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Review. Water resources deficit and water engineering

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Abstract

The increasing demand of water for different uses, together with the variable availability of this resource, which is due to the increasingly frequent periods of drought, make necessary to undertake a set of structural and contextual actions to cope with the permanent or temporary scarcity situations. Within the search for solutions to the progressively more widespread situation of limited water availability for agriculture, this paper aims to state the role that engineering can play to face up this deficit, taking into account the social, economic, and environmental issues of water, together with the priority of uses. Structural measures can help to:1) increase the water availability (increased or more flexible supply through reservoirs, water transfers, water rights interchange centres, desalination, reuse, aquifer recovery, and conjunctive use of surface water and groundwater), and 2) rationalize water consumption by improving demand management, including the irrigation management improvement, as well as maximizing the efficiency of irrigation systems. In addition to these measures, other social issues can be implemented through public awareness and education, adequate economic policies, legislative adaptation, and technical support to municipalities and water use associations. Thus, to face up water scarcity in a region it is necessary to identify the different water sources, including alternative sources such as desalination and reuse, and develop an appropriate model of management as well as infrastructure for water storage and regulation.

Additional key words: desalination; drought; irrigation; wastewater reuse; water management; water scarcity; water transfers.

Resumen

Revisión. El déficit hídrico y la ingeniería del agua

La creciente demanda de agua para los distintos usos, junto con la variabilidad en la disponibilidad de este recurso debido a los cada vez más frecuentes periodos de sequía, hacen necesario llevar a cabo un conjunto de acciones estructurales y coyunturales para poder hacer frente a las situaciones de escasez temporal o permanente que se producen. Dentro de la búsqueda de soluciones a la situación cada vez más generalizada de limitada disponibilidad de agua para la agricultura, el presente trabajo pretende incidir en el papel que puede jugar la ingeniería a la hora de hacer frente a esta situación de déficit, teniendo en cuenta los aspectos sociales, económicos y ambientales del agua y sus prioridades de uso. Las medidas estructurales pueden contribuir a: 1) aumentar los recursos (aumento o flexibilidad de la oferta mediante embalses, trasvases, centros de intercambio de derechos de agua, desalinización, reutilización, recarga de acuíferos, o el uso conjunto de aguas superficiales y subterráneas), o 2) racionalizar los consumos (mejorando la gestión de la demanda, incluyendo la mejora de la gestión del regadío y la mejora de la eficiencia del riego en parcela). Además de estas medidas puede llevarse a cabo otras de carácter social como la concienciación y educación ciudadana, el fomento de políticas económicas adecuadas, la adecuación de la legislación, o la asistencia técnica a municipios y comunidades de regantes. En definitiva, para poder hacer frente a la escasez de agua en una región es necesario identificar las diversas fuentes de agua, incluidas las fuentes alternativas como la desalación y la reutilización, y disponer de un modelo adecuado de gestión, así como de las infraestructuras necesarias para su almacenamiento y regulación.

Palabras clave adicionales: desalinización; escasez de agua; gestión del agua; reutilización del agua; riego; sequías; trasvases.

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Abbreviations used: CHJ (Confederación Hidrográfica del Júcar); DWR (Desalination Water Recommendations report); GHG (Confederación Hidrográfical de Guadiana); GIS (Geographic Information Systems); IAS (Irrigation Advisory Services), IWRM (Integrated Water Resource Management); OPTI (Observatorio de Prospectiva Tecnológica Industrial); PNR (Plan Nacional de Regadíos), SIAR (Servicio Integral de Asesoramiento al Regante); SIGA (Sistema Integral de Gestión del Agua), UGSP (Upper Guadiana Special Plan), WCP (World Climate Programme), WFD (Water Framework Directive).

Introduction

Water is traditionally considered a renewable resource. However, indiscriminate increased water demand results in reduced quality and, sometimes, in changes in temporal and spatial distribution. The consequences of these effects are not always adequately predicted and could have extreme environmental, social, and economic impacts.

