Looking backward to look forward: water use and economic growth from a long-term perspective

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Recent research has examined the relationship between natural resources and economic growth. Considered vitally important, not only for humanity’s well-being but also for the integrity of the ecosystem, the relationship between water use and economic growth has nevertheless traditionally attracted little attention by analysts. This article studies water use trends from 1900 to 2000 throughout the world and their relationship to the main determinants of economic growth. To do this, we first analyse water use trajectories. Second, to proceed with the determinants of water use, we reformulate the Ehrlich and Holdren’s impact, population, affluence, technology (IPAT) equation (1971), decomposing water use trends into changes in economic demands and in water use intensity on the basis of a decomposition analysis. Finally, a simple scenario analysis is conducted, to project future water use trends under different economic, demographic and technological assumptions.

The empirical evidence shows that economic and population growth have been crucial in explaining the increase in water use over the past 100 years, with significant regional differences. Nevertheless, the decline in water use intensity has been responsible for a significant reduction in the growth of total water use.

**Keywords:** water use; economic growth; Kuznets environmental curve; IPAT model

**JEL Classification:** Q25; Q56; N50

\section*{I. Introduction}

The threat of a global water crisis is one of the challenges to be faced in the twenty-first century both by society and the research community. Sustainability is becoming a central issue for all regions and sectors, international agencies are increasingly coping with water stress problems, setting water-related goals, especially since 1972 (UN Water, 2009).

Looking back, water use experienced a sharp rise. According to L’Vovich and White (1990), while global water withdrawals remained stable for centuries, these increased thirty-five-fold from 1687 to 1987. McNeill (2000) shows a forty-fold increase in freshwater consumption from 1700 to 1900 and a seven-fold rise in the twentieth century.
The expansion of agriculture and irrigation entailed an enormous rise in water use but allowed food security to be achieved for large populations. Today, agriculture accounts for 66% of freshwater withdrawals and 85% of freshwater consumption. From the onset of industrialization, when industrial water use was negligible, substantial growth has taken place. Today, industry accounts for approximately 20% of total freshwater withdrawals. During the twentieth century, urban populations experienced a huge rise. As a result, urbanization created a greater need for water; today, urban use currently accounts for 7% of the total (Shiklomanov, 2000).

In this general context, our work aims to study the drivers of water use from a long-term perspective. More concretely, we analyse world and regional trends in water use during the last century and their relationships with population, economic growth and technological change. On the basis of this analysis, we anticipate possible scenarios regarding water stress in the future.

To date, a number of studies have examined environmental pressures from an economic perspective, bringing the consequences of unsustainable resource use to the forefront. This literature mainly focuses on the long term (Kander and Lindmank, 2004; Gales et al., 2007) and on the recent past (Feng et al., 2009). However, these investigations basically aim to assess the evolution of energy use or pollution emissions.

To our knowledge, on the subject of water withdrawal from a global and historical perspective, little research has focused on this limited resource, given the lack of reliable regional and world data. Some studies, such as L’Vovich and White (1990); Shiklomanov (2000); Goklany (2002); Barbier (2004) and Gleick et al. (2008), have made a general assessment of water resources and only a few of them have focused on the relationship between water and income (Cole, 2004; Katz, 2008; Duarte et al., 2013). Nevertheless, the long-term perspective has often been excluded from the analysis, mainly due to the lack of reliable historical data on global water use.¹

This article is an attempt to analyse the determinants of water use trends in the long term from a global perspective, as well as disentangling the major drivers responsible. In this regard, the impact, population, affluence, technology (IPAT) model (Ehrlich and Holdren, 1971) is reformulated for and adapted to the case of water withdrawal to analyse the general twentieth century trends in water use, and to identify the major issues underlying water use dynamics. This analysis will be the baseline scheme to formulate scenarios for economic and demographic growth, in which we analyse water pressures under different hypotheses of population and economic growth. Looking back at historical water use offers certain lessons in order to manage current and future water scarcity in the world.

Therefore, the contribution of this article is twofold. First, the IPAT model, together with our decomposition analysis, offers understanding and quantification of the drivers of water use. Second, the combined study of demographic, economic and water use trends from a historical perspective offers guidance for the future.

The results show that water withdrawal experienced a sharp rise until 1980, when a smooth levelling off took place. On the whole, this growing trend could have been caused by the rapid upturn of population and GDP, together with the intensification of agriculture. Industrialization and the gradual increase in standards of living may also have boosted water use. The substantial decrease in intensity is probably one of the reasons behind the flattening of water use of the past twenty years. Thus, it is reasonable to expect elements such as economic or efficiency improvements to have exerted a significant influence on water use.

The rest of the article is organized as follows. Section II reviews the theory behind the relationship between economic growth and the environment, as well as the methodology and data we use. In Section III, we present the main results of the analysis. Section IV closes the article with a discussion of the results and our conclusions.

II. Material and Methods

Since the 1970s, social and physical scientists have shown concern over the impact of industrial economies on the environment. The work of Georgescu-Roegen (1971) and the seminal report ‘The Limits to Growth’ (Meadows et al., 1972) marked the beginning of a more academic concern for environmental impacts associated with growth. In this line, economists such as Martínez Alier (1991) and Nakicenovic et al. (2000) claim that economic and population growth, as well as improved living standards, involved ever-increasing requirements for energy and materials.

