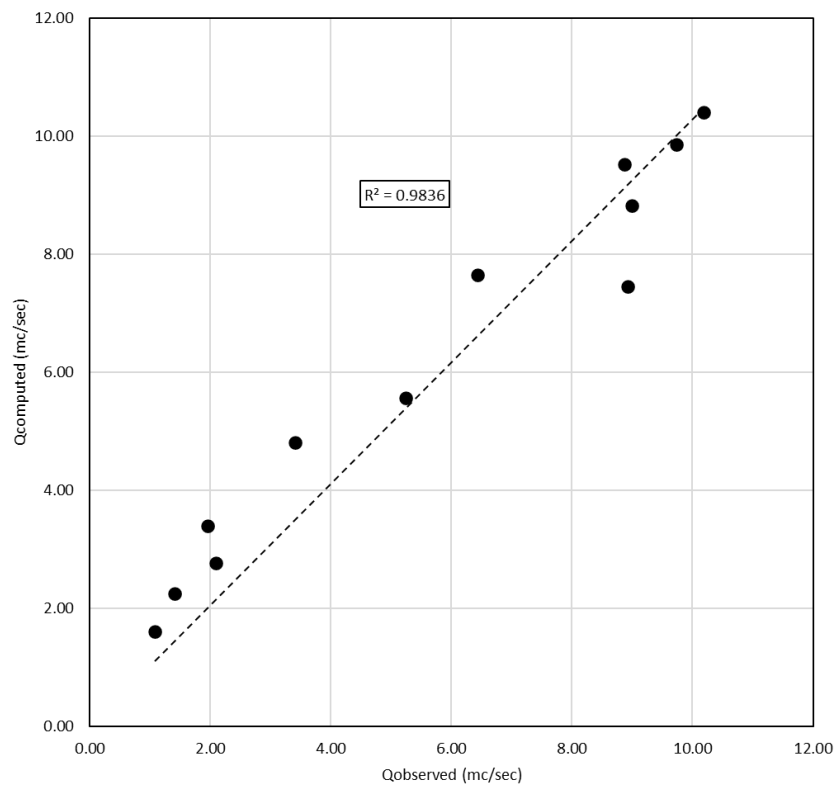


Figure 6 – Computed vs observed average monthly water discharge at the Pertusillo Lake cross section

3. implementation of the IHA calculation code (TNC) to the reconstructed flow discharge time series in each control cross section obtaining the EFC's time distributions;
4. implementation on "a non-parametric basis" analysis at the control cross section scale and for the entire observation period covered by the hydrological dataset (minimum 10 years), of the IHA code and evaluation of the corresponding EFCs;
5. analysis of the regressive trend of the flow components and assessment of the flow rate corresponding to the 25-th and 75-th percentile of the flow distributions computed and observed on the reference time base respectively;
6. in each control cross section, assessment of the hydrological Eflow as the *i*-th percentile of the monthly flow distribution for which the corresponding value of the IARI falls in the range 0,05-0,15, consistent to the "good" level; in the present case study the Eflow is assumed to be the 20-th percentile of the monthly water discharge.

Tables 4 and 5 report the computed and observed flow components in terms of annual and monthly average discharges and the 25-th and 75-th percentiles, evaluated at the Pertusillo Lake cross section as well as the monthly distribution of the 20-th percentile, here assumed to be the monthly Eflow. The corresponding values of the IARI are 0.12 and 0.05 for the computed and observed values of the Eflow respectively, both falling into the class of "good" level.

Furthermore, Figures 7 and 8 draw the distribution of the main environmental flow components (average annual discharge, average monthly discharge, 20-th, 25-th and 75-th percentile) for both computed and observed and the relative variability during the year. These plots outline how the generic assumption of the Eflow as a constant value equal to a defined percentage of the average annual discharge (i.e. 20% of the average annual discharge) generates a relevant penalization to natural river conditions causing and overexploiting water resources throughout the year except for the summer season. In other words, the assumption of Eflow as a percentage of the average annual flow does not consider the natural variability of the river flow which provides different flow components in order to obtain the best condition for freshwater ecosystems, habitats, and wetland species.