Freshwater is unequally distributed throughout the world, as it is linked to precipitation. The continent with the most water resources is Asia, followed by South America, Africa, North America, Europe, and Australia. However, availability per inhabitant follows an inverse trend, due to population density in those countries.

Humans have increased the number of water applications as well as their dependence on this resource. In Western Europe, urban water supply represents 15-25% of total freshwater (approximately 150 L inhabitant^{-1} day^{-1}). In Eastern Europe the average is 10-15%, and it is 10% in the USA. Industrial demand of water is directly related with the degree of development of a country. In the USA, industry consumes 50% of available freshwater, in Germany 72%, UK 65%, and 10% in developing countries or countries with high agricultural water requirements, such as Japan or Spain. The majority of water used in industry is not consumptive, for use by hydraulic pumps, thermal and nuclear plant refrigeration, and others. Agriculture consumes 70% of the total freshwater in the world, with large differences between countries and even between different regions within the same country (Martín de Santa Olalla and De Juan, 2001; Molden, 2007). For arid or semiarid countries, this value could reach 80%. In Spain, agriculture uses 80% of freshwater, reaching 90% in areas with limited resources (MMA, 2000). However, the role of irrigation should also be considered under a context of public and global awareness on food safety (Martín de Santa Olalla and De Juan, 2001).

Water has always been a strategic resource, but nowadays its role is becoming even more important. Some reflexions by the United Nations on this issue are the following (UNESCO, 2009):

«Water is probably the natural resource that defines the limits of sustainable development. The freshwater supply is essentially constant, and the balance between water demands by humans and water availability is continually worse».

«While the world population has tripled during the 20th Century, water demand has multiplied by 6 (Cosgrove and Rijsberman, 2000). *In the whole world, 54% of available freshwater is utilized annually. In 2025 consumed freshwater could reach 70% due to population growth. If consumption per capita were to reach the same level in all countries as it is in developed countries, 90% of the total freshwater could be consumed.»*

In this scenario, water scarcity has emerged as one of the most pressing problems in the 21st century. It is estimated that 2.7 billion people will face water scarcity by 2025 (UN, 2003). Against a growing alarmism of «water wars» (*i.a.*, Shiva, 2002), several global agencies, national governments, and NGOs have been concerned with emerging water «crises» and potential water conflicts (UN, 2003; Rijsberman, 2006; Mehta, 2007; Gupta and Van der Zaag, 2008).

A concerto that can be considered in situations of water scarcity is the virtual water. This refers, in the context of trade, to the water used in the production of a good or service. For instance, it takes 1,300 m^3 of water on average to produce one tonne of wheat. The precise volume can be more or less depending on climatic conditions and agricultural practice. Hoekstra and Chapagain (2007) have defined the virtual water content of a product (a commodity, good or service) as «the volume of freshwater used to produce the product, measured at the place where the product was actually produced». It refers to the sum of the water use in the various steps of the production chain.

Virtual water has major impacts on global trade policy and research, especially in water-scarce regions, and has redefined discourse in water policy and management. By explaining how and why nations such as the US, Argentina and Brazil «export» billions of litres of water each year, while others like Japan, Egypt and Italy «import» billions, the virtual water concept has opened the door to more productive water use.

There are, however, significant deficiencies with the concept of virtual water that mean there is a significant risk in relying on these measures to guide policy conclusions. Accordingly, Australia's National Water Commission considers that the measurement of virtual water has little practical value in decision making regarding the best allocation of scarce water resources.

Although the available volume of water is increased by building reservoirs, other processes such as pollution and deforestation (leading to erosion) decrease the available storage volume. In addition, global changes due to climate change are expected to affect water availability. There are varied points of view related to climate change, but the different Administrations are

Table 1. Percentages of reduction in the natural runoff contribution, considering the effects of climate change

Hydrographical demarcation	Percentage of decrease (%)
Miño-Sil	3
Cantábrico	2
Duero	6
Tajo	7
Guadiana	11
Guadalquivir	8
Segura	11
Júcar	9
Ebro	5

Source: Hydrologic Planning Instruction (BOE, 2008b).

defining strategies to mitigate the effects. In Spain, the Hydrologic Planning Instruction (Order ARM/2656/2008; BOE, 2008b) established the need to perform detailed analyses on the effects of climate change on water resource availability, which should be included in Hydrologic Plans. If this analysis is not performed, the percentage of reduction from the natural contribution established as a reference for each hydrographical demarcation will be applied (Table 1).

