4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

IAHRIS: NEW SOFTWARE TO ASSESS HYDROLOGIC ALTERATION

Martínez C.[1], Fernández J.A. [1], Sánchez J.[2], Magdaleno F.[3], García E.[4]*

[1]U. D. Hidráulica. EUIT Forestal. Universidad Politécnica de Madrid. Spain
[2]Dirección General del Agua. Ministerio de Medio Ambiente. Spain
[3]Centro de Estudios y Experimentación de Obras Públicas (CEDEX). Spain
[4]INCLAM, Ingeniería del Agua, Madrid. Spain
[*]Corresponding author, e-mail: carolina.martinez@upm.es

ABSTRACT

Indicators of **H**idrologic **A**lteration in **RI**ver**S** **(IAHRIS)** is a software designed to fulfill:

1. Parameters for the characterization of the natural or regulated flow regime, in a section of the river. These parameters evaluate those aspects of the flow regime with the highest environmental meaning (magnitude, variability, seasonality and duration). Their definition has given priority to the consideration of the singular characteristics of the Mediterranean regimes.
2. If the user enters data of the natural flow regime and data for any other flow regime in the same section or reach (altered regime, environmental regime, management scenario, …) the software calculates, furthermore, a set of indicators that assess the degree of hydrologic alteration in comparison with the natural regime. These indicators of alteration have been defined attending to the CIS-WFD recommendations for the Ecological Quality Ratios.

The software requires, at least, 15 entire years with data (daily average flows and/or monthly volumes).

The type of data entered in IAHRIS determines, directly, the results accomplished. In particular, they depend on the data periodicity –daily or monthly-, and the simultaneous character of the data associated to the natural and the altered flow regimes.

IAHRIS is free software, available at the website of the Spanish Ministry of the Environment.

Key words: hydrologic alteration, stream flow regime, large dam environmental effects, environmental flows

1. INTRODUCTION

Why evaluating the alteration of the flow regime?

This question can be answered by focusing on three different approaches: the legal, the scientific and the management approach.

From a legal approach, the evaluation of the hydrologic alteration is necessary, as a core requirement of the Water Framework Directive (WFD). This Directive fixes, as the most important target of the water resources management, the establishment of a good ecological status of the associated ecosystems. In order to reach this target, it is necessary to make use of protocols that allow for an efficient and objective knowledge of the ecological status of rivers. The WFD, in its Annex V, determines a set of components of the river ecosystem that must be considered in order to assess its ecological status. Between those, the flow regime is expressively quoted.

From a scientific approach, the transcendence of the flow regime as a linking element of the river ecosystem has been widely recognized (Richter *et al,* 1998, Arthington , 1997, Poff *et al.*, 1997): success in the conservation of the biodiversity and functioning of our rivers depend on our ability to know, protect and/or restore the main components of the natural flow regime.

Public agents, dealing with river management, need to know the status of the most relevant environmental components of the flow regime. Only from this knowledge it is possible to formulate adequate diagnoses to establish management politics that allow advances in the consecution of the "*good ecological status*". Also for the water bodies eventually designated as "heavily modified", it is necessary to characterize both the situation of its flow regime, and its optimum hydrological potential, compatible with the conditions that enhance this status.

2. HOW COULD THE MOST ENVIRONMENTALLY MEANINGFUL ASPECTS OF THE FLOW REGIME BE CHARACTERIZED?

The natural flow regime paradigm (Poff *et al*., 1997) already establishes the most environmentally meaningful aspects of the flow regime: magnitude, frequency, seasonality, duration and rates of change.

In IAHRIS, the process of characterization includes those five aspects, attending both to the normal or habitual discharge (determinants of the general disposability of water in the ecosystem) and the extreme data – floods and droughts – (since they define the most critical conditions in the ecosystem, specially in the Mediterranean region, considering the intra and interannual variability).

Table 1 summarizes, for every component of the flow regime, the aspects and parameters proposed for its characterization. They are justified, in detail, in Martínez & Fernández (2006).

Table 1 – List of parameters used to characterize the flow regime.

