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Structural change in Tagus River basin. Discussing the "Eighties Effect"

David Nortés Martínez^{*†}

March 11, 2014

Abstract

This paper aims to discuss the existence of the so-called "Eighty effect". This phenomenon refers to the general decline in river flows in the Spanish headwaters until the 1980s.

We chose the Tagus River Basin as a case study for several important reasons: it is subject to certain increasing demands as well as environmental objectives; it is under the constraints imposed by the Albufeira International Agreement, and it is the origin of water transfers to other basins, ensuring water supply for urban, agricultural and ecological purposes.

In the context of multiple demands and potentially decreasing levels, a clear understanding of existing water supply is essential to ensure its proper management. To promote this crucial understanding, we use recognized statistical methods in economics and hydrology, such as Time Series Analysis, intervention analysis and structural change contrasts.

The empirical evidence found shows clearly a level shift in flows from Tagus sources.

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1 Introduction

There is an apparent change in the river flows patterns since the 1970s-80s. In the new hydrological Plan for the Tagus river basin [Tagus River Basin Authority, 2013], and before, in the Provisional Main Topics Outline [Tagus River Basin Authority, 2010], we find references to a what is clearly a serious problem: according to the River basin authorities, the flows from the upper river area have been decreasing since the eighties, therefore affecting the whole basins hydrologic system and causing a lack of water to attend to water demands.

In the documents cited, we can find several figures on this topic. One of the most illustrative is figure 1, in which, the Tagus River Authority is trying to demonstrate the lack of flows from the upper Tagus at Entrepeñas and Buendía Dams¹. As we can see in figure 1, apparently flows from the headwaters pass from an average of 1457 hm³ per hydrologic year from 1958/59-1980/81 to an average of 773 hm³ (776 according our own calculations) from 1981/81-2005/06, which means 47% less water after 1980 from the headwaters of Tagus. The prospections made by CEDEX [CEDEX, 2010] in its climate change studies are not optimistic and predict a general reduction in rainfall along 21th century, increases in temperatures and rises in evaporation patterns, causing a reduction of available water.

Using a simple average for a couple of different periods, as seen in figure 1, could be a good way to illustrate the phenomenon graphically, but unfortunately, it is not enough, nor the best way to capture and prove an effect along with all of its implications.

Why could that phenomenon be an important problem as we stated? what are its implications under an economic point of view? The Tagus River Basin is an international basin shared between Spain (55750 km²) and Portugal (28033 km²), with the capital cities of both countries (Madrid and Lisbon) located in the headwaters and the estuary respectively. Average water demand in the Spanish section of the basin in 2010 amounted to 3750 hm³/year and is expected to steadily increase (to 4100 in 2015 and 4485 in 2027). The majority of water demand in the basin comes from agriculture (64.4%) but urban water, also accounts for a significant and increasing share (35.6%) [Tagus River Basin Authority, 2010] because of the expansion of the largest metropolitan area in the Iberian Peninsula: Greater Madrid (6 million inhabitants and 76% of the Tagus River Basin total population), which is located upstream. This expansion, moreover, is generating environmental

¹These dams are located in the upper Tagus area and are, moreover, the starting point for water transfers to Segura River Basin

and water quality problems downstream of Madrid because of the pollutants discharged by the area. As a part of the international river basin, the Spanish area of the Tagus is subject to constraints imposed by the Albufeira Agreement, which fixes a minimum amount of flow of 2700 hm³ per year at Cedillo Station and 4000 hm³ at Ponte Muge station for the Portuguese part of the basin.

Water demand in Tagus is a fraction of the renewable resources produced in the basin, however, there are significant pressures in the headwaters where 45% of the water demand is located and only 25% of the water resources are generated. The headwaters area of Tagus River are connected with the Segura, since 1978, and Guadiana river basin, since 2009, through a water transfer facility [Tagus River Basin Authority, 2010]. This infrastructure, which begins at Entrepeñas and Buendía Dams, is authorized to transport a maximum amount of 600 hm³ per year², used for surveys and irrigation in Segura basin. Recently, the infrastructure is also used to provide water for environmental uses in Guadiana (Tablas de Daimiel National Park) and for several towns in Guadiana basin (see figure 2).

The Segura river basin is an example of a water scarce region in Europe (EEA, 2009). Although relatively small and sparsely populated (18870 km² and less than 100 inhabitants per km²), water demand is relatively high when judged in relation to its area (more than 100 billion m³ per km² a year) or its permanent population (more than 1000 m³ per inhabitant a year). Furthermore, water demand in the basin actually amounts to an average of 1900 hm³/year while the renewable rainfall and runoff over the last 40 years averages only 823 hm³/year (and between 650 and 700 hm³/year, if we consider only the last two decades) [Segura River Basin Authority, 2010]. Accordingly, average water demand per year is between 2.3 and 2.7 times larger than renewable long-term resources available. This situation is known as structural deficit, a common phenomenon in all of the south-east of Spain [Morales et al., 2005]. According to the regional classification given by the Water Exploitation Index³, both basins are located in regional areas with high water stress, with water exploitation values of over 40%. Tagus and Segura count as two of

²The original project was designed to transfer 1000 hm³ in two phases: the first with 600 hm³ and a second one with 400 hm³ more. Nonetheless, this second phase never was done.

The 600 hm³ from the first phase had to be shared between agriculture (400 hm³ per year), urban supply (110 hm³ per year) and losses of the system (90 hm³ per year) in the Murcia River basin. However, new needs were appearing, and the aqueduct is now additionally used to bring water to some areas of Guadiana for environmental and urban supply uses.

³Measure defined as the mean annual total abstraction of freshwater divided by the mean annual total renewable freshwater resource, expressed in percentage. Available at the European Environment Agency.

the EU river basins with a semi-arid climate [Segura River Basin Authority, 2010, Tagus River Basin Authority, 2010]. This type of climate can be defined by rainfall patterns that are highly variable in space and time, and a major source of uncertainty in the regional water balance [Ad de Roo et al., 2012, Contreras et al., 2008]. Nature, however, is only one of the reasons behind water scarcity and drought exposure; current trends towards increasing water stress can be explained by a combination of powerful economic incentives. Water intensive activities, such as irrigated agriculture and tourism, especially in the Segura basin, have been perceived as competitive and financially profitable. Additionally, water governing institutions in place have failed, which is evident in their long-term inability to balance existing water demands with the capacity limits of the bodies of water, thus satisfying those uses in a sustainable way.