Table 4. Computed flow components and IARI for the control cross section of Pertusillo Lake: average annual discharge, average monthly discharge, 20-th percentiles (updated Hydrological Eflow), 25-th and 75-th monthly discharge and, IARI values for updated Eflow conditions (20-th percentile)

Average Annual Discharge (mc/s)											
6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.18
Average Monthly Discharge (mc/s)											
9.52	10.40	8.82	7.46	5.56	2.77	2.25	1.62	3.40	4.82	7.65	9.86
25-th percentile (mc/s)											
6.25	6.59	6.65	5.19	4.22	2.42	2.12	0.74	2.57	4.65	6.39	8.32
75-th percentile (mc/s)											
11.52	14.23	10.61	8.35	6.34	3.26	2.62	2.68	3.96	5.53	8.67	11.29
20-th Percentile - hydrological Eflow (mc/s)											
6.16	6.36	6.08	4.95	4.15	2.19	2.03	0.67	2.51	4.42	5.91	7.83
pj,k -20-th percentile											
0.02	0.03	0.14	0.08	0.03	0.27	0.19	0.04	0.05	0.25	0.21	0.16
IARI	0.12										

Table 5. Observed flow components and IARI for the control cross section of Pertusillo Lake: average annual discharge, average monthly discharge, 20-th percentiles (updated Hydrological Eflow), 25-th and 75-th monthly discharge and, IARI values for updated Eflow conditions (20-th percentile)

Average Observed Annual Discharge (mc/s)											
5.73	5.73	5.73	5.73	5.73	5.73	5.73	5.73	5.73	5.73	5.73	5.73
Average Observed Monthly Discharge (mc/s)											
9.29	10.19	8.99	8.92	5.24	2.10	1.41	1.08	1.96	3.40	6.43	9.73
Observed 25-th percentile (mc/s)											
6.10	6.43	6.42	6.17	3.55	1.40	1.00	0.55	1.13	2.36	4.00	7.23
Observed 75-th percentile (mc/s)											
11.35	13.71	11.65	10.87	7.16	2.73	1.77	1.55	2.67	3.52	7.43	10.48
Observed 20-th Percentile - hydrological Eflow (mc/s)											
5.71	5.89	6.39	6.13	3.39	1.37	0.58	0.45	1.13	2.26	3.70	5.87
pj,k -20-th percentile											
0.04	0.00	0.05	0.02	0.09	0.01	0.13	0.00	0.00	0.00	0.00	0.25
IARI	0.05										