COMPONENTS OF THE REGIME		ASPECT	PARAMETER
HABITUAL DISCHARGE	MONTHLY OR ANNUAL VOLUMES	MAGNITUDE	Average of the annual volumes
		VARIABILITY	Difference between the maximum and the minimum monthly volume along the year
		SEASONALITY	Month with the maximum and the minimum water volume along the year
	DAILY FLOWS	VARIABILITY	Difference between the average flows associated to the percentiles 10% and 90%
EXTREME DATA	MAXIMUM VALUES of the daily flows (FLOODS)	MAGNITUDE AND FREQUENCY	Average of the maximum daily flows along the year Effective discharge Connectivity discharge Flushing flood (Q5%)
		VARIABILITY	Coefficient of variation of the maximum daily flows along the year Coefficient of variation of the flushing flood series
		DURATION	Maximum number of consecutive days in the year with q> Q 5%
		SEASONALITY	Average number of days in the month with q> Q 5%
	MINIMUM VALUES of the daily flows (DROUGHTS)	MAGNITUDE AND FREQUENCY	Average minimum daily flows along the year Ordinary drought discharge (Q 95%)
		VARIABILITY	Coefficient of variation of the minimum daily flows along the year Coefficient of variation of the ordinary droughts series
		DURATION	Maximum number of consecutive days in the year with q < Q 95%
			Average number of days in the month with a daily flow equal to zero
		SEASONALITY	Average number of days in the month with q<Q 95%

This characterization can be obtained for any flow regime with enough available data, natural or regulated (resulting from a real regulation and/or abstraction, or a simulation under different management scenarios).

3. HOW COULD THE HYDROLOGIC ALTERATION DUE TO AN ALTERED FLOW REGIME BE QUANTIFIED?

On the assumption of the natural flow regime, as the most determinant factor for the integrity of the fluvial, and on the basis of the tools –parameters- that allow for a quantification of the most environmentally meaningful aspects of the flow regime, a set of indicators is formulated (Martínez & Fernández, 2008). Those indicators are designed to assess, objectively, the degree of similarity of a flowing regime –altered regime-, or any other –for instance, an environmental flow regime- with the natural flow, since those similarities or differences will determine the real or potential integrity of the river.

Attending to the recommendations of CIS-WDF (2003) for the EQR, most of the INDICATORS OF ALTERATION were defined as a ratio between the parameter value in the altered regime and the parameter value in the natural regime.

Table 2 shows the links between the Indicators of Hydrologic Alteration calculated by IAHRIS and the components of the flow regime whose alteration is evaluated.

All these indicators, in order to make their analysis more homogeneous and easier, vary in the range 0-1 (meaning 0 the maximum alteration and 1 the absence of alteration).

Following the recommendations for the EQR, five different levels or Hydrological Status were established, linearly distributed in the range of the indices (0-1), assigning them the code colour recommended for the EQR (figure 1).

Figure 1 – Criteria used to assign qualitative categories to the Indicators of Alteration (Very low value of the Index=Very high Hydrologic Alteration=Very deficient Hydrologic Status; Very high value of the Index=Very low Hydrologic Alteration=Excellent Hydrologic Status).

***HYDROLOGIC STATUS*:** **PARTIAL INDICATORS (IAH)**				
HIGH	**GOOD**	**MODERATE**	**POOR**	**BAD**
0,8< IAH ≤1	0,6<IAH ≤0,8	0,4<IAH ≤0,6	0,2<IAH ≤0,4	0≤IAH ≤0,2

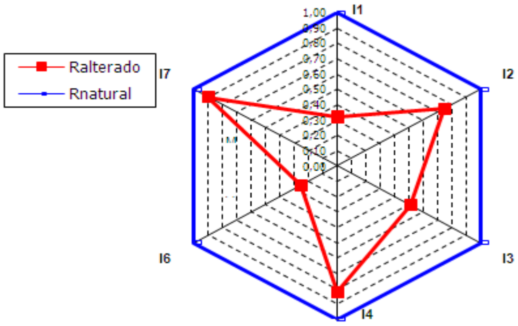
Table 2 – List of Indicators of Hydrologic Alteration (IAH1 – IAH21)

ASPECT		CODE	NAME
HABITUAL DISCHARGE	MAGNITUDE	IAH 1	Magnitude of the annual volumes
		IAH 2	Magnitude of the monthly volumes
	VARIABILITY	IAH 3	Habitual variability
		IAH 4	Extreme variability
	SEASONALITY	IAH 5	Seasonality of maximum values
		IAH 6	Seasonality of minimum values
FLOODS	MAGNITUDE AND FREQUENCY	IAH 7	Magnitude of the maximum floods
		IAH 8	Magnitude of the effective discharge
		IAH 9	Magnitude of the connectivity discharge
		IAH 10	Magnitude of the flushing floods
	VARIABILITY	IAH 11	Variability of the maximum floods
		IAH 12	Variability of the flushing floods
	DURATION	IAH 13	Flood duration
	SEASONALITY	IAH 14	Flood seasonality (12 values, one for each month)
DROUGHTS	MAGNITUDE AND FREQUENCY	IAH 15	Magnitude of the extreme droughts
		IAH 16	Magnitude of the habitual droughts
	VARIABILITY	IAH 17	Variability of the extreme droughts
		IAH 18	Variability of the habitual droughts
	DURATION	IAH 19	Droughts duration
		IAH 20	Number of days with null flow (12 values, one for each month)
	SEASONALITY	IAH 21	Droughts seasonality (12 values, one for each month)

In order to make easier the global interpretation, and for any of the three main components of the flow regime –habitual values, floods and droughts-, two helps are offered.

