**I Specialized Conference on Ecology, Management and River Restoration: Practices and Experiences. 2015**

*Lisbon University/FLUVIO Programme – Federal University of Bahia/MAASA*

Salvador, Brazil, 27-28 July 2015

# Impact of a modified flow regime by irrigation in the key hydrologic parameters of Mediterranean region

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## Abstract

The alteration of flow regime is often mentioned as the most continuing and serious threat to ecological sustainability of rivers. In other hand, agriculture is one of the anthropogenic activities with more impact in a flow regime because of the need of irrigation, especially in the Mediterranean regions as Portugal and Spain, due to the characteristics dry and hot summers of this region.

In this work, the key hydrologic parameters that characterize the Mediterranean region were selected from a group of 66 and then the impact caused by a modified flow regime by irrigation was simulated using artificial series of mean daily discharge for 12 gauging stations of Portugal.

*Keywords: Altered flow regime; hydrologic indicators; irrigation.*

## Introduction, scope and main objectives

Freshwater management is one of the biggest challenges of 21st century. The construction of dams will increase even more than the 45000 big and 800000 small dams that presently exists, due to grow of world population and subsequently, the increase of the needs of freshwater for food supplies, energy requirements and social/cultural uses, (Poff *et al.*, 2009; Poff and Ward, 1989).

The natural flow regime of a river defines the hydrologic variability pattern and reflects the interaction between the climatic regime and the watershed characteristics (Belmar *et al.*, 2010; Gao *et al.*, 2009). It varies on a timescale of hours, days, months and years and it is necessary a large timescale series to characterize it. For many riverine species, the life cycle requires an array of habitat types; therefore it is reasonable to assume that the natural flow regime organizes and defines the riverine ecosystems (Poff *et al.*, 1997).

Poff *et al.* (1997) defined five critical components of flow regime that can be used to characterize it: Magnitude (volume of water that circulates through a point per unit of time), Frequency (number of times that a flow condition occurs during a time interval), Duration (period of time associated with the flow condition), Timing or predictability (measure of the regularity of the flow condition of discharge) and Rate of change or Variability (velocity of change between different flow conditions). Using these five components it should be possible to characterize the flow regime of a river and its alteration rate, related to the natural flow regime (Bunn and Arthington, 2002; Martinez *et al.*, 2008; Martins, 2012), and then establish reasonable limits of that alteration.

Due all these aspects, the alteration of flow regime is often mentioned as the most continuing and serious threat to ecological sustainability of rivers and their associated floodplain wetlands regime, due to the increased anthropogenic pressures (Bunn and Arthington, 2002; Gao *et al.*, 2009). Several works highlight the need of simplest methodologies and metrics to characterize the hydrologic alterations in flow regimes in a regional scale (Arthington *et al.*, 2006; Arthington, 2015; Poff *et al.*, 2009).

Agriculture is one the human activities with the greatest impact on water resources. In n Mediterranean region, this activity is the main land use, user of water, and key activity for rural population, with more than 80% of water resources allocated to irrigation, with relatively high losses, above 50% (Iglesias *et al.*, 2011; Laraus, 2004).

The objective of this work is to simulate a modified flow regime caused by irrigation in Mediterranean region, using a cluster of selected Indicators of Hydrologic Alteration (IHA) which translate the pressures caused and represent each of the components of hydrologic regime proposed by Poff *et al.* (1997): magnitude, frequency, duration and timing of discharge (seasonality) and rate of change of hydrological conditions (variability).

## Methodology/approach

*Selection of gauging stations*

From an initial group of 35 gauging stations from North to South of Portugal with the information of average daily discharge in natural regime of least, 15 years of data without gaps, a selection of 12 stations (6 from North and 6 from South) was made taking in account the amount of data available for each one. So, the selected stations were Amieira, Monte da Ponte, Monte dos Fortes, Pavia, Ponte Coruche and Vale da Ursa in the South, and Castro Daire, Cunhas, Fragas da Torre, Ponte Santa Clara Dão, Quinta das Laranjeiras and Santa Marta do Alvão from the North, which are represented in Figure 1.