This situation of water scarcity and overexploitation is far from new and dates back to the 1940s, when development projects and policies promoted the extensive use of Mediterranean aquifers. Since then, prevailing supply-side policies have tried to keep up with increasing water demands from the simultaneous developments of agriculture, manufacturing, tourism, and urbanization, without proper consideration given to the ecosystems ability to continue to provide this critical resource. [EPI-Water, 2013, Morales et al., 2005].

Water transfers from the Tagus river basin were, and still are, an important element in the Segura basins economic development. The main reasons to support this supply measure were (and continue to be) determined by certain comparative advantages of the receptor basin. Based on physical facts, the area has productive lands and a favourable climate for high yield productions that subsequently allows producers to export their products at competitive prices. The area also boasts a strong agricultural vocation, commonly used irrigated crops, highly specialized agrarian workers, and tourism developments as a result of its economic structure as well as traditions [Morales et al., 2005].

Within this context, the impact of water transfers from the Tagus basin has been extremely important for the regional economic development in the Segura basin. According to the latest study on the economic impacts of the transfers, their existence, linked with incentives for technological improvements (derived from the structural scarcity in the area,) have generated a gradual change in crop vocation. This change favours newer high added value varieties and the modernization of irrigation systems, which have spurred the development of an internationally focused industry of technology and components for irrigation systems. Water transfers in Segura, and consequently its economic impact on the area, have also been a useful way to attach pop-

ulations in rural areas [PriceWaterHouseCoopers, 2013]. Irrigated crops and urban supply of the Lower Segura, Lower Vinalopó, Campo de Alicante, Campo de Cartagena, Guadalentín’s Valley coupled with the littoral of Aguilas-Mazarrón, and the Almanzoras Valley, in Almeria, all have a strategic dependency on water from the Tagus river basin [Morales et al., 2005] for their economies. In this way, the contribution of the agricultural sector of the area is valued at 1286 millions of Euros per year, with an indirect impact of 447 millions of Euros in the economy of the region. Impact on employment is estimated at around 58632 jobs, which translates to 38.8% of the agrarian employment in Alicante, Murcia and Almería, plus 15000 more in indirect employments [PriceWaterHouseCoopers, 2013]. Urban supply is also highly dependent on transfers from Tagus. 95% of Murcia Region and 57% of Alicante province, where some of the traditional and intensively used tourist areas can be found, are supplied by the Community of Taibilla. Tagus transfers account for an average of 57% of the water resources available in this community [PriceWaterHouseCoopers, 2013]. Several environmental uses and facts are also important factors to consider. Authors like Millán Millán [Millán et al., 2005, Millán, 2008, 2007] have found relationships between various land uses, changes in plant cover and modifications in climate patterns, which directly affect the availability of water resources. This availability is crucial to maintain the climates statu quo, to avoid modifying long-term rainfall patterns, and to prevent an even deeper structural drought in Segura river basin. As we can see, the existence of these water transfers plays an important role in the economic dynamics of the Segura River basin. Within this framework, the possible decreasing trends in flows from the headwaters in Tagus river basin, as studied in this work, bring up significant and not easy to solve problems for the economy and the environmental state of the ecosystems in both basins. Its correct management will likely require economic instruments to create appropriate incentives on the demand side and to assure sustainability. Possibly even more importantly, we need to know what to expect from the resource performance in order to design efficient and correct instruments to create precise and practical incentives.

2 Data and Methodology

As it was stated in the introduction, we do not think simple average method can be the most convenient one to analyze and prove a potential structural shift. That method ignores whether or not the difference between averages

is statistically significant and, moreover, does not account for exactly when the effect started: Did it start right at 1980? Before? After? What was the criterion to choose 1980 as a beginning point? For all of these reasons, especially given the importance of the phenomenon in order to find the best way to manage water resources supply, we propose a statistical approach to study the problem in the Upper Tagus area.

We aim to use structural change tests to confirm the existence of the problem and, in case of an affirmative result, to employ outlier detection techniques and Time Series Analysis, thus creating a model of the behavior of flows.

Structural break test are commonly used to test the constancy of certain parameters, such as mean, variance and/or trends, over time. Classical break-point test need to know the breakdate to be tested, which means that breakdate have to known a priori. Our case is quite different: we are discussing the existence of an unknown potential breakpoint, thus breakdate cannot be identified a priori. To test it, we will use the CUSUM test. This kind of test, as opposed to Chows⁴, tests a null hypothesis of constancy parameters, as calculated by the regression, against an alternative of unknown break points in the series. There have been several different approximations and transformation proposals since the original one by Quandt. We use here the one proposed by Brown, Durbin and Evans [Brown et al., 1975], based on recursive residuals. This kind of test is really intuitive in a graph form: basically, the procedure plots the recursive residuals; the null hypothesis is rejected if the residuals cross the boundaries given by the confidence level of the test⁵. In case we find empirical evidence of an structural breakpoint we still wouldn't know the breakdate. The Quandt-Andrews Breakpoint Test will be useful at this point: the idea behind the test is that a single Chow Breakpoint Test is performed at every observation between two dates or observations. The n test statistics from those Chow tests are then summarized into one test statistic for a test against the null hypothesis of no breakpoints⁶. The individual test statistics again can be summarized into three different statistics; the Maximum statistic, the Exp Statistic, and the Ave statistic⁷ (see

⁴The Chow test was developed to test the null hypothesis of constancy parameters against an alternative of a priori known point of rupture or structural change.

⁵We need to calculate, before of all, a regression against a constant, that allows us to use the CUSUM test to check if our data have an structural change).

⁶From each individual Chow Breakpoint Test two statistics are retained, the Likelihood Ratio F-statistic and the Wald F-statistic. The Likelihood Ratio F-statistic is based on the comparison of the restricted and unrestricted sums of squared residuals. The Wald F-statistic is computed from a standard Wald test of the restriction that the coefficients on the equation parameters are the same in all subsamples.