One point that is clear is that water availability for different uses will be drastically decreased from both the effects of climate change and the application of the Water Framework Directive (WFD; OJ, 2000). Therefore, these aspects should be considered in any planning and management process.

The aim of this review paper is to state the role that engineering can play to face up the more widespread situation of limited water availability for agriculture, taking into account the social, economic, and environmental issues of water, together with the priority of uses.

Concepts of aridity, drought and scarcity

The first complex question to solve is the definition of water scarcity. The approach can vary depending on the interest of the agents involved, as well as on the specific context of each scenario of water scarcity in the World, as mentioned in the introduction section.

Hydrological concepts with a solid theoretical base, such as the hydrologic deficit obtained when performing a water balance at the river basin level, can be clearly established for any of the considered water uses. However, since water scarcity is not only a natural characteristic of the river basin, it is difficult to define as a concept. Thus, depending on the definition of water scarcity and on the model of social decision making, engineering should solve specific problems, which should be clearly identified from the beginning.

Aridity is a permanent climatic condition characterized by low annual or seasonal precipitation (Paulo *et al.*, 2005; González and Valdes, 2006; Iglesias *et al.*, 2010). Often, the concepts of drought and aridity are indistinctly used. However, aridity in a region is a natural situation of permanent and habitual water scarcity related to water demand on the hydrological system. It is characterized by an arid climate or by a fast increase in water demand. If the systems are properly designed and managed, and the demand is adequate to the climatic characteristic of the region, there should not be a deficit, even for arid areas. To accomplish this, planning should account for the mid- and long-terms.

In the MEDROPLAN project (Mediterranean Drought Preparedness and Mitigation Planning; Iglesias *et al.,* 2003), drought is considered a transitory natural anomaly, more or less prolonged, characterized by a period of time with precipitation rates lower than those considered normal in the area. Drought does not always lead to water supply problems, since this depends on the level of water demand in the area together with the distribution systems.

Usually, drought produces a transitory water deficit, requiring temporary measures to solve the problem (Drought Plans, Emergency Plans, among others). However, aridity is a permanent situation of water scarcity that requires long-term actions integrated in hydrological planning. These actions affect both: 1) water supply, with new infrastructures, transfers, balanced use of surface and groundwater resources, among others; and 2) water demand management with water conservation strategies, increased information, and disciplinary measures in cases of nonconformity with distribution conditions.

The main cause of drought is a decrease in the precipitation rate (meteorological drought), which causes a scarcity of water resources (hydrological drought) needed to satisfy demand. Therefore, there is not an universal definition of drought, which depends on the region analyzed. There are at least four different types of drought, classified by the consequences (McKee *et al.*, 1995; MMA, 2006; Iglesias *et al.*, 2010):

1. Meteorological drought, based on the precipitation deficit, is defined in different ways. The United Nations Development Programme requested a definition of meteorological drought from The World Climate Programme (WCP, 1986), and the following criterion was proposed: drought is present in a region when the annual precipitation rate is lower than 60% of the normal precipitation rate during two consecutive years or in over 50% of the region.
2. Agricultural drought can be defined as a deficit of soil moisture required for satisfying crop water requirements in a determined crop stage. In rain-fed crop areas this definition matches that of meteorological drought but there is a small time lag due to soil water retention. In irrigated areas, agricultural drought is linked to hydrological drought due to a lack of water for irrigation.
3. Hydrological drought can be defined as the decrease in surface and groundwater availability in a management system during a specific time that can result in only partial supply of the total demand. In contrast to agricultural drought, hydrological drought can happen months or even years after meteorological drought. If the precipitation rate increases in a short period of time after meteorological drought started, hydrological drought may not be registered.
4. Thus, the temporal sequence is: meteorological drought, agricultural drought, and hydrological drought. The consequences of hydrological drought do not only depend on river and steam discharge, but on the volume of water stored in reservoirs and aquifers and on how the stored water is managed. Thus, the definition of hydrological drought is always linked to the management system of water resources.