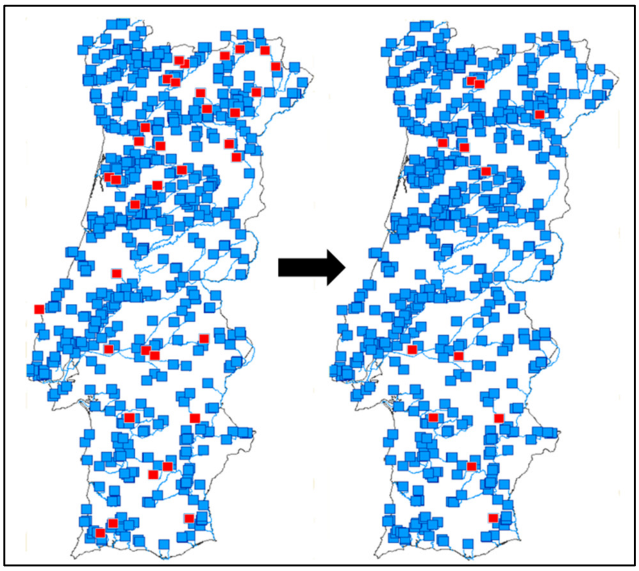

**Fig. 1: National network of gauging stations with studied stations in red. In the right, the selection of 12 gauging stations from the original group of 35 in the left. (adaptated from SNIRH, 2015)**

*Selection of hydrologic indicators*

A Principal Component Analysis (PCA) was made using the data of 66 hydrologic indicators obtained from the 35 gauging stations, in order to take the dominant patterns from the analyzed parameters and identify the group of IHA that explains the major variance with the less possible redundancy. It was used the correlation matrix to be sure that all parameters analyzed have the same significance for the PCA and are independent in temporal and spatial scale. The PCA was made for all the 35 stations, for the two regions in separated (North and South) and for the selected clusters.

*Simulation of modified flow regime by irrigation*

The modified flow regime resulting from the existence of a dam used for irrigation, was simulated using the original series of average daily discharge in natural regime as initial data, for the followed conditions:

1) If $V_t + Q_t \geq N_t$ , then $R_t = N_t$ ; If $V_t + Q_t \leq N_t$ , then $R_t = V_t + Q_t$

2) If $V_t + Q_t – R_t \leq K$, then $S_t = 0$; If $V_t + Q_t – R_t > K$, then $S_t = V_t + Q_t – R_t – K$

3) $V_{t+1} = V_t + Q_t – R_t$ ($S_t$ should be 0)

Where: $Q_t$ = Affluent discharge (natural flow regime); $V_t$ = Stored volume in the dam; $R_t$ = Volume released, K = Dam capacity $S_t$ = Volume spilled when the dam capacity is complete; $Q_{out}$ = Effluent discharge (modified flow regime); $N_t$ = Needs (amount of water necessary to satisfy the requirements)

The environmental flow was not considered, so it was assumed that $Q_{out} = S_t$. In this case, there were considered as $N_t$ the values: $0,1Q_t$; $0,2Q_t$; $0,3Q_t$ and $0,5Q_t$. These values were selected taking into account the needs of irrigation of the most common cultures in Portugal, represented the Mediterranean region: tomato, vineyards, olives and fresh fruits (INE, 2011; INE, 2014).

## Results

*Selection of hydrologic indicators*

The results presented are referred to the first PCA made with all stations and all parameters. The cluster obtained was the same for the PCAs made for each region and for the selected groups.

The first four principal components of the PCAs explained up than 97% of the variance (Table 1), which demonstrates the redundancy in the parameters analyzed.