⁷Maximum statistic is simply the maximum of the individual Chow F-statistics, while Ave is just the average of the n Chows test and exp is an exponential transformation of

Andrews [1993] and Andrews and Ploberger [1994]). The maximum statistic gives us a date, which is the most likely breakpoint location.

Time Series Analysis is well developed in econometrics and widely used in economics, and other social sciences, to predict and forecast, for example, the main macroeconomic variables behavior. Since the first works cited by Salas et al. [1980] at the fifties and sixties decades of the past century, until our days, Time Series Analysis have also been widely applied in water resources management, hydrology and climate phenomena, to develop mathematical models to generate synthetic hydrological records, to forecast hydrological events, to detect trends and shifts in hydrological records, and to fill in missing data and extend records [Salas et al., 1980].

In relevant literature on hydrology and water management we can find also developments of deterministic models instead those stochastic approaches. That kind of models describes mathematically the hydrologic systems in a physical way, needing for that some parameters related to the characteristics of these physical systems and detailed historical observations. Those data, usually unavailable, are needed in order to both describe thoroughly the system and ensure a good calibration of the model. Stochastic models, such a time series models, do not show such pre-requirements and avoid thus the problems given by deterministic approaches. Those models by their part describe mathematically the system processes and the statistical relationship directly from the real data. Just to cite some cases, we can find ARIMA models to evaluate effects of climate an human intervention or to forecast levels in ground water in [Gemitzi and Stefanopoulos, 2011], [Aksoy et al., 2013] and [Von Asmuth et al., 2008]; to model rainfall in Momani [2009] and Wang et al. [2011]; to reconstruct natural flows in regulated river systems in Wen [2009] or to model Stream flows in Özcelik and Baykan [2009].

Time series observations are sometimes influenced by events -known or unknown- and/or measure errors. The observations affected can therefore have a different structure and appear as outliers. Series can also have deterministic effects: for example, seasonality phenomena in a climate series or non-regulated river flows, subject to different patterns according to the season. While focusing on the same goal, outliers and intervention analysis help us in two different ways: firstly, including outlier analysis in the ARIMA models reduces the residual variance of the model, which may otherwise distort the properties of correlation, and secondly, intervention analysis allows us to capture irregular effects on our data, improving the accuracy of our models. Aljoumani et al. [2012], for instance, applies this kind of analysis to explain the influences of irrigation management on soil water content.

those chow test

Climate series as well as water data presents often seasonality. What means seasonality? It means special annual dependence. From the point of view of economic theory, the seasonal dependence of economic time series is especially interesting because substantial components of seasonal fluctuations are predictable. It allows the decision-makers to plan better, at the same time improvements in seasonal forecasting lead to sharp the restrictions on decision rules. Obviously, in the context described before, this is particularly important.

For the statistical analysis of river flows in this study, we use the monthly data available from the Center for Study and Experimentation in Infrastructures (CEDEX⁸) of the Spanish Government. Data availability in CEDEX is available from the hydrologic year 1953-54 until 2009-10. There are also other data sources, such as the Automatic System of Hydrologic Information (SAIH) but precisely because of the automatic character of the data -they are real time observations-, they are not previously evaluated and the potential errors are therefore not corrected. So it was not pertinent to include these sources in the study.

The data series employed in this primary long term trends analysis is an aggregate, by hydrological year, of monthly data available. This method allows us to study the series without taking into account the seasonality of the series, which does not add information to determine long term trends and to figure out whether there is a structural change in flows from the sources throughout the sample. To replicate the graph given by the Tagus river basin authority, the same time sample will be used in the first phase of the trend analysis, although the econometric analysis will be done with all the data available

3 Data analysis and results

Figure 3 shows line graphs of the inflows to Entrepeñas and Buendía within the sample considered. As we saw in the graph above, since hydrologic year 1968/69 there has been a sustained decrease in the total amount of water that arrived to both dams until 1976/77, when a wet year occurs. However, after that last year, the dry years have been drier than the previous ones, indicating a potential structural change in the mid 70s rather than 80s. In the series represented in the smaller graphs bellow, which shows the water that arrived to each dam, both areas show the same effects and trend.

Returning to the aggregated series of both dams, in figure 4 we can identify

⁸<http://hercules.cedex.es/anuarioaforos/default.asp>

a decreasing trend for the period 1958/59-1975/76 with dry years becoming increasingly drier and a no-trend period -from 1975/76 to 2005/06- with flows fluctuating around a constant mean value (which means stationarity). Moreover, there appears to be a constant negative trend for wet years (being little by little less wet) while dry years have eventually leveled off after the initial decreasing period. However, there is clearly not a level shift, according to the graphs, as is suggested in the initial graph.

We clearly need some kind of analytical analysis to confirm or reject that hypothesis. In order to do that, as we said, intervention analysis and structural change tests allow us to make a more comprehensive study. First, we will model our datasets against a constant value, using the structural change test to ensure we have different trends throughout the sample. Then, if we have statistical evidence of structural change, the second stage will show us how it changed, using intervention analysis.

Thanks to the graphical analysis, we suspect that there is a change in the trends of the river flows from the head waters. Nonetheless we cannot be sure when the change occurred or even if it exists. The best way to proceed is to use the CUSUM test to find empirical evidence of structural change and then to try to model it.

As we can see in figure 5, the test rejects the null hypothesis of constant coefficients for water inflows to Entrepeñas and Buendía. This means, as suspected, there is a structural change in the main trends of water flows from the Tagus sources. However, we still do not know when our break point could happen. Table 1 shows us the results for Quandt-Andrews Breakpoint test. We reject the null hypothesis of no breakpoints, and, according the result, the breakpoint will most likely take place in 1980. We have thus another confirmation of our suspicions.

Previous conclusions make it possible to check three different interventions: constant trend until hydrologic year 1980/81, constant trend for the whole sample and level shift in 1980. Results from the regressions can be seen in table 2.

