CRITICAL ANALYSIS OF METHOD USED TO ESTABLISH ENVIRONMENTAL FLOWS IN THE SEGURA RIVER BASIN

Baeza Sanz, Domingo[a] and Novo Ruiz, Patricia[b]

[a] Departamento de Ecología de la Universidad Autónoma de Madrid; *domingo.baeza@uam.es*

[b] Ecohidraulica S.L., Madrid, ESPAÑA. (www.ecohidraulica.com) ; *patricianovo@ecohidraulica.com*

Abstract

Minimum environmental flows can be calculated by different methodologies. The main methods habitually used in Spain can be grouped under the headings of **Hydrological** or **Habitat Simulation** methodologies. As part of the planning process established by the WFD, the Subdirectorate General for Water Planning and Sustainable Use of the Spanish Environment Ministry has developed a standard that sets out the specific way in which these methodologies must be used to determine **minimum environmental flows**.

In the present work, minimum environmental flow values have been determined using different criteria on nine reaches in the Segura river basin (Spain), on the main course and in several tributaries. Calculations have been made by the most habitual methods and considering the official flow estimation criteria defined in the Segura Basin Management Plan and Spanish Environment Ministry recommendations, including those set out in the new Hydrologic Planning Regulation (RPH). The results obtained have then been analysed and compared. The values obtained using the official methodologies and instructions have been evaluated taking into account the criterion of the water lamina created on each reach and considering whether this is adequate for fish movement.

Keywords: *fish habitat, river basin management, highly modified water bodies, environmental flow.*

1. INTRODUCTION

The Segura river basin in south-east Spain is one of the most hydrologically controlled basins. Water demands exceed natural inflows, and since 1954 extra water has been sourced by transfers from another basin. Besides the alterations caused by infrastructures regulating natural flows inside the basin, external contributions also modify flow volumes as rivers are turned into canals to divert water throughout the basin (Richter et al, 1996). For instance the river Mundo, the main tributary of the river Segura, receives water from a transfer in the Talave reservoir and is used to channel it to locations several kilometres downstream. In the past five years this transfer has diverted approximately 600 hm³/y (Law on Tajo-Segura Joint Use, 21/1971) (Contreras, 2002; Confederación Hidrográfica del Tajo, 2002). The main consequence is the huge modification of natural flows on the river Mundo. The many reservoirs built throughout the basin also

contribute to altering the flow regime on the rest of its rivers.

Figure 1: Location of the Segura river basin in Spain.

Baeza et al, (2006a)

The Spanish Environment Ministry commissioned a study to assess the state of ecosystems affected by flow modifications and, on the basis of its results, to establish and implement restoration actions. The geographic scope of the study included the reaches affected by the Tajo-Segura transfer and other highly modified reaches in the Segura river basin (figure 1). Among other decisions it was proposed to implement environmental flows that allow the maintenance of the structure and functioning of the fluvial system. The result was the design of an environmental flow regime for several different reaches in the basin.

With the aim of standardising the criteria used to establish environmental flows and the methodologies for their calculation, the Subdirectorate General for Water Planning and Sustainable Use developed a method that will be the basis for the implementation of environmental flows in all Spanish river basins. The guidelines have been included in a document that will assist in the development of River Basin Management Plans, according to the WFD. This document, known as the Hydrologic Planning Regulation (RPH) (R.D. 907/2002), sets out guidelines for the planning and management of river basins.

In this work we have calculated minimum environmental flows and the subsequent flow regimes using different methods, with reference to the criteria set out in the RPH. Several aims have been pursued: firstly to calculate the environmental flow volumes necessary to restore the functioning of fluvial systems; secondly to test and compare the different methodologies applied; and finally to assess the difficulties that arise when calculating environmental flows at basin scale following the criteria proposed in the RPH.