**Table 1: PCA of the correlation matrix obtained from**

| % VARIATION | PC1 | PC2 | PC3 | PC4 | TOTAL |
|---|---|---|---|---|---|
| Total of stations | 81,19 | 8,31 | 4,84 | 2,19 | 96,52 |
| North | 63,17 | 19,78 | 5,95 | 4,46 | 93,36 |
| South | 85,12 | 6,18 | 4,44 | 2,07 | 97,81 |
| Selection | 80,84 | 8,80 | 5,09 | 2,09 | 96,82 |
| Selection N | 46,85 | 42,12 | 5,92 | 4,28 | 99,18 |
| Selection S | 85,50 | 11,18 | 2,44 | 0,53 | 99,65 |
| Average | 73,78 | 16,06 | 4,78 | 2,6 | 97,22 |

The figure 2 represents the dispersion graphic of the PCA with the correlation factors of each parameter. The correlation between two parameters is evaluated by the angle between the vectors of each one. It is possible to verify that there are four main groups of parameters, two groups with horizontal values (with more parameters), and two with vertical values. The first horizontal one represents mostly parameters related with the seasonality, duration and variability and the second group include parameters related with magnitude, variability, duration and some parameters related with seasonality.

The first vertical group include parameters associated with seasonality and the second vertical group has parameters related with magnitude, variability and seasonality.

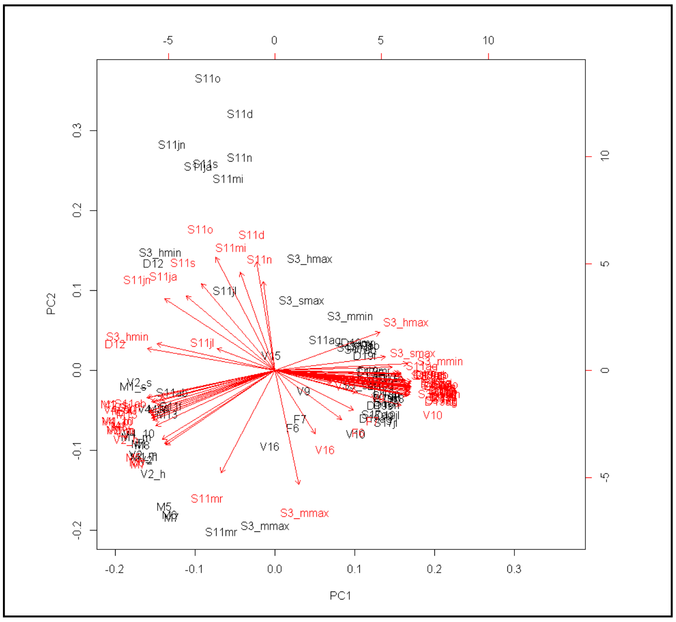


**Fig. 2: PCA of the 66 hydrologic parameters obtained for the 35 gauging stations analyzed.**

The choice of the group of parameters without redundancy that explained the observed variability was made by the selection of the parameters with major correlation with each principal component of the PCA.

In table 2 the selected parameters are described. All the parameters which the correlation factor was less than 6% were excluded, and were selected two parameters for each component of the hydrologic regime: magnitude, variability, duration, frequency and seasonality.

**Table 2: Description of the hydrologic parameters selected.**

| PARAMETER | DESCRIPTON | ASPECT |
|---|---|---|
| M1 | Weighted average of the annual volumes | Magnitude |
| M1_h | Average of the annual volumes in a wet year | |
| M13 | Average of the minimum daily flows along the year | |
| V2 | Weighted difference between the maximum and minimum water volume along the year | Variability |
| V2_h | Difference between the maximum and minimum water volume along a wet year | |
| V10 | Coefficient of variation of the flushing flood series | |
| F6 | Return period of effective discharge | Frequency |
| F7 | Return period of connectivity discharge | |

| | | |
|---|---|---|
| S11o | Average number of days in October with q≥Q 5% | Seasonality |
| S11d | Average number of days in December with q≥Q 5% | |
| S17o | Average number of days in October with q≤Q 95% | |
| S17n | Average number of days in November with q≤Q 95% | |
| D12 | Maximum number of consecutive days in the year with q≥Q 5% | Duration |
| D18 | Maximum number of consecutive days in the year with q≤Q 95% | |
| D19n | Average number of days in November with a daily flow equal to zero | |

*Simulation of modified flow regime by irrigation*

The Figure 3 represents the alteration level of each selected IHA caused by the different levels of needs imposed, divided by the components of flow regime (magnitude, variability, seasonality and duration) and by region (North, South and both together). For each parameter, the values represented were calculated by the rate between the value in modified regime and natural regime.