For all of the interventions checked, individual tests for significance rejects their respective null hypothesis –regression coefficients equal zero-, i.e. all of the interventions purposed are significant. Ljung-Box Q statistic⁹ does not find any empirical evidence to reject the null hypothesis of uncorrelated residuals; neither does the Normality contrast of Jarque-Bera¹⁰ find any em-

⁹The Ljung-Box Q statistic is commonly used to test the existence of autocorrelation, under the null hypothesis of the correlations of the data taken are zero, that is, data is independently distributed

¹⁰The Jarque-Bera tests the normality of the residuals, under the null of hypothesis of normality. For that, the test evaluates if, for the data sample, the skewness is zero and

irical evidence to reject the null hypothesis of normality.

All of these tests mean the interventions are all valid and useful to explain what is happening with the flows from Tagus sources. At the same time, the residuals do not offer us any ARIMA structure that can be used to forecast the future. So, unfortunately, all of these models permit us no more than to offer a constant value as a prediction for each time period:

$$\text{Water flows}_t = e^{7.20-0.62\text{level shift}_{1980}} + \epsilon_t \quad (1)$$

In any case, what is important in this Intervention Analysis is to figure out the shape of our structural change. Table 2 also collects the values for the different info criterions traditionally used to choose between models. The way to calculate this criterions make the lowest value the best choice, and, as we can see, the level shift has the lowest values for both criterions.

This means that before 1980 the yearly average flow reached a value of 1345.91 hm³, and then, from that moment on, it decreased to an average of 722.68 hm³. Figure 6 illustrates how the model fits the data.

Seasonality analysis.

Our Area of study is located in the Tagus Headwaters, without any regulation infrastructures -in fact, Entrepeñas and Buendía are the first regulation infrastructures. It means the flows in the study are close to the so-called natural regime of the river, thus showing periods of high and low levels of water depending on the season. Moreover, as we said before, most of the river basins in Spain, because of their climate patterns, show high inter-annual and inter-season variability, and dramatic reductions of water flows in the summer months. This brings up some questions: can we expect the same patterns about structural change during the seasons? Could we find extreme phenomena in specific seasons to help us to explain the evidence we have found? In order to answer these questions, we propose a seasonal analysis on the monthly series of the water inflows to Entrepeñas and Buendía.

Figures 7 and 8 illustrate this point. We show the values gathered by months as well as the groups average. As we can see in both dams, effectively every month series draws different patterns according the years season: the lowest water levels correspond to August and September, increasing month by month up until March. Then, the decreasing trend starts again in April. Inflows from the headwaters follow in both dams the same seasonal patterns, and they even have the same, or close to the same, average values.

Within each monthly group, we also can appreciate trends, like in the ag-

the kurtosis is three in the data sample.

gregated series. Figures 9 and 10 show more detailed graphs of the evolution of river flows in each month. First of all, we can see a clear difference between spring-summer and fall-winter in both dams: during the spring-summer months, the decreasing trend seems to have been longer than for the rest of them. Concretely, decreasing trends in May, June, July, August and September in Buenda and also Entrepeas, seem to continue to the 90s, while in the another months seem to finish at 80s. However, apart some years especially wet, we cannot appreciate extreme phenomena.

These trends offer us the chance to check again if the structural breakpoint in the series along all the months is stable. To test the breakpoints, we will use again the Quandt-Andrews Breakpoint test, looking for both evidence of structural change and the most likely point of change. Results are summarized in Table 3 almost all of the contrast are significant -just November in Entrepeas- shows a probability that impedes to reject the null hypothesis of the contrast -the other ones higher than 0.05 (our confidence level) are really near of the level, and doubtless are significant at 0.10 level. 1980-81 seems the most likely breakpoint, however as we said, spring-summer data have different patterns, delaying their breakpoint to 1990.

Once the same structural dynamics are identified, models for each month pattern will be also proposed. This time, instead checking which intervention fits better to the data available, we are going to build models incorporating, in case we need, the best intervention. 24 models have been estimated (12 months and 2 dams) in order to, first, test the best intervention and, secondly, offer a tool for planning forecasting. Models use a month as a dependent variable¹¹ to make regressions against both the intervention variables and previous months, in order to take in count the dynamics of previous months.

The first 12 equations showed -equations 2 to 13- correspond to Buendía's flows while the following 12 are for Entrepeñas' -equations 14 to 25. As we can see some of them follow the exactly same equation to explain their flows, being the coefficients what slightly vary from equation to another one. This is the case of December, January, February, April, May, June. The rest present some variations in their equations.

$$\text{bOct}_t = e^{1.40+0.58 \log \text{bSept}_t+1.5i_{1966}+0.5i_{1980}+1.04i_{2000}-0.22ls_{1981}} + \epsilon_t \quad (2)$$

$$\text{bNov}_t = e^{0.27+0.97 \log \text{bOct}_t} + \epsilon_t \quad (3)$$

$$\text{bDec}_t = e^{3.08+0.98 \log \text{bNov}_t-0.68 \log \text{bOct}_t-0.05rp_{1968}} + \epsilon_t \quad (4)$$

¹¹Series from Buendía were named with 'B', while series from Entrepeñas were with 'E'. Intervention variables were indentified with 'ls' for level shifts, 'i' for impulses, 'rp' for ramps and 'tr' for trends

$$\text{bJan}_t = e^{0.34+0.97 \log \text{bDec}_{t-1}} + \epsilon_t \quad (5)$$

$$\text{bFeb}_t = e^{1.45+0.69 \log \text{bJan}_t - 0.44l_{1980}} + \epsilon_t \quad (6)$$

$$\text{bMarch}_t = e^{1.81+0.65 \log \text{bFeb}_t + 0.119i_{1969} + 1.08i_{2001} - 0.02rp_{1980}} + \epsilon_t \quad (7)$$

$$\text{bApril}_t = e^{1.67+0.54 \log \text{bMarch}_t} + \epsilon_t \quad (8)$$

$$\text{bMay}_t = e^{0.94+0.72 \log \text{bApril}_t} + \epsilon_t \quad (9)$$

$$\text{bJun}_t = e^{0.73+0.76 \log \text{bMay}_t - 0.27l_{1990}} + \epsilon_t \quad (10)$$