2. METHODS

The **minimum environmental flow** value was derived using two different approaches. **The first approach** followed hydrological methodologies, in this case calculating moving averages with variable intervals from a representative series of daily flows. Minimum flows were selected according to two different proposals: that normally used by official bodies, known as the minimum flow for sustenance (QBM, Palau et al, 1998); and a second proposal derived from improvements on previous research by Baeza and García de Jalón (1997). In order to test the results, minimum flows were also determined following the methods used by the Segura Basin Authority, based on the calculation of 10% of the module. **The second approach** followed hydrobiological methodologies, running hydraulic simulations in accordance with IFIM methods.

The **minimum environmental flow** values were used to design monthly flow regimes. The problem when applying hydrological methodologies, and calculating guidelines for the derived monthly environmental flow regimes, is the need for sufficiently long natural flow records.

A long series of natural daily measurements was not available for the study reaches because the flow was regulated. Consequently, the natural daily flows necessary for the subsequent calculation of flows were derived using:

- Daily data from upstream gauging stations where no evident intense regulation or diversion of flows had taken place.

- Series of monthly flows returned as natural flows calculated by hydrological modelling.

Having calculated the minimum values for each interval of moving averages, minimum flows were chosen either by taking the flow corresponding to the highest slope on the derived curve (Palau et al, 1998), or by representing the curve (flow-interval size) and choosing the flow value immediately upon the greatest change in slope, which can be derived by direct observation of the curve.

The selected hydrobiological simulation method was IFIM-PHABSIM (Stalnaker, 1994; Bovee, 1982), which links the habitat requirements of river species with variations in habitat properties according to different flows. The simulation was performed using River 2D software, which simulates in two dimensions and provides more information.

The RPH also includes as part of the different available methodologies that of hydrobiological simulation with the final obtainment of habitat suitability-flow curves (HSC). Two alternatives are proposed for choosing the minimum ecological flow on these curves:

"Obtainment of minimum flow curves

The minimum flow distribution will be settled by adjusting the minimum flows obtained with hydrological methodologies to the result of habitat suitability modelling according to one of the following criteria:

a) *Considering the flow corresponding to a suitable potential habitat threshold of between 50-80% of the maximum suitable potential habitat.*

b) *Considering the flow corresponding to a significant change in slope on the habitat suitability curve."*

The second criteria is that most commonly used in studies carried out in Spain. The present study applies both criteria in order to compare the results obtained.

The RHP considers an exception that should be applied in the case of **highly modified water bodies**, where minimum flows should be calculated as follows:

"Whenever it is proved that the difference between the real flow regime and that estimated according to one of the previous criteria is very high, the threshold used to define the minimum flow regime in the case of highly modified water bodies will be between 30-50% of the water body's maximum suitable potential habitat for any of the considered target species."

Although highly modified water bodies have not yet been defined, within the studies of classification of water bodies in the Segura river basin it is quite likely that several of the studied reaches may be classified as such, since they are located downstream of reservoirs that modify the natural flow regime. Consequently, minimum flows have been estimated following the criteria applicable to highly modified water bodies.

In order to test the validity of the results obtained, the flows derived from the percentages of the HSC-flow curve recommended by the RPH were simulated to establish the area occupied by the river and the different depths of the reaches corresponding to these flows. The test to select the optimum values is to identify whether the water

lamina created with these flows is sufficient to facilitate fish movement.

3. RESULTS

The following figure shows the location of the reaches where environmental flows were calculated (figure 2).

*Figure 2*. Location of reaches where environmental flows were calculated
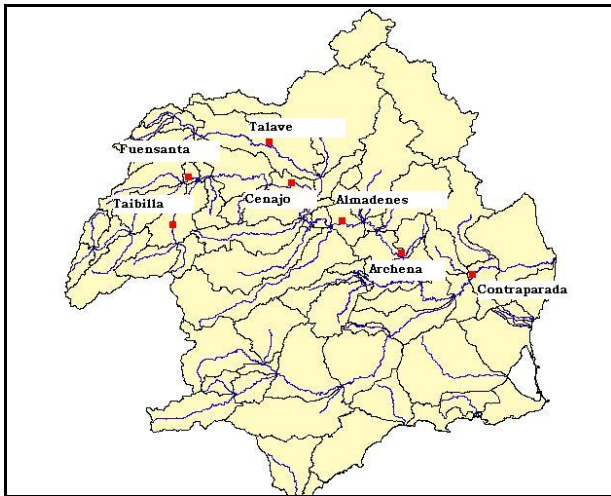
Baeza et al, (2006b)

A) Minimum flows calculated according to hydrological criteria.