Alternatively, other economists maintain that higher levels of income reduce environmental degradation. They consider development essential for environmental quality and believe in a de-linking between natural resources and economic growth. From this perspective, the idea of dematerialization found support on the Environmental Kuznets Curve (EKC hereafter). Important papers (Grossman and Krueger, 1992; Selden and Song, 1994, 1995) found empirical evidence regarding EKC and suggested three effects that explain the

¹ On the contrary, there exists an abundant and interesting literature studying more specific topics such as water footprints (Hoekstra et al., 2009), virtual water (Hoekstra and Hung, 2002), water quality (Dabrowski et al., 2009) or water demand (Ruijs et al., 2008), for specific areas and recent periods.
relationship: scale, composition and technology. In general terms, shifts towards the service sector, improvements in technology, trade and societal changes in attitudes towards the environment have been cited as contributors to the decrease of environmental damage when countries become richer (Ekins, 1997; Gales et al., 2007).

The debate continues today, focusing on the possible explanations of environmental trends. It would appear that consensus regarding the location of different economic, technological and demographic factors behind the relationship between growth and environmental pressures exists. Thus, many studies have focused on the analysis of the contribution of these factors. In this context, the SDA has been applied to the IPAT model (Commoner et al., 1971; Ehrlich and Holdren, 1971) to synthesize the role played by economic growth, population demands and technology in explaining these environmental impacts. This combined methodology is applied to examine water use factors for the first time in this article. Given that we are dealing with global trends, this tool appears to be useful to highlight the determinants of water use. As Turner (1996) has stated, the IPAT model is suitable for the macro-scale assessment of environmental impact drivers. However, it seems to be less appropriate when making local scale assessments, since other factors such as policy or institutions may play a larger role. The IPAT model emerged as a result of the interaction between economic growth, population and affluence. Variable $I$ generally means $I/GDP$, that is, environmental impact per unit of GDP, or environmental intensity. This latter factor is the most difficult to define and quantify, since other important elements, apart from technology, are also captured (economic structure, factor endowments, geography, infrastructure, cultural history and/or climate). Dietz et al. (2007) use a comparative study to demonstrate that population and affluence are the main determinants of environmental change, while ‘other widely postulated drivers (e.g., urbanization, economic structure, age distribution) have little effect’. Methodologically, a similar expression can be derived in terms of the forces driving water use:

$$W_t = N_t \frac{Y_t}{N_t} \frac{W_t}{Y_t} = N_t Y_t W_t$$

In this case, water consumption in a period $t$ can be expressed as a result of the interaction between population ($N$), per capita income ($y$) and an index of water intensity ($w$).

Analytically, in order to study trends in water use and disentangle the forces contributing to such trends, a decomposition analysis is applied.

It tries to separate a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998; Lenzen et al., 2001; Hoekstra and van der Berg, 2002).

Generally speaking, considering a variable $y$ depending on $n$ explicative factors $y = f(x_1, \ldots, x_n)$, an additive structural decomposition can be obtained through its total differential.

$$dy = \frac{\partial y}{\partial x_1} dx_1 + \frac{\partial y}{\partial x_2} dx_2 + \ldots + \frac{\partial y}{\partial x_n} dx_n$$

On the basis of a multiplicative relationship, that is $y = x_1 \ldots x_n$, expression (4) states:

$$dy = (x_2x_3 \ldots x_n)dx_1 + \ldots + (x_1x_2x_3 \ldots x_{n-1})dx_n$$

$$= \sum_{j=1}^{n} \left( \prod_{j=1}^{n} x_j \right) dx_j$$

In a discrete schema, when we try to measure the changes in the dependent variable between two periods, $t-1$ and $t$, there are different ways of solving this expression by way of exact decompositions, which lead to the well-known problem of nonuniqueness of the structural decomposition analysis solution. In our case, if decomposition is based on three factors, we can obtain the following 3! exact decompositions. In practice, as a ‘commitment solution’, the average of all possible solutions is considered. Nevertheless, as Dietzenbacher and Los (1998) demonstrate, the simple average of the two polar solutions
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decompositions is a good approximation of the average of the 3! exact forms.

Thus, based on (2), the two polar decompositions can be written as follows:

\[
\Delta W_t = W_t - W_{t-1} = N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} \\
= \Delta N_t y_t w_t + N_{t-1} \Delta y_t w_t + N_{t-1} y_{t-1} \Delta w \\
= A_{1t} + A_{2t} + A_{3t} \\
\]

\[
\Delta W_t = W_t - W_{t-1} = N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} \\
= \Delta N_t y_t w_t + N_{t-1} \Delta y_t w_t + N_{t-1} y_{t-1} \Delta w \\
= B_{1t} + B_{2t} + B_{3t} N_t y_t w_t - N_{t-1} y_{t-1} w_{t-1} + N_t \Delta y_t w_t - N_{t-1} \Delta w \\
+ N_{t-1} y_{t-1} \Delta w = B_{1t} + B_{2t} + B_{3t} \\
\]

and taking the average we obtain (7),

\[
\Delta W_t = \frac{1}{2} (A_{1t} + A_{2t} + A_{3t}) + \frac{1}{2} (B_{1t} + B_{2t} + B_{3t}) \\
= \frac{A_{1t}}{2} + \frac{A_{2t}}{2} + \frac{A_{3t}}{2} + \frac{B_{1t}}{2} + \frac{B_{2t}}{2} + \frac{B_{3t}}{2} \\
= PE_t + INE_t + IE_t \\
\]