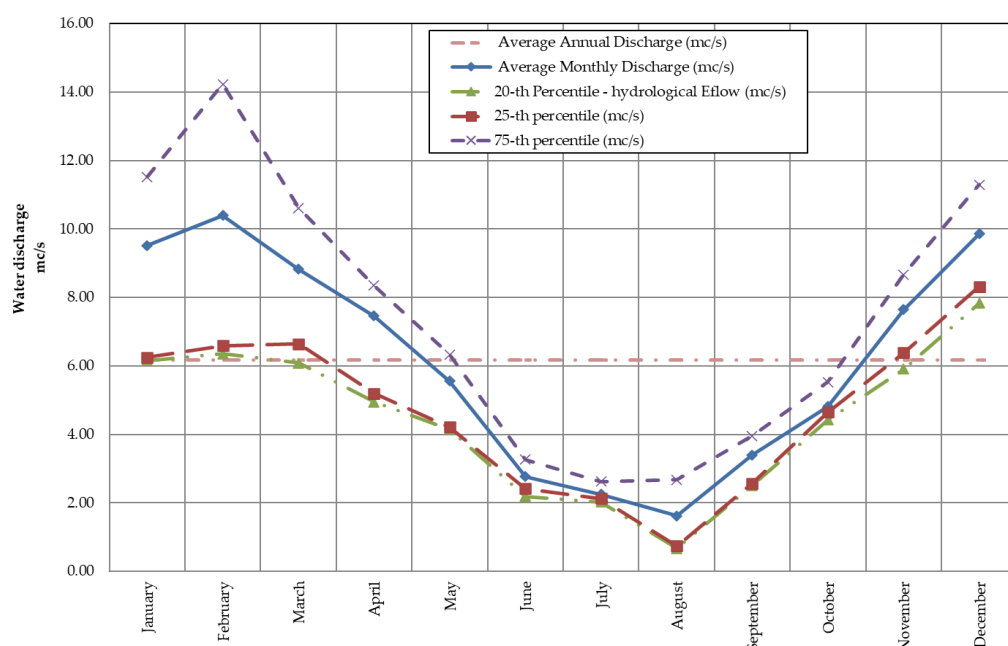


Figure 7 – Computed flow rate components for the control cross section of Pertusillo Lake

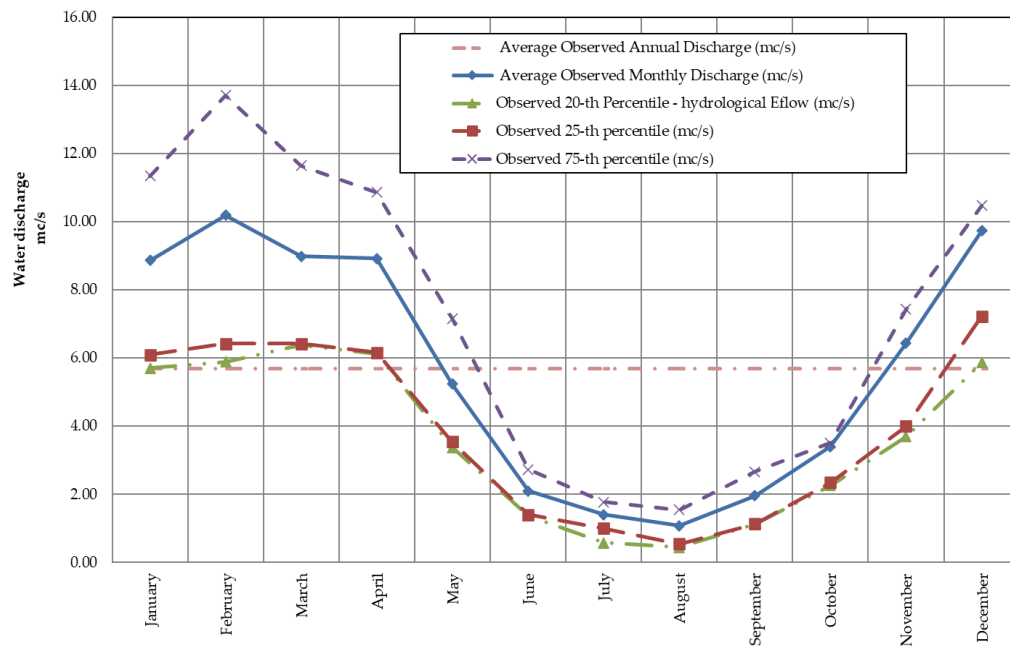


Figure 8 – Observed flow rate components for the control cross section of Pertusillo Lake

The proposed methodology, indeed, considers the maintenance of the environmental flow components variability as relevant and essential condition to cope with the impacts induced on the river system by anthropogenetic water discharge alteration. It does not represent a limitation of the water resources, but rather the valorisation and enhancement of the river environmental heritages.