On one side, a meshed diagram for the simultaneous comparison of the indicators associated to the aspect under analysis (figure 2). This diagram makes possible an easy interpretation of the distance of the real value of each index –in red in the figure- to its natural value (always 1, following the afore-mentioned assumption).

Figure 2 – Diagram for the simultaneous comparison of the indicators associated to the habitual data.



On the other side, an index of global alteration (IAG) is calculated for each component –habitual values; floods; droughts-. That index combines the values of the indicators used to evaluate any of the aspects considered for any component of the regime. The global index is evaluated as the ratio between the area defined by the polygon associated to the altered flow regime (surrounded by the red line in figure 2), and the area defined by the polygon associated to the natural flow regime –logically linked to the area defined by the value 1 in all the indicators (blue-lined in figure 2)-. Also for these global indicators, a colour code has been established (figure 3).

Figure 3 – Criteria used to assign qualitative categories to the Indicators of Global Alteration.

***HYDROLOGIC STATUS*: GLOBAL INDICATORS (IAG)**				
HIGH	**GOOD**	**MODERATE**	**POOR**	**BAD**
0,64< IAG ≤1	0,36<IAG ≤0,64	0,16<IAG ≤0,36	0,04<IAG≤0,16	0≤IAG ≤0,04

It is essential to acknowledge that the global indicators compare areas. Thus, they consider the square values of the indicators for the different components analyzed –habitual, floods or droughts-. Accordingly, the range of assignation for the different status is different –it follows a quadratic law- compared to the range used for the individual indicators.

4. WHICH ARE THE DATA REQUIREMENTS IN IAHRIS? WHICH ARE THE RESULTS?

4.1 Required data

The software was designed to generate results only when the user enters, at least, fifteen entire years with flow data, be these data daily or monthly. This threshold was established on the assumption that at least fifteen years are necessary to base the analyses in a minimum set of information, so that the conclusions extracted are reasonable and accordingly related to the extreme values and variability of the flow series.

Data are grouped in two types:

i) Series in the NATURAL regime: It contains data linked to the natural flow regime. A maximum of two flow series may be associated in any point of the analysis: one with monthly data and the other with daily data.

ii) Series in an ALTERED regime: It contains data linked to a flow regime different from the natural.

The software admits, in each point of the analysis, any number of altered regimes. The user should enter, for all of these, a maximum of two series: one with monthly data and the other with daily data.

4.2 Results

The type of information entered in the software determines, largely, its results (Martínez *et al.*, 2008). In particular, those results depend on the data periodicity –daily or monthly-, and the simultaneous character of the natural and altered data being compared.

When the largest set of information is used in a point –natural and altered series of daily flows, with simultaneous registers-, the software offers:

a) For the characterization of the natural flow regime:

• Interanual variability, classifying the years in wet, normal or dry, should their annual water volume be situated in the highest quartile –wet-, the lowest quartile –dry-, or the two intermediate quartiles –normal-.

• Intrannual variability. For any type of year –wet, normal, dry- it calculates the monthly median volume for every month.

• 19 parameters (numerical variables that allow the characterization of the most environmentally meaningful aspects of the flow regime): 4 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.

• Average flow duration curve.

b) For the characterization of the altered regime:

• Intrannual variability. For any type of year –wet, normal, dry, according to the criteria obtained with the natural regime- but using the altered data, it calculates the monthly median volume for every month.

• 19 parameters (numerical variables that allow the characterization of the most environmentally meaningful aspects of the flow regime): 4 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.

• Average flow duration curve.

c) For the characterization of the alteration:

• 21 individual Indicators –each of them assessing the alteration of a parameter-: 6 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.

• 3 global Indicators – each of them assessing the alteration of a component; it considers, jointly, the alteration of the parameters used for the characterization of that component-.

IAHRIS offers all these results, numeric tables and diagrams, ordered in reports, set as spreadsheets in an Excel book.

One of these reports may be seen in Figure 4.