$$\text{bJul}_t = e^{0.87+0.66 \log \text{bJun}_t} + \epsilon_t \quad (11)$$

$$\text{bAug}_t = e^{0.82+0.73 \log \text{bJul}_t - 0.20l_{1985}} + \epsilon_t \quad (12)$$

$$\text{bSept}_t = e^{0.30+0.93 \log \text{bAug}_t - 0.008tr} + \epsilon_t \quad (13)$$

$$\text{eOct}_t = e^{0.61+1.05 \log \text{eSept}_t - 0.23 \log \text{eAug}_t + 1.5i_{1961} + 0.89i_{1966} + 0.8i_{1944} + 0.84i_{2000}} + \epsilon_t \quad (14)$$

$$\text{eNov}_t = e^{0.39+0.92 \log \text{eOct}_t + 0.92i_{1962} + 1.67i_{1964} + 1.05i_{1966} + 0.93i_{1998}} + \epsilon_t \quad (15)$$

$$\text{eDec}_t = e^{3.52+0.9 \log \text{eNov}_t - 0.81 \log \text{eOct}_t - 0.04rp_{1968}} + \epsilon_t \quad (16)$$

$$\text{eJan}_t = e^{0.38+0.90 \log \text{eDec}_{t-1}} + \epsilon_t \quad (17)$$

$$\text{eFeb}_t = e^{1.57+0.65 \log \text{eJan}_t - 0.41l_{1980}} + \epsilon_t \quad (18)$$

$$\text{eMarch}_t = e^{1.85+0.60 \log \text{eFeb}_t + 0.35l_{1980}} + \epsilon_t \quad (19)$$

$$\text{eApril}_t = e^{1.75+0.55 \log \text{eMarch}_t} + \epsilon_t \quad (20)$$

$$\text{eMay}_t = e^{0.99+0.72 \log \text{eApril}_t} + \epsilon_t \quad (21)$$

$$\text{eJun}_t = e^{0.80+0.76 \log \text{eMay}_t - 0.31l_{1990}} + \epsilon_t \quad (22)$$

$$\text{eJul}_t = e^{0.91+0.64 \log \text{eJun}_t - 0.18l_{1990}} + \epsilon_t \quad (23)$$

$$\text{eAug}_t = e^{0.34+0.83 \log \text{eJul}_t - 0.08l_{1990} - 0.38i_{1988} + 0.41i_{1989}} + \epsilon_t \quad (24)$$

$$\text{eSept}_t = e^{1.39+0.55 \log \text{eAug}_t - 0.14l_{1980}} + \epsilon_t \quad (25)$$

All of these models explain the trends observed in the monthly series, using, in almost all cases, the month immediately before and also intervention analysis. Only in three cases (December in both dams and October in Entrepeñas) was it necessary to use two previous months to explain the patterns. Comparing month by month in each dam, we see that January, April and May, in both dams, and also July, in Buendía, do not need any intervention to model the flows. Their changes are related to the changes of the month

immediately before. July in Entrepeñas has a significant intervention (level shift) in 1990. Both Decembers show a dependency on the two previous months and they also have a significant intervention (constant trend until 1968). August, June and February show, in both dams, a significant level shift intervention in their respective breakpoints; however, August's series in Entrepeñas also needs several more interventions in dry/wet years (1988 and 1989). March and September display different equations depending on the dam. September in Buendía fits the data better with a constant trend, while, in Entrepeñas, we find a level shift. March in Entrepeñas has also a level shift, but in Buendía we find a significant constant trend intervention until 1980 and also several isolated interventions for wet years (1969 and 2001). October in Buendía shows dependency just with September, but also we need several interventions to fit data available: level shift in 1981 and impulse intervention in 1961, 1966, 1980 y 2000. October in Entrepeñas has almost the same impulse interventions (one in 1994 instead of 1980) with no level shifts; Octobers dynamics can only be explained using August and September. Changes in November are explained using just October's series in Buendía, while in Entrepeñas we need a few impulse interventions: 1962, 1964, 1966 and 1992.

4 conclusions

This work aims to study the empirical evidence in support of the hypothesis of the so-called Eighty Effect, the reduction of water flows from the sources along the Iberian Peninsula up until 1980. Water inflows to Entrepeñas and Buendía were used to study this phenomenon. The Eighty Effect appeared undeniable while analyzing the main trends shown in the graphs, and then the statistical tests confirmed it. Using the Quandt-Andrews Breakpoint Test, we fixed the most likely breakpoint in 1980.

Once the breakpoint was specified, we used intervention analysis to find the shape that fits the available data better. Three different interventions were checked: constant trend until hydrologic year 1980/81, constant trend for the whole sample and a level shift in 1980. As a result, the best way to model the phenomenon is with a level shift. However, we cannot find any other statistical structure to provide a model (our best prediction would be the value of the average).

Based on inter-annual and inter-season variability, we propose a seasonal analysis to determine if the same patterns are followed every month and to try to provide valid models of the data. Monthly series provide us with the

same evidence as the aggregate ones (there is structural change), but with a different likely breakpoint depending on the month. The models proposed use the previous months and different intervention variables to model the structural change and to explain their dynamics.

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5 Annex of tables and figures

Table 1: Quandt-Andrews Breakpoint test

	Statistic	Probability
Maximum LR F-statistic (1980)	8.253804	0.0058
Maximum Wald F-statistic (1980)	16.50761	0.0058
Exp LR F-statistic	2.497839	0.0083
Exp Wald F-statistic	5.742408	0.0041
Ave LR F-statistic	4.211433	0.0035
Ave Wald F-statistic	8.422866	0.0035