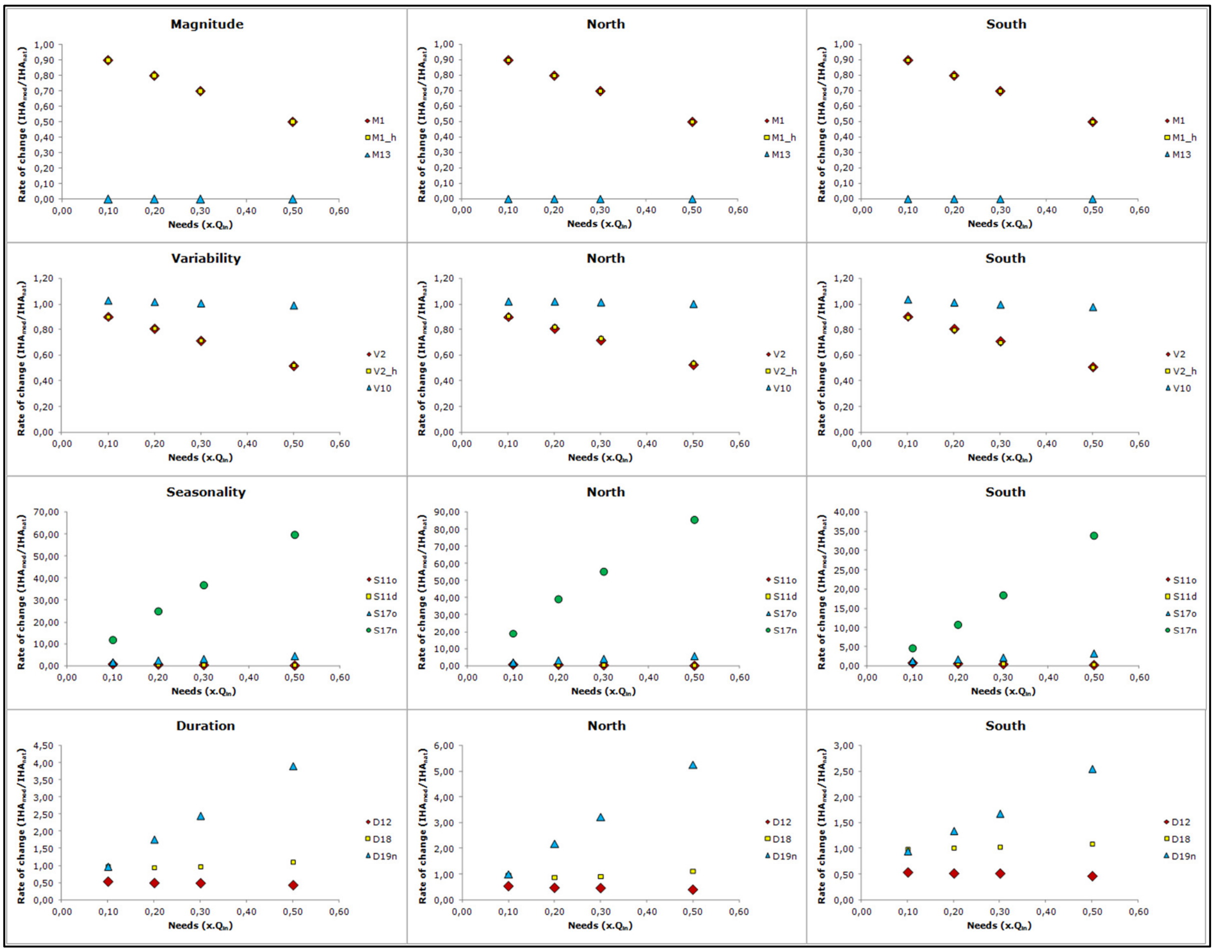


**Fig. 3: Variation rate of each selected IHA with the need imposed, represented by region (North, South and both) and by component of flow regime.**

The term 'Seasonality' represents the component 'Timing' or 'Predictability'. It is the term used by the software that calculate the parameters (IAHRIS), which was built taking into account the Mediterranean region, where the predictability of hydrologic events is mainly influenced by seasonality.