The series of natural daily flows for the reaches considered in this study were derived from the returned monthly series using the flows recorded at upstream gauging stations whenever there was no significant disturbance. The following figure (figure 3) shows the daily series on the Cenajo reach and the daily series of natural flows used to calculate it (Fuensanta gauging station).

Figure 3. Monthly flow regime on the river Segura: Fuensanta gauging station (natural regime) and Cenajo reach (returned regime).
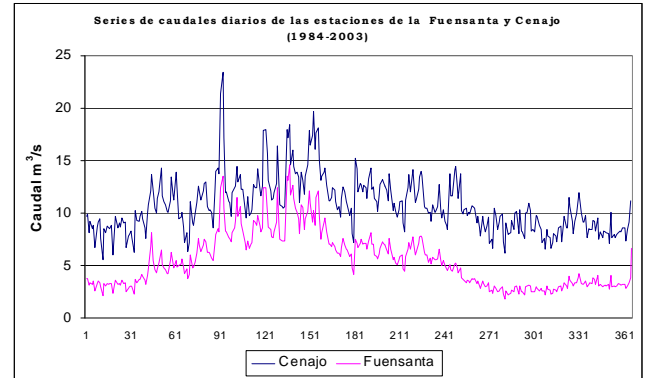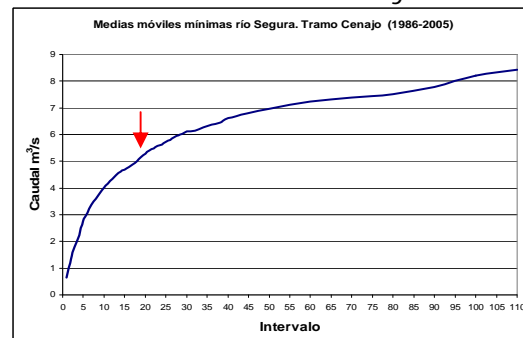

Baeza et al, (2006a)

As noted above, once the minimum values for each interval of moving averages had been calculated, the minimum flows could be chosen either by taking the flow corresponding to the highest slope on the derived curve (Palau et al, 1998), or by representing the curve and choosing the flow value upon the greatest change in slope observed on the curve (flow-interval size).

The following graph shows the flow versus interval size curve for the Cenajo reach, indicating the point at which the greatest change in slope was seen.

Figure 4. Graph of minimum flows obtained with moving averages versus number of days (interval) used for calculations. Segura river reach downstream of Cenajo reservoir.

Baeza et al, (2006a)

Daily flow series data was not available for the river Taibilla, so the flow was not calculated according to the QBM methodology. The other two

values were derived from precipitation-runoff models. The results are presented in Table 1.

Table 1. Minimum environmental flow values calculated following hydrological methods: value corresponding to greatest slopes in moving average series (QBM), value of change in slope, and value corresponding to 10% of module.

1.1.1.Method	Moving averages QBM. m^3/s	Moving averages (change in slope). m^3/s	10% of module. m^3/s
Taibilla		0.8	0.23
Fuensanta	0.25	1.04	0.6
Cenajo	1.34	5.64	1.07
Talave	0.78	1.18	0.44
Almadenes	3.8	7.7	1.97
Archena	4.01	8.7	2.05
Contraparada	4.52	9.2	2.1

B) Minimum flows calculated according to hydrobiological simulation criteria.