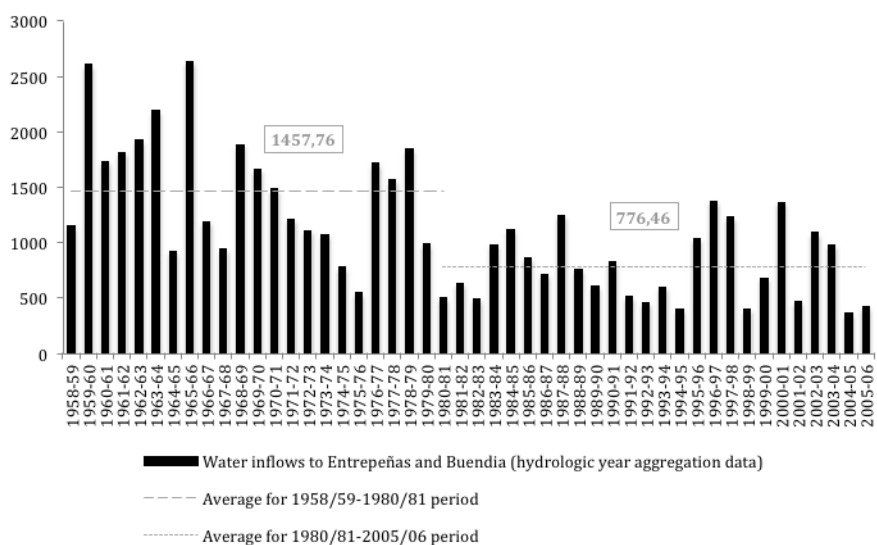
Table 2: Interventions in logarithmic transformation of river flows. Main values

Regressor	Coefficient	Standard deviation	t statistic ¹²	Probability	AIC	BIC
Constant Trend	-0.017329	0.003566	-4.860169	0	1.190876	1.263210
Level shift in 1980	-0.621854	0.110258	-5.639979	0	1.090590	1.162923
Constant Trend until 1980	-0.031887	0.007392	-4,313771 0	1.257634	1.329968	

Table 3: Quandt-Andrews Breakpoint test. Max values.

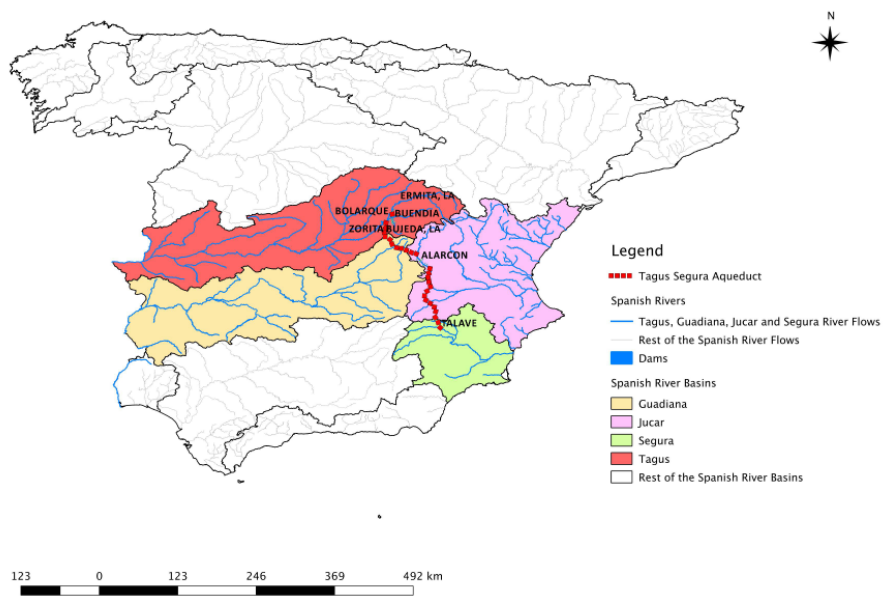
Month	Statistic for Buendia	Probability	Breakpoint	Statistic for Entrepeñas	Probability	Breakpoint
October	24,05164	0	1981	9,945728	0,0270	1981
November	9,971997	0,0267	1981	5,368404	0,2114	1981
December	10,55563	0,0204	1967	10,55563	0,0204	1967
January	10,93536	0,0171	1980	7,729099	0,0473	1971
February	14,64048	0,0030	1980	11,61437	0,0124	1980
March	18,02187	0,00006	1980	14,18199	0,0037	1980
April	17,33976	0,00008	1980	12,46606	0,0083	1980
May	17,23803	0,00009	1990	8,395444	0,0551	1990
June	28,70944	0	1990	24,75158	0	1990
July	37,21769	0	1990	34,06897	0	1990
August	21,29227	0,00001	1985	36,80903	0	1990
September	7,201515	0,0945	1992	22,97255	0,0001	1980

Figure 1: Evolution of water inflows from Upper Tagus



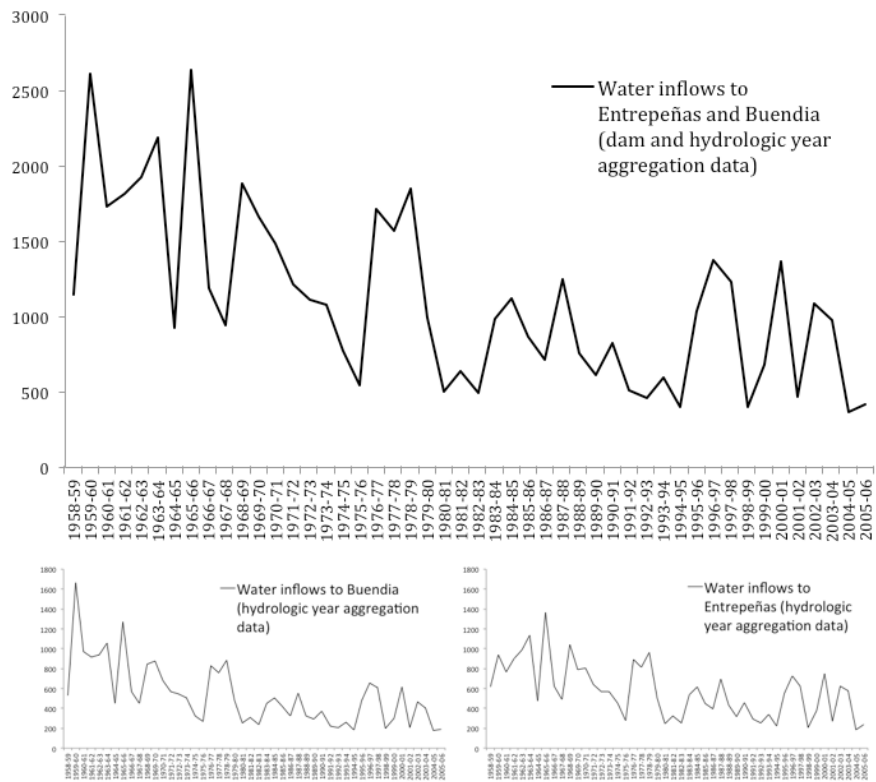
Source: Own elaboration from Tagus River Basin Authority