In this way, water use evolution can be obtained as a result of the contribution of population, income and intensity effects.

\[
PE_t = \Delta N_t \left( \frac{y_t w_t + y_{t-1} w_{t-1}}{2} \right) \\
INE_t = \Delta w_t \left( \frac{N_t y_t + N_{t-1} y_{t-1}}{2} \right) \\
IE_t = \Delta y_t \left( \frac{N_t w_t + N_{t-1} w_{t-1}}{2} \right)
\]

On these bases, we apply this methodology to a regional world water withdrawal data set over the period 1900 to 2000 (UNESCO, 1999). This data set, prepared for the Comprehensive Assessment of the Freshwater Resources of the World in the framework of the International Hydrological Programme (IHP) of UNESCO by the Russian IHP National Committee, contains data on global freshwater resources from 1900 to 1995 as well as forecasts for 2000, 2010 and 2025 and covers all economic regions and continents in the world. Since our main goal is to examine aggregate trends from a long-term perspective, we use regional and world historical data. For a more specific study on local facts, country or basin data should be used. To carry out the analysis, we need income and population data series. Income is measured by GDP (in 1990$ on a purchasing power parity basis) and comes from Maddison (2010). Population information is also provided by Maddison (2010).

III. Results and Discussion

In order to organize the results and discussion, this section is divided into three subsections: an initial description of global and regional water withdrawal features (‘Historical water use’ section), the quantification of the factors that entail changes in water use and the explanation of these determinants (‘Looking behind the data’ section) in the light of the applied IPAT_DA decomposition and finally, the results obtained from the scenario analysis (‘Perspectives on water use in 2050: results from a scenario analysis’ section).

Historical water use

Figure 1 and Table 1 show the main features in water use from 1900 to 2000, both in global terms and for the seven regional areas in which the world has been divided.

Data show that water withdrawal increased approximately seven-fold, from 539 km$^3$ in 1900, to 4000 km$^3$ in 2000. As shown in Fig. 1, throughout the twentieth century there was a continued growth in per capita income, and global freshwater withdrawal also experienced a continuous climb, with a weak levelling off from the 1980s. This expansion was slightly faster in the second half of the twentieth century and especially in the 1950s, when the highest annual growth rates were reached (3.6%). Since that time, freshwater use continued to expand, although much less rapidly than in the past. In fact, from 1990 to 2000, the average annual growth rate decreased to 0.9% (Table 1).

Fig. 1. Worldwide water withdrawal, 1900–2000
Source: Authors’ elaboration, from UNESCO (1999).

The identification of the different factors underlying the growth in an economic or environmental variable has been performed in the literature by way of different decomposition forms. The term structural decomposition analysis has been most commonly used when decomposition analysis is developed on the basis of an input–output model, which captures direct and indirect effects, which is not our case. However, the referred problems and solutions of SDA techniques, also apply to our analysis.
Water use slowed down from 1980 on. Consequently, and use accelerating from 1950 to 1980 and growth rates century shows moderate annual growth rates, with water distinguish three stages. The

percentages will shoot up due to simple calculations. Furthermore, if changes in water use are insignificant, percentages will shoot up due to simple calculations.

Table 1. Cumulative annual average growth rates in water withdrawal (%)

|                | 1900–2000 | 1950–2000 | 1900–1950 | 1950–1960 | 1960–1970 | 1970–1980 | 1980–1990 | 1990–2000 |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Africa         | 1.8       | 2.9       | 0.6       | 4.8       | 3.3       | 3.0       | 2.0       | 1.5       |
| Latin America  | 2.5       | 2.9       | 2.0       | 3.9       | 2.9       | 3.9       | 2.0       | 2.0       |
| North America  | 2.3       | 1.6       | 3.1       | 3.4       | 3.1       | 1.6       | –0.6      | 0.5       |
| Oceania        | 3.1       | 2.3       | 3.8       | 3.4       | 3.2       | 1.7       | 1.9       | 1.3       |
| Europe         | 2.5       | 2.3       | 2.7       | 5.1       | 2.8       | 2.2       | 0.8       | 1.0       |
| Asia           | 1.8       | 2.1       | 1.4       | 3.3       | 1.9       | 1.8       | 2.1       | 1.3       |
| Ex-USSR        | 2.0       | 2.3       | 1.7       | 3.1       | 5.0       | 5.5       | 0.9       | –2.7      |
| World          | 1.9       | 2.1       | 1.8       | 3.6       | 2.5       | 2.3       | 1.4       | 0.9       |

Source: Authors’ elaboration, from UNESCO (1999).

From a regional perspective, a general trend can also be observed; both developed and developing regions displayed an upward trajectory through the twentieth century (see regional charts in the Appendix). Nonetheless, this strong growth became weaker, mainly from the 1980s onwards. This was particularly true in the developed areas, where water use deceleration was sharper.