## Discussion

The parameters with higher levels of alteration with the modified regime in the analyzed gauging stations were M1 and M1_h for the component magnitude, V2 and V2_h for variability, S17n for seasonality (or timing) and D19n for duration.

The parameters M1 (weighted average of the annual volumes), M1_h (average of the annual volumes in a wet year), V2 (weighted difference between the maximum and minimum water volume along the year) and V2_h (difference between the maximum and minimum water volume along a wet year) had an alteration relatively constant according to the need imposed. For these four IHA, the values obtained can be translated by this relation $IHA_{mod}/IHA_{nat}=1-X$, where X is the fraction of the affluent discharge which is used for the needs, which is expected, since these parameters have to do with annual volumes.

Related with to seasonality, the parameters S17o and S17n (number of days in October and November with $q \leq$ drought discharge), were the ones with the higher response to the alteration of regime, particularly the S17n. This fact has to do with the characteristic dry and long summers of Mediterranean region and the low stored volume in the autumn (October and November).

Related with the above topic is the parameter D19n (average number of days in November with a daily flow equal to zero) with approximately four times more days with a null daily flow in modified regime, than in natural. This fact confirmed that the critical time related to dam management in Mediterranean, is the end of the summer.

## Conclusions/outlook

This research showed the main hydrologic parameters that describe the natural flow regime in Mediterranean regions, using the data of 35 gauging stations of Portugal. With the simulation of a modified flow regime caused by irrigation, this work confirmed the great influence of seasonality in this region with the parameters associated to the number of days with a discharge less than drought discharge and the daily flow equal to zero, being much higher in modified regime (and increasing with the increasing pressure) than in natural regime.

To a future work, a similar simulation should be made for other pressures in flow regime as dams for hydropower and multiprupose dams. It is demanding more knowledge about the critical hydrologic characteristics in Mediterranean, where the increased construction of dams is a reality and a need, due the irrigation problems during the dry season.

## References


1. Arthington AH, Bunn SE, Poff NL, Naiman RJ. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications*, 16(4):1311-1318.
2. Arthington AH. 2015. Environmental flow: a scientific resource and policy framework for river conservation and restorations. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 25:155-161.
3. Belmar O, Velasco J, Martínez-Capel F, Marín AA. 2010. Natural flow regime, degree of alteration and environmental flows in the Mula stream (Segura River basin, SE Spain). *Limnetica*, 29:353-368.
4. Bunn SE, Arthington AH. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30(4): 492–507.
5. Gao Y, Vogel RM, Kroll CN, Poff NL, Olden JD. 2009. Development of representative indicators of hydrological alteration. *Journal of Hydrology*, 374:136-147.
6. INE. 2011. Recenseamento Agrícola 2009 – Análise dos principais resultados. Instituto Nacional de Estaística I.P., Lisboa-Portugal.
7. INE. 2014. Estatísticas agrícolas 2013. Instituto Nacional de Estaística I.P., Lisboa-Portugal.
8. Martínez C, Fernández JA, Sánchez J, Magdaleno F, García E. 2008. IAHRIS: New software to asses hydrologic alteration. *4th ECRR Conference on River Restoration*. Italy, Venice. 16-21 June.
9. Laraus J. 2004. The problems of sustainable water use in the Mediterranean and research requirements for agriculture. Annual of Applyed Biology, 144:259-272.
10. Martins J. 2012. Avaliação ecohidrológica de caudais modificados e de caudais ecológicos em troços de rios fortemente modificados. *Master thesis*. Instituto Superior de Agronomia, Lisboa.
11. Poff, NL and Ward JV. 1989. Implications of Streamflow Variability and Predictability for Lotic Community Structure: a Regional-Analysis of Streamflow Patterns. *Canadian Journal of Fisheries and Aquatic Sciences*, 46(10):1805-1818.
12. Poff NL, Richter BD, Arthington AH., Bunn SE, Poff NL, Naiman RJ, Kendy E, Acreman M, APSE C, Bledsoe BP, Freeman MC, Henriksen J, Jacobson RB, Kennen JG, Merritt DM, O´Keeffe JH, Olden JD, Rogers K, Tharme RE and Warner A. 2009. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology*, 1-24. Blackwell Publishing.