Figure 2: Geographic location



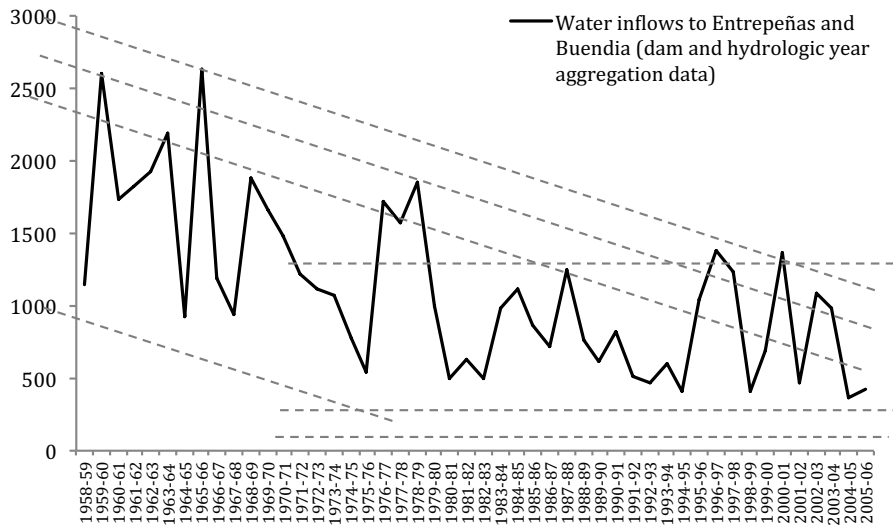
Source: Own elaboration

Figure 3: Water Inflows to Entrepeñas and Buendia. Total aggregate inflows (hm³)



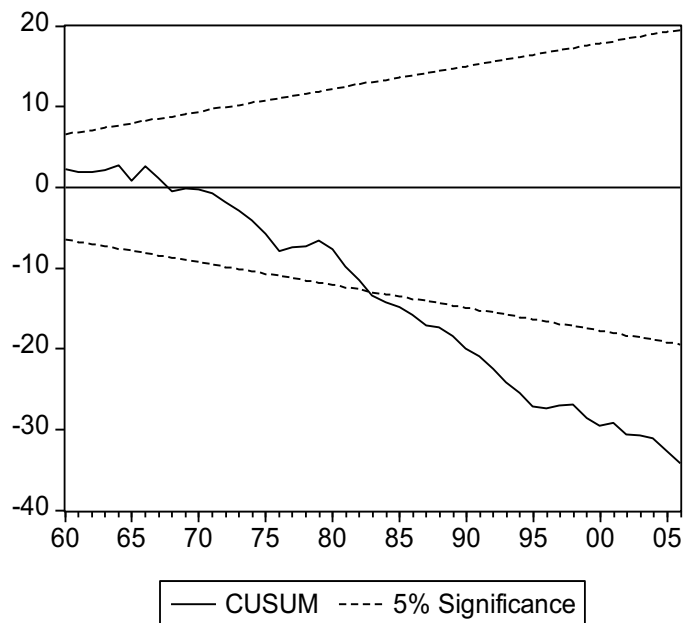
Source: Own elaboration

Figure 4: Total Aggregate Water Inflows to Entrepeñas and Buendia in (hm^3)