North America and the ex-USSR show a growing trend that reverses from 1980. However, the reasons for this decline in water withdrawal seem to be completely different. While in the former, this change could be due to wide range of factors that will be examined in ‘Looking behind the data’ section, in the latter it may be closely related to the economic transition to a market economy.

While in developed areas water withdrawal growth is higher during the first half of the century, developing regions exhibit sharper growth from 1950 onwards. As observed in the global pattern, every region except the ex-USSR and Oceania reached their peak annual growth rates through the 1950s and 1960s (Table 1). North America and Europe show the largest annual growth rates.

In short, there can be observed a long-term increase in water use that seems to have steadied somewhat. However, we must ask, what forces have driven the increase in water use in the long term?

Looking behind the data

On the basis of the IPAT model, water use trends are decomposed into three components, showing the effects of population growth, economic growth and other factors underlying water-intensity changes. The results are presented in Tables 2 and 3.

If we look at water use growth rates we can clearly distinguish three stages. The first half of the twentieth century shows moderate annual growth rates, with water use accelerating from 1950 to 1980 and growth rates ranging between 2.3% and 3.6%. Finally, the pace of water use slows down from 1980 on. Consequently, and
to represent possible changes in long-term trajectories, we have divided the twentieth century into three periods: 1900–1950, 1950–1980 and 1980–2000.

To begin with, let us consider the world as a whole. For 100 years, global water withdrawal described a significant upward trend (Table 2). Basically, Table 3 shows how population and especially income growth, that is, demand for freshwater, boosted aggregate withdrawal. In turn, the constant drop in intensity prevented a greater increase.

Table 2. Yearly growth rates in water use, population, per capita GDP, water use intensity (1900–2000) (%)

|                | 1900–1950 | 1950–2000 | 1980–2000 | 2000–2000 |
|----------------|-----------|-----------|-----------|-----------|
| Africa         | 0.63      | 1.47      | 0.79      | –1.6      |
| 1950–1950      | 3.7       | 2.5       | 1.79      | –0.61     |
| 1980–2000      | 1.75      | 2.68      | –0.23     | –0.68     |
| Latin America  | 1.99      | 1.9       | 1.64      | –1.52     |
| 1950–1950      | 3.57      | 2.53      | 2.71      | –1.65     |
| 1980–2000      | 1.97      | 2         | 0.26      | –0.28     |
| North America  | 3.1       | 1.43      | 1.71      | –0.06     |
| 1950–1950      | 2.59      | 1.4       | 2.26      | –0.97     |
| 1980–2000      | 0.08      | 1.09      | 2.11      | –3.2      |
| Oceania        | 3.81      | 1.62      | 1.26      | 0.88      |
| 1950–1950      | 2.75      | 1.88      | 2.06      | –1.18     |
| 1980–2000      | 1.63      | 1.26      | 1.99      | –1.59     |
| Europe         | 2.71      | 0.51      | 0.91      | 1.26      |
| 1950–1950      | 3.34      | 0.7       | 3.53      | –0.88     |
| 1980–2000      | 0.85      | 0.28      | 1.74      | –1.15     |
| Asia           | 1.42      | 0.93      | 0.23      | 0.26      |
| 1950–1950      | 2.35      | 2.09      | 3.54      | –3.18     |
| 1980–2000      | 1.69      | 1.69      | 3.17      | –3.07     |
| Ex-USSR        | 1.68      | 0.74      | 1.68      | –0.73     |
| 1950–1950      | 4.52      | 1.32      | 2.76      | 0.39      |
| 1980–2000      | –0.91     | 0.41      | –1.81     | 0.51      |
| World          | 2.81      | 1.89      | 2.57      | –1.62     |
| 1950–1950      | 1.13      | 1.59      | 1.45      | –1.88     |

Source: Authors’ elaboration, from UNESCO and Maddison data set.

In Table 3, if $\Delta W > 0$, positive signs on the different effects indicate that they contribute to the increase in water withdrawal. If $\Delta W < 0$, a negative sign on a component entails that it plays a part in the increase in water withdrawal. An effect promotes water withdrawal stabilization or decline if, and only if, it exhibits a positive sign. Furthermore, if changes in water use are insignificant,
The income effect stands out, particularly until 1980, given that from this time on intensity becomes stronger. During the first half of the century, the contribution of GDP growth to the increase in water use was 60%, and this increased notably during the three following decades. Taking growth rates into account (Table 2) we can see the vast growth in income between 1950 and 1980. The ratio of water use to GDP steadily decreased throughout the twentieth century. It is in the last two decades that the intensity effect appears to be the most prominent. From 1980 to 2000, this effect fell about 1.8% every year.

Broadly speaking, every region follows a path similar to the world as a whole. Nevertheless, it is feasible to divide the world into two different groups. On the one hand, North America, Europe and Oceania are included in the same cluster. On the other hand, developing regions differ significantly from the others.

In developed areas, the income effect has been the most important determinant of water use, mainly during the second half of the twentieth century. Moreover, the intensity effect appears to have encouraged water use moderation.

North America is the only case in the world where, between 1980 and 2000, intensity outbalances the sum of population and income, involving an imprecise but essential fall in water withdrawal levels. The decrease in water use levels took place during the 1980s, mainly due to the vast improvement in intensity, which decreased annually by 3.7%. Per capita levels of water use attain astonishingly different values at very similar income levels, depending on the prevailing urban approach and other land-use related issues. These diverse land-use patterns clearly distinguish European cities from typical North American conurbations. The high per capita water use seen for North America could have led to efficiency improvements once the turning point was reached.