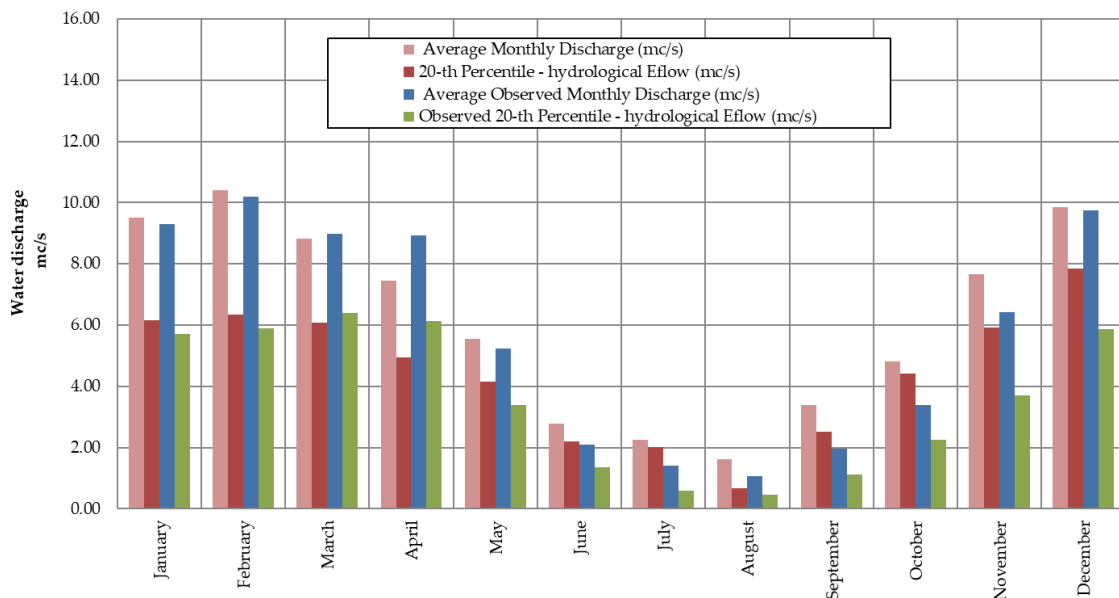


Figure 9 – Monthly distribution of the observed and computed flow rates at the Pertusillo Lake control cross section

Finally, Figure 9 shows the monthly distribution of the observed and computed flow rates at the Pertusillo Lake control cross section outlining a general good response of the proposed modelling versus the real data, but, at the same time, proposes the main deviation between the two datasets. The computed monthly distributions, for both average discharge and Eflow, fit the observed values well during the winter, spring and partly in summer, while the autumnal season shows a relatively high deviation between the computed and observed values. Such a difference might be attributable to the necessity of a better calibration of the infiltration rate and aquifer recharge rate, which require

further in site data and measurement. Nevertheless, the global response of the proposed methodology, still remains positive and generally conservative with respect to the water resource protection and the possible hydrological alteration induced to the river system and eco-system.

5. Conclusions

The aim of the study was to propose a hydrologically based methodology to define the ecological flow basing on the application of the Indicators of Hydrologic Alteration methodology (IHA by TNC) coupled to the valuation of the Index of Hydrological Regime Alteration (IARI by ISPRA).

The approach deals with the application of cascade models starting from a classical rainfall-runoff model, like HEC- Hydrological Modelling System (HEC-HMS) for the assessment of the daily/monthly water discharge flowing in a generic control cross section along the water body, feeding the IHA. Then, the methodology defines the ecological flow as the *i-th* percentile of the distribution of the average monthly flows which provides a value of IARI corresponding to a “good” level at least. In the study the 20th percentile fit well the results and the corresponding monthly discharge has been assumed as the monthly Eflow.

The procedure has been carried out on monthly discharge data derived applying the HEC-Hydrological Modelling System at the basin scale of Agri River, using the daily rain data measurements obtained by the regional rainfall gauge stations and calibrated through the observed inlet water discharge registered at the Lago del Pertusillo reservoir station.

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