With regard to the results obtained in the habitat simulation, it was also not possible to apply this technique on the river Taibilla, which is dry for most of the year. Thus the minimum environmental flow was taken as that which indicated a significant change on the HSC curve, and the optimal environmental flow as that corresponding to the highest weighted usable area (WUA). The results for the rest of the reaches are shown in the Table 2.

Table 2. Environmental flow results obtained following the habitat simulation method. Optimal Qenv shows the flow providing the greatest WUA, and minimum Qenv shows the flow corresponding to the change in slope on the HSC-flow curve.

1.1.2.Flow in m^3/s	Opt. Qenv	Min. Qenv
Taibilla		
Fuensanta	4.7	2.5
Cenajo	14	6
Talave	6	3.5
Almadenes	15	5
Archena	8.5	5.5
Contraparada	8.37	3.2

A complementary objective of this study was to check whether the values of the interval proposed by the RHP would be the most appropriate to contribute to improving the current state of the system. According to the RPH, for a water body with no hydrological alterations the valid interval within which the minimum environmental flow should be located is between 50 to 80% of the maximum WUA. The flows that yield different maximum WUA percentages within this interval were calculated for some of the reaches and are included in the following table (Table 3).

*Table 3.* Different flows according to the percentages of the maximum WUA produced.

1.1.3.Flow in m^3/s	30% max WUA	50% max WUA	80% max WUA
Cenajo	0.9	3.2	8
Talave	0.15	0.6	2.6
Almadenes	0.8	1.29	2.8
Archena	0.6	1.8	10.5
Contraparada	0.8	1.18	2.34

In order to test the validity of the results obtained with this proposal, the flows derived from the percentages of the HSC-flow curve

recommended by the RPH were simulated to establish the area occupied by the river and the different depths of the reaches corresponding to these flows. Taking the case of the Cenajo reach on the river Segura, the flows corresponding to HSC-flow curve percentage values from 30 to 60% of the maximum habitat are between 4.4 and 0.9 m^3/s. The whole interval is lower than the minimum environmental flow obtained by change in the slope , and the lowest extreme value would imply reducing the minimum environmental flow value by more than six times. Consequently the utility of using this method as a restoration measurement to improve the ecological state is highly questionable. The area occupied by the river and the respective water depths were also calculated for flows of 0.9 m^3/s, and it was seen that the water area decreases quite evidently and the depths left would not be sufficient to allow fish movements. Some isolated areas would appear within which the movement of fish would be practically impossible (figure 5).

Figure 5. Distribution of depths and river flow area on the Cenajo reach of the river Segura simulated for a flow of 6 m^3/s (left) and 0.9 m^3/s (right). In the second case, when the depth is shallower than 20 cm the river loses continuity
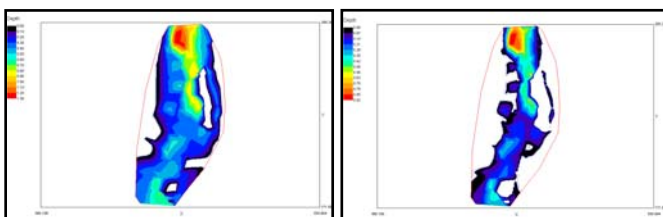
Baeza et al, (2006b)

In most of the rivers there is a significant decrease in areas deeper than 20 cm with the flows that represent either 30% or 50% of the WUA.

4. DISCUSSION AND CONCLUSIONS

In the case of the values obtained following hydrological methods, it can be seen that the value corresponding to a change in slope on the moving averages curve returns higher flow values than the other methods. Lower values are obtained with the QBM method, in some cases less than half of the value derived from the previous method. The flows corresponding to 10% of the module (official method implemented by the Segura River Basin Authority) yield much lower values than the rest of the methods.

The flows derived from the hydrological methods increase downstream from one survey station to the next, in accordance with an increase of the shape of the basin and the total water budget. This is somehow a logical result taking into account that the results depend of the magnitude of the flows, yielding higher values for the reaches where more water flows.