On the other hand, the less developed areas of the world describe a different evolution from the other regions. Nonetheless, in this case they are more heterogeneous. Although, throughout the developing world, per capita GDP and population growth trigger water withdrawal, the relative importance of both has not been the same. On the whole, population has been a more important driver than income. In developing countries, the reduction in intensity has not offset the impulse of income and population on water use, but has reduced it, except for Asia between 1900 and 1950 and the ex-USSR from 1950 to 1980.

Table 3. Contribution of the factors to water use changes (1900–2000) (%)

| Region   | 1900–1950 | 1950–1980 | 1980–2000 | 1980–1950 | 1950–1980 | 1980–2000 |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|
| ΔW(abs)* | N         | y         | w         |           |           |           |
| Africa   | 15.1      | 240.1     | 162.5     | −302.6    |           |           |
| Latin America | 46.9      | 95.1      | 112.9     | −108      |           |           |
| North America | 139.7     | 70.4      | 89.6      | −60.1     |           |           |
| Oceania  | 8.8       | 43.9      | 30        | 26        |           |           |
| Europe   | 13.1      | 68.1      | 82.2      | −50.3     |           |           |
| Asia     | 57.4      | 33.3      | 205.7     | −139.1    |           |           |
| Ex-USSR  | 47.4      | 44.2      | 106.7     | −50.8     |           |           |
| World    | 785.4     | 89        | 204.9     | −193.9    |           |           |
|          | 232.3     | 30.8      | 59.4      | 9.8       |           |           |

Note: *ΔW(abs) shows water use absolute variation in km³. Source: Authors’ elaboration, from UNESCO and Maddison data set.

Data on per capita water use for all regions are available on request.
The decline in per capita GDP between 1980 and 2000 caused a reduction in water demand for economic purposes in both Africa and the ex-USSR. In the latter, contrary to what happened in Africa, this decline was so intense that it allowed the smooth drive caused by population and intensity to be offset. In what follows, we try to delve deeper into the discussion of the historical facts underlying the different effects driving the evolution of world water demands.

**Income effect.** Increase in per capita income has been one of the most important economic facts during the two last centuries. This increase has meant not only a greater demand for traditionally consumed goods, but also a change in the structure of demand itself. In line with the increase per capita, demand has increased principally for manufactured products, while that for food has increased at a notably lower rhythm. Consequently, the production of and trade in industrial goods has increased proportionately much less than that of agricultural products (Serrano and Pinilla, 2012). Furthermore, urbanization, parallel to industrialization, has also modified the patterns of demand. Despite these changes, agriculture continues today to be the principal consumer of water.

Growing per capita income not only increased the demand for food, but also modified food consumption patterns. Consumption of water-intensive goods has increased sharply, resulting in a significant increase in water use. However, the most serious strain on freshwater resources comes from the mounting weight of meat in the consumption package. To cope with the increase in demand, agriculture has substantially increased its production throughout the past century. The expansion of irrigation has contributed significantly to this increase in production; the global irrigated area jumped from approximately 48 million hectares in 1900 to 235 million in 1989 (Gleick et al., 1993). The development of modern irrigation systems has been also identified as a necessary condition for the efficient use of the agricultural technologies that emerged in the second half of the twentieth century (Hayami and Ruttan, 1985). In the case of the green revolution, the new high-yield varieties worked best where irrigation infrastructure was already available and chemical fertilizers were widely used (Federico, 2005). Huge investment in dams and irrigation canals became necessary and, accordingly, food supply more than doubled and water withdrawal grew by 2.81% annually. Consequently, it was the intensification of agriculture which caused water withdrawal figures to soar, as agricultural water use is the most voluminous of all uses.

In parallel, water has been increasingly used in production processes for purposes such as cooling, transportation, solvents and so on, hand in hand with industrialization and urbanization processes. Accordingly, the development of the industrial sector meant an increase in water demand. On the other hand, growing urbanization increased the facilities and amenities that people enjoy. Furthermore, the gradual provision of water for urban needs also increased water use.

Geographical and temporal differences in economic growth may help us to see the different relevance of income as a determinant of water use. The importance of per capita income improvement as the driving force behind water withdrawal in developed countries, such as Europe during the first half of the twentieth century, can be understood perfectly if we take into account its pioneering character regarding industrialization and economic growth. On the contrary, the late entry of developing areas, such as Asia, in the process of development explains that it is not until the second half of the twentieth century when per capita income shows a higher share than population growth.

**Population effect.** Undoubtedly, one of the most impressive changes of the past century has been population growth. A greater number of inhabitants on the planet involves, ceteris paribus, an increase in the use of water proportional to that of population increase. Data from Madison (2010) give evidence of the sharp rise taking place during the last 100 years, from approximately one billion to six billion people. The global population grew by approximately 1.3% annually during the twentieth century. The demographic transition was not only a key phenomenon concerning the socioeconomic changes in developed countries from the second half of the nineteenth century, but also affected developing areas from 1950 onwards (Reher, 2004). From Table 2, we can clearly see how population exerted a considerable impact on water use throughout the century. However, it was not until the period 1980 to 2000 that population and income gave a similar boost to worldwide water use.