Socioeconomic drought is the effect of water scarcity on the population and on economic activity. The minimization of socioeconomic drought is the result of proper water management. Socioeconomic drought appears when any economic sector is affected by water scarcity with unfavorable economic consequences at times when there are no water supply restrictions imposed. The growing pressure of human activity on water resources causes socioeconomic drought with high economic losses to become more frequent. Economic water scarcity appears when there is a lack of investment in infrastructures, on a small or large scale.

In an interesting paper, Rijsberman (2006) asks «what is water scarcity?», and concludes that when an individual does not have access to safe and affordable water for her or his needs for drinking, washing or livelihood we call that person «water insecure». When a large number of people in an area are water insecure for a significant period of time, then we can call that area «water scarce». Whether an area qualifies or not as «water scarce» depends on, for instance: how people's needs are defined (whether the needs of the environment, for nature, *inter alter* are taken into account in that definition); what fraction of water resources is made available; the temporal and spatial scales used to define scarcity; and the relationship of all these subjects with natural water resources in the area (river basin or part of a basin).

Water scarcity represents the extent to which water demand exceeds available water resources. This difference can be due to meteorological drought or to human activity through an increase in the population growth rate, improper use of water or unequal access to it (Del Moral, 2010).

Water scarcity, defined in terms of access to the resource, represents a handicap for agriculture in several regions of the world. One fifth of the world population (1.2 billion) lives in regions with physical water scarcity and, therefore, do not have enough to satisfy water requirements (Molden, 2007). Approximately 1.6 billion people live in river basins that suffer from water scarcity and have insufficient human capacity or economic resources to develop infrastructures for regulating available and scarce water resources. Demographic growth is linked to current water resource scarcity. However, the main problems related with water availability are: no commitment to water conservation, lack of adequate investments, and the inefficiency of organizations and improper governance.

In order to quantify water scarcity, the most widely used measurement is the Falkenmark indicator or «water stress index» (Falkenmark *et al.*, 1989). This proposes 1,700 m^3 of renewable water resources per capita per year as the threshold, based on estimates of water requirements in the domestic, agricultural, industrial and energy sectors, as well as the needs of the environment. Countries whose renewable water supplies cannot sustain this figure are said to experience water stress. When supply falls below 1,000 m^3 a country experiences water scarcity, reaching absolute scarcity below 500 m^3.

In a global water assessment for the United Nations Commission on Sustainable Development, Raskin *et al.* (1997) suggest that a country is water scarce if annual withdrawals (defined as the amount of water taken out of rivers, streams or groundwater aquifers to satisfy human needs) are between 20 and 40% of annual supply, and severely scarce if this figure exceeds 40%.

Water will be scarce where there is low rainfall and relatively high population density. Many countries in arid regions of the world, particularly Central and West Asia and North Africa, are already close to or below the 1,000 m^3 $capita^{-1}$ yr^{-1} threshold. This is the part of the world that is most obviously and certainly water scarce in the physical sense (Rijsberman, 2006).

The concept of supply guarantee is also useful. Demand can be unsatisfied due to the following causes (Iglesias *et al*., 2003; MMA, 2006): temporary decrease in natural resources (drought); lack of infrastructure regulation capacity; inadequate management and utilization rules as well as failure of management models and infrastructure planning (Estevan and Naredo, 2004; Molle, 2009): excess demand.

It is important to define the failure to supply, which is the threshold where demand is considered unsatisfied. Obviously, satisfaction of demand should be based on guaranteeing supply criteria for each type of demand, which represents the acceptable resistance capacity of a failure scenario. Each type of demand (urban, agrarian, industrial, or recreational) has a different tolerance of failure.

Supply guarantee is an agreement that establishes quantitative and, eventually, qualitative conditions under which demand is considered satisfied (MMA, 2006). It is necessary to establish the definition of supply guarantee since it is technically and economically impossible to completely satisfy the demand at all places and times in areas with scarce resources.