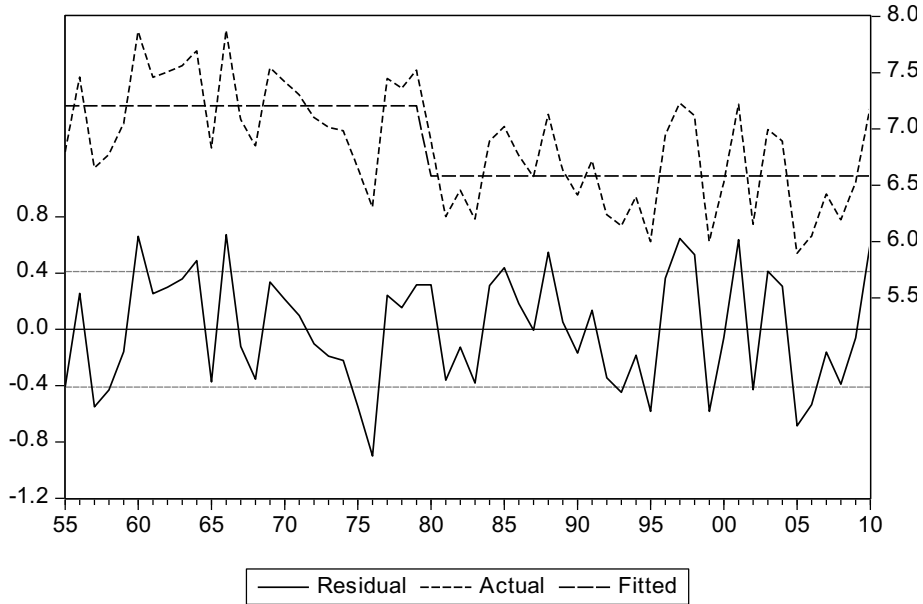
Source: Own elaboration

Figure 5: CUSUM test results for water flows from the Tagus headwaters



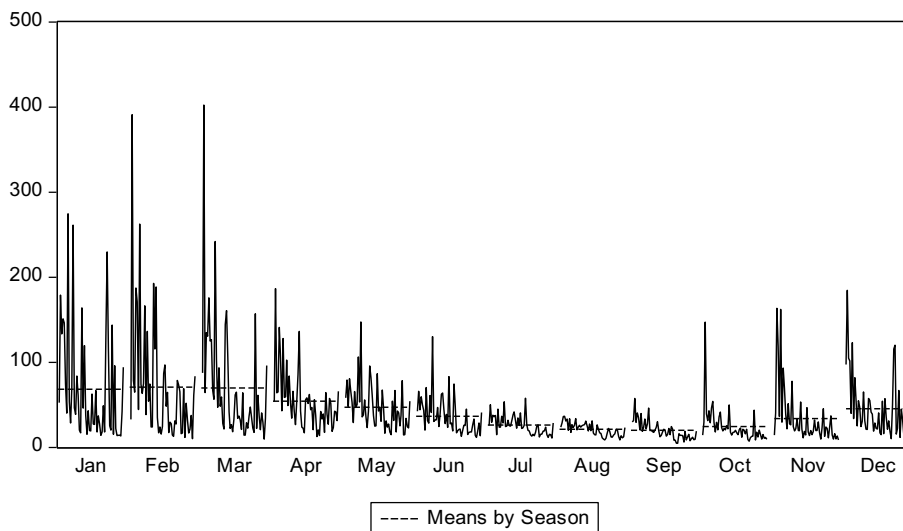
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Figure 6: Tagus Headwaters flows, model fitting, and regression residuals



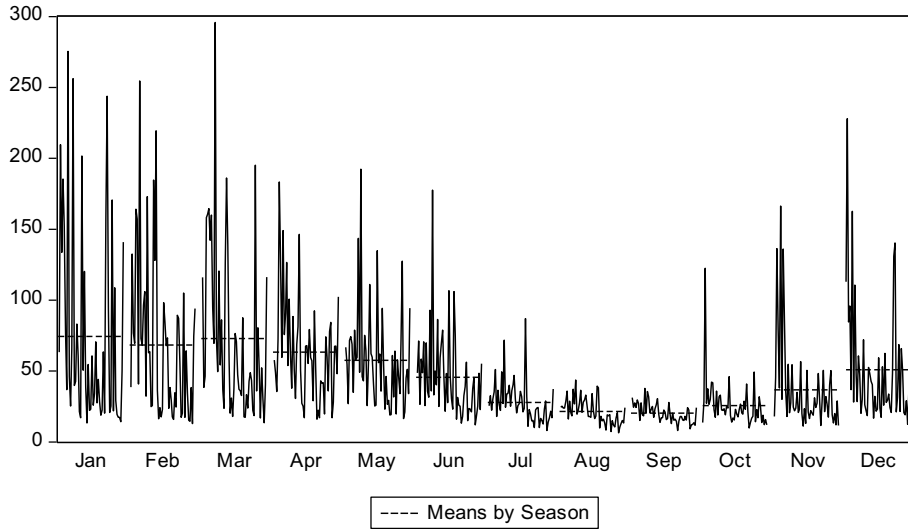
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Figure 7: Means by season at Buenda dam.



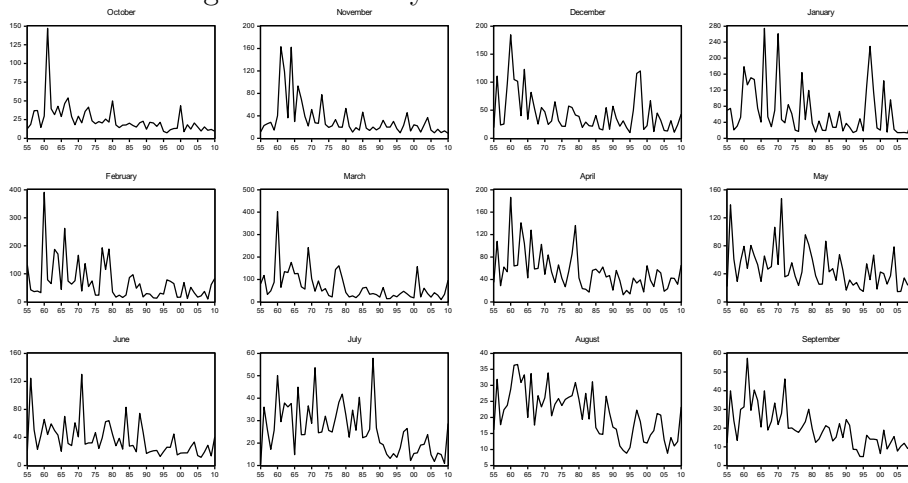
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Figure 8: Means by season at Entrepeas dam.



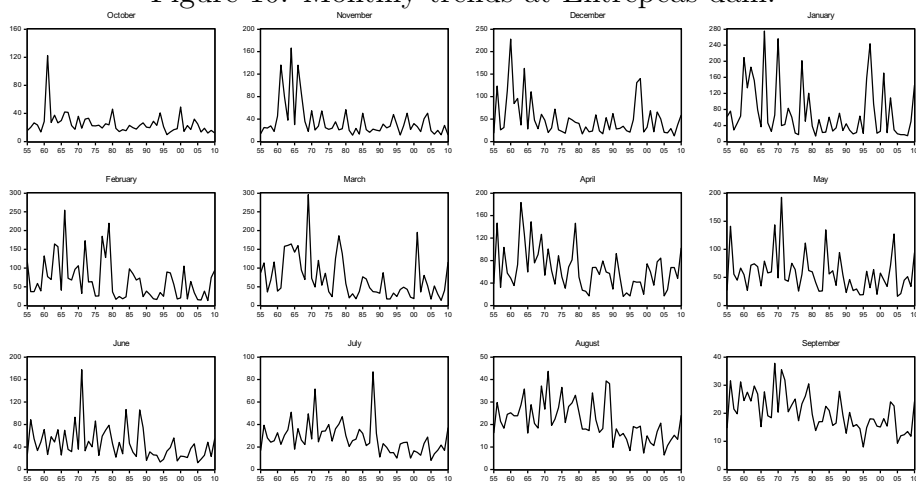
Source: Own elaboration

Figure 9: Monthly trends at Buenda dam.



Source: Own elaboration

Figure 10: Monthly trends at Entrepeas dam.



Source: Own elaboration