**Intensity effect.** Intensity is, without doubt, the most difficult component to quantify and explain.

We will try to disentangle the intensity effect by examining some of the factors which, in our view, could lie behind the intensity effect through the twentieth century. From the beginning of the twentieth century to the late 1970s, efficiency improvements were limited. Water users paid a negligible price, supply side approaches relied on the construction of highly subsidized hydrological infrastructure, and wastewater discharges were rarely penalized. This involved a great disincentive for the implementation of water conservation practices in every region and economic sector. From the mid-1970s things began to change, especially in developed countries. Water was no longer considered an unlimited and cheap resource and a broad array of technical, managerial and institutional instruments were introduced. These changes have generally affected both the efficiency with which current needs
are met and the efficiency with which water is allocated among its users (Gleick, 2000).

Important advances have recently been implemented in agriculture. In this regard, some of the most effective methods for saving agricultural water are micro-irrigation techniques, such as drip or micro-sprinkler irrigation. According to Reinders (2006), the area under micro-irrigation experienced a seven-fold increase during the last two decades of the twentieth century, from 436 590 hectares in 1981 to 3 201 300 hectares in 2000. However, land under drip or sprinkler irrigation, today globally only constitutes about 1% of total irrigation. That is to say, developing regions appear to be a long way behind developed areas. Nonetheless, a growing use of these methods has taken place in both developed and developing countries during the 1990s. Recently micro-irrigation has become more affordable, allowing these innovations to be implemented in developing countries and for low value crops (Postel et al., 2001).

During the 1990s, income growth allowed some industrial processes to undergo a period of transition from inflow to circulating water supply systems. This shift was especially acute in developed countries (Shiklomanov, 2000).

When dealing with other resources, some authors (Collard et al., 1988; Jänicke et al., 1997) have suggested that the composition of an economy could be an important factor in accounting for the historical pattern followed by energy use, contaminating emissions, etc. From this historical perspective, one of the main features of modern economic growth has been structural change. This consists of the industrial and service sectors growing more quickly than agriculture. This fact led to an increased weight of the apparently less water-intensive economic sectors; that is why structural change implies a decline of weight of the apparently less water-intensive economic activities. However, as we have already said, that is not generally the case in agriculture, since production tends to move towards highly water-intensive crops over time.

Economics may also be a determining factor in water evolution. Roughly speaking, the twentieth century could be divided into two stages.

The first covers the period 1900 to 1980. During this time, water was believed to be abundant and inexpensive, and no efforts were devoted to its conservation (Gleick, 2000). Governments and international institutions got involved in water management, giving financial support to water infrastructure. This process was exceptionally intense between 1950 and 1980, when the irrigation boom took place. Dams, canals and pipelines spread at an unprecedented pace. Governments and international agencies subsidized not only the construction costs of macro-projects, but also the delivery and distribution of water. As a result, water was underpriced and there was a significant degree of overspending.

From 1980 onwards, water was no longer cheap and plentiful, but had become a costly and scarce resource. Suitable locations for dams or irrigation canals had already been exploited, the rehabilitation and construction of new ones became more and more expensive and the exploitation of groundwater entailed going deeper into aquifers and thus to growing capital costs of pumping water. High financial costs, together with low crop prices, led to diminishing returns for irrigation (Postel, 1999).

Accordingly, new management directions appeared. Although public projects can still be found, especially in developing countries, there now appears to be a trend towards the reduction of public funding for hydraulic infrastructure.

Another possible explanation could be the increasing interest in environmental issues. During the first half of the twentieth century, economic growth was given priority at the expense of environmental deterioration, which led to a dramatic increase in hydrological projects. As a result, water use rose considerably, water quality was seriously damaged and many freshwater habitats were endangered.

From the early 1970s onwards, environmental awareness grew notably all over the world. The emergence of new environmental values meant a significant change in the conception of water ecosystems and the idea of a necessary balance between economic development and freshwater resources emerged. This governing belief influenced water policies and management. Opposition to large scale water constructions became stronger, water policy gradually assimilated ecological ideas and water management addressed many concerns of the environmental movement. Likewise, the reallocation of water to the environment is gradually achieving one of the main environmental goals, namely the restoration of water ecosystems. Accordingly, a new paradigm for water planning emerged (Gleick, 2000). As a result of the implementation
of these new policies, efficiency gains have been possible, as in the case of urban water consumption (Tello and Ostos, 2012).