As stated by Roldan (2008), measures to alleviate water scarcity can be grouped into three types of actions: 1) proactive actions, developed on the mid- and long-term, 2) reactive actions, performed in specific episodes of water scarcity such as drought, and 3) complementary actions, to facilitate the development of the two previous actions. The proactive measures, which depend on economic, social, and environmental criteria, require an adequate budget, proper political negotiation, social acceptance, and, eventually, legislative changes. Reactive actions establish how to manage drought as a function of its evolution.

The proactive measures, which are the most interesting measures in terms of permanent water scarcity, are classified into the following groups:1) resource increase (increased or more flexible supply), and 2) rationalizing water consumption (demand management). Examples of the first group are reservoirs, water transfers, water rights interchange centres, desalination, reuse, aquifer recovery, and conjunctive use of surface and groundwater. Examples of the second group are water resource management in a system previous to a water scarcity scenario, which is very useful in the case of drought. This includes an alarm system and characterization by using indicators and mathematical models for decision making. Irrigation management improvement is also included in this group, as well as maximizing the efficiency of irrigation systems.

Complementary actions supporting proactive actions are the following: 1) public awareness and education, implication of the media and promotion of public participation, and 2) adequate economic policies such as encouraging efficient water use and flexibility, legislative adaptation, and technical support to municipalities and water use associations.

Complementary actions also involve generating reliable information that allows for improving management of the reactive actions previously designed. These complementary actions are: meteorological assessment and adequate data treatment, generation of meteorological and drought management indicators, and identification of the limit for activating action plans, among others.

Water availability. Water planning and management

According to legislation in Spain and in most countries in the world, Hydrological planning has the main objective of keeping good water status and adequate protection of the riparian areas. Additional objectives are to satisfy water demands and to guarantee equilibrium and harmonization in regional development. In addition, water availability and water conservation must increase while protecting water quality, and distribution to different uses in harmony with the environment and other natural resources. In order to reach these objectives, hydrologic planning will be guided by sustainability criteria through the integrated management and long-term protection of water resources. In addition, water quality deterioration will be prevented, aquatic ecosystems will be protected and contamination reduced. Hydrologic planning will also contribute to minimize the effects of floods and droughts (adapted text of the Water Law, BOE, 2001b).

These objectives, and the content of the Hydrological Plans, which are basic elements of water management in a region (river basin), are also considered in the European WFD. In addition, the WFD establishes criteria to determine the amount of available resources, mostly based on environmental issues, as well as community-based participation models to elaborate Hydrological Plans. Thus, it is necessary to develop decision making procedures on issues related with water, mostly when elaborating legislative and administrative documents for water management. Based on these documents, the role of engineers and society in general should be established, together with the definition of the actions required for the proposed water management scheme.

In this sense, the community-based participation approach has been widely discussed, using existing criteria for establishing a specific model. For water planning and management, political criteria have a priority in participation and decision making. After analyzing the evolution of the water management and decision making processes, Allan (2003) established five paradigms from the end of the 19th century to today (Fig. 1). Other authors (*e.g.*, Rijsberman, 2006; Molle, 2009; Del Moral, 2010) have followed similar models.

The environmental and economic phases are still in development. The authors argue that they are being supplemented by a new fifth paradigm, which is based on the notion that water allocation and management are political processes. This approach is particularly relevant to Integrated Water Resource Management (IWRM). Environmental fundaments such as the hydrological scheme of the river basin and economic fundamentals relating to the value of water are central to the paradigm and to the implementation of IWRM.

Finally, before analyzing the supply and demand of such a complex resource as water, it would be necessary to define the amount of water available to meet requirements or economic uses of water. Thus, the demand that could be adequately satisfied can be defined. The procedure of environmental protection should be guaranteed before considering the available water for the human activities (WFD —2000/60/CE—; Ferrier and Jenkins, 2010).