5. HOW CAN IAHRIS BE APPLIED?

Time, experience and suggestions from the users will answer this question, but we hope IAHRIS will contribute to answer some of the following subjects, in a rigorous and objective manner.

Why using IAHRIS?

- To handle the scientific and the water management communities a tool specifically designed to help in the fulfilment of those WFD requirements associated to the characterization of the hydrological status of the water bodies.
- To quantify, objectively, the hydrological alteration caused by water abstractions on the natural flow regime.
- To interpret the affections of the alteration of the flow regime on the integrity of the fluvial ecosystem.
- To serve as a test-bed:
    - Assessing the alteration induced by different management scenarios on the natural flow regime.
    - In heavily modified water bodies, characterizing the optimum hydrological potential, as that regime derived of the alterations linked to the strict consideration of the conditions that enhance the heavily modified character.

- To identify the elements of the flowing regime most directly linked to the rehabilitation or recovery of the reach under analysis.
- To fix objective criteria, in order to establish priorities in the restoration of the fluvial ecosystems.

REFERENCES

Arthington A.H. (1997). Wounded Rivers, Thirsty Land: Getting Water Management Right. Inaugural Professorial Lecture, Griffith University, Queensland.

CIS-WFD, EUROPEAN COMMON IMPLEMENTATION STRATEGY (CIS) FOR THE WATER FRAMEWORK DIRECTIVE, 2003. Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters. Working Group 2.3, REFCOND Guidance. http://forum.europa.eu.int/comm/Public/irc/env/wdf/libraryl

Martínez C. & Fernández J.A. (2008). IAHRIS: Manual de referencia metodológica (Decididir que poner)

Martínez C., Fernández J.A., García E., Tabernero, D. (2008). IAHRIS: Manual de usuario (Decidir que poner)

Martínez C. & Fernández J.A. (2006). Índices de Alteración Hidrológica en ecosistemas fluviales. Ministerio de Fomento. Ministerio de Medio Ambiente, Madrid. 178 pp.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E., Stromberg C. (1997). The Natural Flow Regime. A paradigm for river conservation and restoration. BioScience Vol. 47 No.11

Richter B.D., Baumgartner J.V., Braun D.P. and Powell J. (1998). A spatial assessment of hydrologic alteration within a river network. Regulated Rivers: Research & Management 14: 329-340

Figure 4 – Example: results of IAHRIS for a current situation (Jarama River at Vado Dam, Spain)

ASPECT		INDICATORS OF HYDROLOGIC ALTERATION (IAH)			HIGH	GOOD	MODERATE	POOR	BAD
		VALUE	CODE	DENOMINATION	0,8< I ≤1	0,6< I ≤0,8	0,4< I ≤0,6	0,2< I ≤0,4	0< I ≤0,2
HABITUAL DISCHARGES	magnitude	0,23	IAH1	Magnitude of the annual volumes				■	
		0,12	IAH2	Magnitude of the monthly volumes					■
	variability	0,25	IAH3	Habitual variability				■	
		0,37	IAH4	Extreme variability				■	
	seasonality	0,54	IAH5	Seasonality of maximum values			■		
		0,01	IAH6	Seasonality of minimum values					■
FLOODS	magnitude	0,81	IAH7	Magnitude of the maximum floods	■				
		0,99	IAH8	Magnitude of the effective discharge	■				
		0,83	IAH9	Magnitud of the connectivity discharge	■				
		0,54	IAH10	Magnitude of the flushing floods			■		
	variability	0,59	IAH11	Variability of the maximum floods			■		
		0,56	IAH12	Variability of the habitual floods			■		
	duration	0,52	IAH13	Flood duration			■		
	seasonality	0,80	IAH14	Flood seasonality	■				
DROUGHTS	magnitude	0,00	IAH15	Magnitude of the extreme droughts					■
		0,00	IAH16	Magnitude of the habitual droughts					■
	variability	0,00	IAH17	Variability of the extreme droughts					■
		0,00	IAH18	Variability of the habitual droughts					■
	duration	0,06	IAH19	Droughts duration					■
		0,00	IAH20	Number of days with null flow					■
	seasonality	0,00	IAH21	Droughts seasonality					■

INDICATORS OF GLOBAL ALTERATION			HIGH	GOOD	MODERATE	POOR	BAD
ASPECT	VALUE	CODE	0,64< I≤1	0,36< I≤0,64	0,16< I≤0,36	0,04< I≤0,16	0< I≤0,04
HABITUAL DATA	0,09	IAG_H				■	
FLOODS	0,47	IAG_A		■			
DROUGHTS	0,00	IAG_S					■