Perspectives on water use in 2050: results from a scenario analysis

Having looked backward, it is appropriate to look forward to design a simple scenario analysis on the water use pattern that can be expected in the first half of the twentieth-first century. The observed historical trajectories of population, economic growth and intensity help us to project the value of these three factors in 2050. To construct the scenarios regarding population, and following Reher (2007), we have considered low and medium variants of UN population prospects. Following these assumptions, global population will display a yearly growth rate of 0.53% in the low variant and 0.81% in the medium. Per capita income has been projected taking into account average annual growth rates obtained for the period 1995 to 2005.6

We contemplate four possible scenarios for water use intensity. The degree of optimism with which we examine the reduction in the use of water per unit of GDP is the difference between them. In the most pessimistic cases (scenarios 1 and 5), let us assume a 10% improvement in global water intensity; in other words, world water intensity would decrease from 0.108 Hm³/$ in 2000 to 0.097 Hm³/$ in 2050. Subsequently, in scenarios 2 and 6, the ratio of water use to GDP notably decreases in developing regions, being as much as twice the intensity of Europe in 2000, i.e., 0.08 Hm³/$. Moreover, North America and Oceania water use intensity converges to European levels in 2000 (0.04 Hm³/$) and Europe’s intensity remains stable. In the third place, scenarios 3 and 7 represent a situation where water use intensity reaches European standards in 2000 all over the world, while Europe’s intensity remains constant. Finally, the most optimistic situation (scenarios 4 and 8) would involve a factor 7 improvement (Harper, 2000) in intensity in developed areas, that is to say water use intensity would decrease seven-fold. Besides, in this optimistic situation developing regions’ intensity would be twice the European levels of 2000.

On these assumptions, we obtain the results given in Table 4, which display different future situations given the year 2000 as a baseline. Worldwide water use will continue to grow under most hypotheses. Only the most optimistic scenario shows a flattening in global water withdrawal from 2000 to 2050. That is, assuming low population growth and a sharp reduction in intensity.

In all other scenarios with low population growth, the use of water would increase globally from a minimum of 14% to a maximum of 177%.

If we now assume a medium population growth, and an economic growth that projects 1995–2005 annual rates, the results are even worse. Under these assumptions, the

Table 4. Scenario analysis results. Water use in 2050 (2000 = 1)*

|                | Africa  | Latin America | North America | Oceania | Europe | Asia | World |
|----------------|---------|---------------|---------------|---------|--------|------|-------|
| N: low variant |         |               |               |         |        |      |       |
| y: 1995–2005   |         |               |               |         |        |      |       |
| w: 10%         | Scenario 1 | 5.37          | 2.17          | 3.16    | 3.59   | 2.25 | 3.41  | 2.77  |
| w: int.        | Scenario 2 | 2.39          | 1.86          | 2.14    | 2.35   | 2.25 | 1.90  | 1.57  |
| w: Eu          | Scenario 3 | 1.19          | 0.94          | 2.14    | 2.35   | 2.25 | 0.95  | 1.14  |
| w: factor7_int. | Scenario 4 | 2.39          | 1.86          | 0.49    | 0.56   | 0.35 | 1.90  | 0.99  |
| N: medium variant |       |               |               |         |        |      |       |
| y: 1995–2005   |         |               |               |         |        |      |       |
| w: 10%         | Scenario 5 | 6.15          | 2.53          | 3.57    | 4.08   | 2.55 | 2.54  | 3.20  |
| w: int.        | Scenario 6 | 2.73          | 2.17          | 2.42    | 2.68   | 2.55 | 1.41  | 1.81  |
| w: Eu          | Scenario 7 | 1.37          | 1.10          | 2.42    | 2.68   | 2.55 | 0.71  | 1.32  |
| w: factor7_int. | Scenario 8 | 2.73          | 2.17          | 0.55    | 0.64   | 0.40 | 1.41  | 1.14  |

Notes: *Values displayed in the table are W2050/W2000 considering W2000 = 1 and under the corresponding assumptions on N, y and w. We consider low and medium variants of UN population (N) prospects. Per capita income (A) has been projected taking into account average annual growth rates for 1995–2005. There are four scenarios for intensity. (a) w: 10%, 10% improvement in global intensity. (b) w: int, by 2050 the developing world’s intensity will be twice Europe’s figure in 2000 and reaches the 2000 European level, where it converges to European levels. (c) w: Eu, by 2050 water use intensity reaches the 2000 European standards all over the world, 0.04 Hm³/$. (d) w: factor7_int, by 2050 developed areas intensity decreases seven-fold, and the developing world’s intensity is twice European levels in 2000.

6 This yearly growth rate can be considered unrealistic, given that years of economic crisis are not included in projections. At this moment, it is difficult to produce a realistic growth rate for the coming 40 years. In any case, we consider that these values (a per capita growth rate maintained equal to that corresponding to the 1995 to 2005 period for each region) can be interpreted as an upper limit to economic growth for the next 40 years.
optimum overall result leads to a 14% global rise in water use. The most pessimistic case entails a greater than threefold expansion in overall water use.

It is undeniable that these results are strongly determined by the former assumptions. However, it is probably reasonable to argue that water use is expected to follow an important trend of growth during the period 2000 to 2050. Population and affluence appear likely to continue to expand into the future, especially in developing regions. This growing demand can only be offset by a great improvement in the ratio of water use to GDP. In our analysis, we have presented several scenarios concerning intensity. Only in the most optimistic of these, scenario 4, would water use remain steady.

From a regional perspective, the scenarios display highly diverse possible trajectories. In the developed countries only strong falls in the intensity of water used per unit of GDP could reduce hydrological necessities. In all the other scenarios the increase of consumption is difficult to sustain. In the case of developing countries sharp falls in the intensity of the use of water per unit of GDP would permit a moderate reduction in the consumption of water.

These conclusions are in line with those made by Shiklomanov (2000) and Glèick et al. (2008), who, respectively, forecast a 31% increase in global water use by 2025, and an approximate 40% rise by 2020. Other studies, such as Rosegrant and Cai (2002) or Alcamo et al. (2003), foresee stabilization in some river basins but high growth in many areas, particularly in domestic and industrial sectors.