Nevertheless, this does not happen with the results obtained following the habitat simulation methods, since this methodology bases the results on the preferences of a certain species (in this case a certain fish species) and the reach topography. Exceptions were noted for the Almadenes reach on the river Segura and the Talave reach on the river Mundo.

The results derived using the hydrobiological simulation methods are quite different, and the values depend on the criterion used to choose the minimum flow. When the flows corresponding to different percentages of the maximum WUA are chosen, as set out in the RPH, in most cases the flow corresponding to 30% of the maximum WUA is not adequate for fish movement and produces a minimal channel that in some cases lacks continuity and is not deep enough for the movement of the fauna. For biological purposes, a safe situation is considered better in which water

continuity is assured not only on the study reaches but along the whole river, for which a depth of more than 20 cm may be adequate, as is reached when the flow values are at least 60% of the maximum WUA for the most exigent class age. Consequently, if this methodology were finally to be adopted for the management of Spanish rivers, the results should only be applied in extreme conditions, always exercising caution and testing that they reach the objectives for which they were proposed. If the finality of the flow is to provide enough water to permit an adequate water lamina continuity that ensures the movement of fish along the whole river, some of the official criteria are very restrictive. The flows that produce 30% of the maximum WUA are far from supplying the optimal habitat and for the correct development of the fauna, which is only assured when higher flow values are established.

BIBLIOGRAPHIC REFERENCES

Baeza, D., García de Jalón, D. (1997). *Caracterización del régimen de caudales en ríos de la Cuenca del Tajo atendiendo a criterios biológicos.* Limnetica 13: 69-78.

Baeza, D., Moreno, J.L., de las Heras, J. (2006a). *Definición de las normas de explotación de la conducción Talave-Cenajo y recomendaciones para la consecución del buen estado de calidad de las aguas en los ecosistemas fluviales afectados.* Centro Regional de Estudios del Agua. UCLM

Baeza, D., Notario, E., Moreno, J.L., de las Heras, J. (2006b). *Establecimiento de un régimen de caudales ecológicos en los tramos afectados por el proyecto de trasvase Fuensanta-Taibilla.* Centro Regional de Estudios del Agua. UCLM.

Bovee, K.D. (1982). *A Guide to Stream Habitat Analysis using the Instream Flow Incremental* Methodology. Instr. Flow Inf. Paper 12. USDI Fish and Wildl. Serv. Washington. 248 pp.

Confederación Hidrográfica del Tajo. Ministerio de Medio ambiente. (2002). *La cuenca del Tajo en Cifras 2ª Edición.*

Contreras, A., Manzano, R. (2002). *Recopilación y elaboración de información sobre los efectos que el funcionamiento del trasvase Tajo-Segura pueda estar produciendo en la cuenca del río Tajo.* Informe Dirección General del Agua. Consejería de Obras Públicas. Junta de Comunidades de Castilla-La Mancha.

Palau, A., Alcázar, J., Alcocer, C., Roi, J. (1998) *Metodología de cálculo de regímenes de caudales e mantenimiento.* Informe técnico para el CEDEX. Ministerio de Medio Ambiente.

Poff, N.L., Ward, J.V. (1989). *Implications of streamflow variability and predictability for lotic community Structure: A regional Analysis of Streamflow Patterns.* Can. J. Fish. Aquat. Sci. 46: 1805-1818.

Richter, B.D., Baumgartner, J.V., Powell, J., Braun, D.P. (1996). *A method for assessing hydrologic alteration within ecosystems.* Conservation Biology, 10, 1163-1174.

Stalnaker, CB., Lamb, BL., Henriksen, J., Bovee, KD., Bartholow, J. (1994). *The Instream Flow Incremental Methodology: a primer for IFIM.* National Ecology Research Center, Internal Publication. National Biological Survey. Fort Collins, Colorado, U.S.A. 99 pp.