Could these forecasts increases in water demand be sustained? Cautiously, we follow the ‘thirds’ hypothesis proposed by Margalef (1996). He suggested that at least two-thirds of total freshwater must be left to surface runoff and resource endowment, if natural systems are to be kept in a healthy state and able to provide environmental services. Therefore, those scenarios that forecast a withdrawal above 33% of freshwater resources seem rather unlikely. The most pessimistic scenarios regarding intensity seem to be unreal, especially in those regions where great population growth is expected.

The implications of these scenarios are important. History shows us that during a large part of the twentieth century, to satisfy the water needs of human societies, stimulated both by population growth and by income per inhabitant, a supply model has prevailed, that is to say principally the construction of infrastructure, to have more water available. This model has great difficulties in continuing to be the most appropriate response.

On the one hand, the scenarios proposed would require a sharp rhythm of new constructions. However, the contribution of hydraulic works to the availability of regulated water is marginally decreasing. In many countries more dams are no longer viable as the best locations have already been taken. This explains the difficulties in increasing supply and also the marginally increasing costs of infrastructure for each new unit of regulated water, which can make them financially inviable. On the other hand, the environmental impacts may also be undesirable or tolerated socially.

Consequently, a new paradigm is necessary. This would be directed more at making a deceleration of demand rather than expanding supply (Postel, 1999; Gleik, 2000; Pinilla, 2008). The possibilities for action are multiple. On the one hand the low prices of water make supply lead demand. Some actions in this direction would be necessary (Anderson, 1998; Schoengold and Zilberman, 2007). On the other hand, the scenarios proposed underline that intensive efficiency gains are the surest way to achieve lower pressure upon the resource of water. The differences in water intensity used per unit of GDP underline the broad margin existing insofar as the developing countries adopt the most modern technologies and the developed countries intensify their application and develop new ones. Here, the implementation of measures to improve efficiency in the distribution and consumption of water in the diverse productive sectors, the systems for the treatment of effluents, the encouragement of good agricultural and industrial practices with regard to the resort to or the introduction of water-saving programs and integrated management of the resource in economic and environmental policies at different institutional levels (local, regional, national and international), could have important effects to mitigate the pressure on water resources in the coming years.

IV. Conclusions

This article has analysed the evolution of water use throughout the twentieth century, and assessed the extent to which certain demographic, social and economic factors have contributed to the water withdrawal pattern, and how they will affect future trajectories.

Both global and regional evidence clearly illustrate a great expansion of water use. Population growth, economic development and the intensification of agriculture have been identified as some of the main drivers for this growing trend. On the other hand, efficiency improvements, structural change, environmental concerns and the increasing costs of supplying water, have made population and income growth compatible with a slight leveling off in water use from 1980.

In regional terms, water withdrawal has followed a similar path, namely a rapid rise that stabilized during the last two decades of the century. Nevertheless, the three effects behave distinctly, depending on the region considered. Chiefly, the income effect has been more
closely related to water use in developed areas since 1900. Likewise, the intensity impact on freshwater use has been more abrupt in the developed regions. However, the population effect has been comparatively more important in developing areas. We find that North America stands out from other areas because of the decline in water withdrawal during the period 1980 to 2000, this decrease being largely driven by the intensity effect, since it offset the boost produced by income and population growth.

On the whole, as seen in our analysis of various scenarios, water use will describe a growing trend during the first half of the twenty-first century. Only in one of the eight future scenarios would global water withdrawal remain stable. Even if important improvements in efficiency took place, water use would grow, mainly in developing regions, where significant increases in population and affluence are expected. Consequently, it appears necessary, given the enormous difficulties and problems that would be created by maintaining a rhythm of expansion of regulated water supply in accordance with the most pessimistic scenarios of the evolution of supply, it would be necessary to achieve a deceleration in the growth of the latter, whether through efficiency gains with a technological base or via pricing and demand management policies.

This study offers great scope for further research. As commented above, intensity comprises a wide variety of interdependent factors that are difficult to measure. One of the natural extensions of this research would involve opening the ‘black box’ of long-term water intensity. Moreover, it would also be of great interest to separate aggregate water uses. In this way, we would be able to study water withdrawal from a local and sectorial perspective.

Acknowledgements

The authors acknowledge the comments received from the participants at the XI Biennial Conference of the International Society for Ecological Economics (Bremen, August 2010), the Water History Conference of the International Water History Association (Delft, June 2010), the Economic History Seminar of the University of Zaragoza (October 2009) and the Economic Development and Environment Seminar held in the Institución Fernando el Católico (Zaragoza, November 2009).

Funding

This work is partially supported by a doctoral grant from the Government of Spain (A. Serrano) and by the Ministry of Science and Innovation of the Spanish Government, projects ECO 2012–33286 (V. Pinilla) and ECO2010–14929 (R. Duarte and A. Serrano) and the Department of Science, Technology and Universities of the Government of Aragon, Research Group for ‘Agri-food Economic History’ (V. Pinilla) and Research Group ‘Growth, Demand and Natural Resources’ (R. Duarte and A. Serrano).

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Appendix