Water management model

The new management model of water demand is based on the efficient use of available resources. This creates a need for defining those resources considered

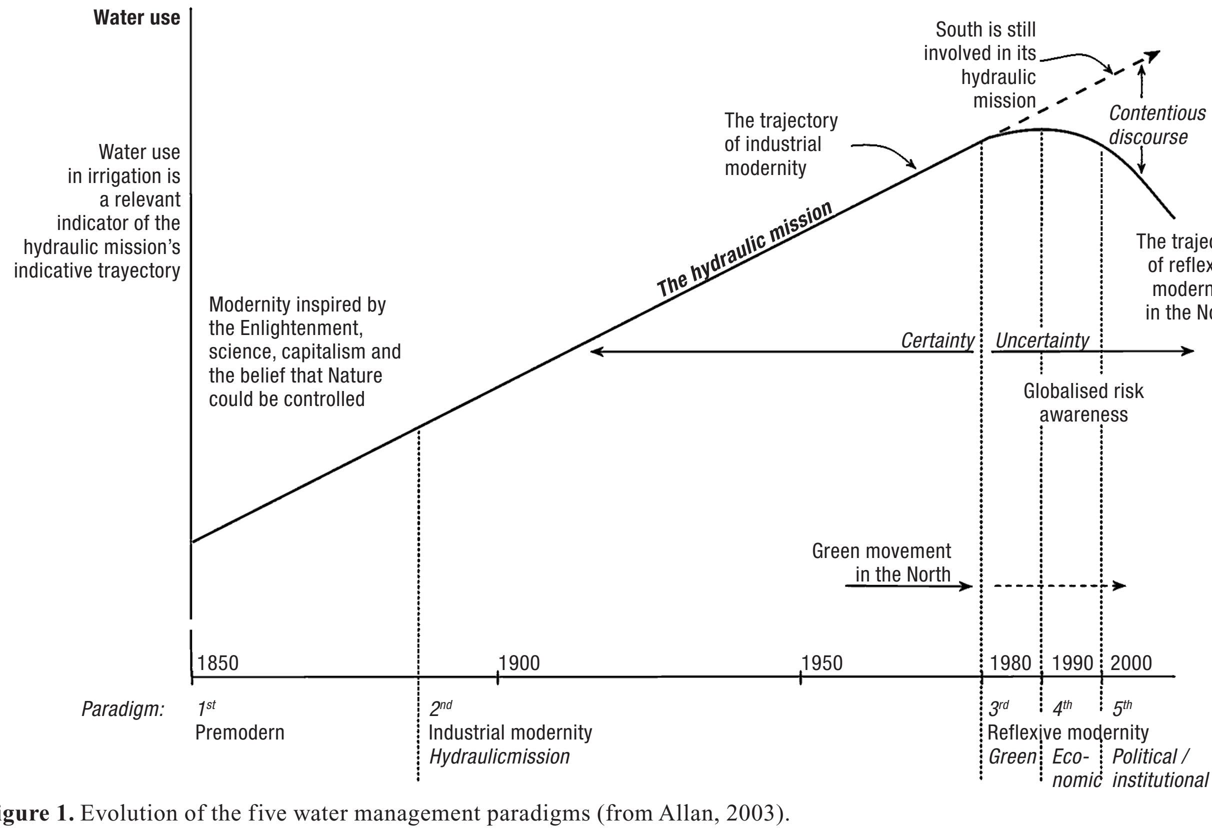

Figure 1. Evolution of the five water management paradigms (from Allan, 2003).

renewable in each hydrologic system and then to monitor and control the different uses. This should be performed in order to avoid exceeding the assigned volume of water for each user while preserving water quality, to minimize the negative effects on ecosystems.

Proper water management should fulfill the following requirements: a) to be treated as a global issue, considering existing natural resources such as water, soil, climate, among others, and their characteristics; b) to be considered sustainable and equitable from the environmental, economic, and social perspectives. Thus, water demand should equal availability in each management unit considering the priorities of uses, especially during drought periods; c) to be efficient and productive; d) to integrate the majority of the involved parties, such as the public administration, users, supporting organisms and institutions. Positive experiences and unsuccessful attempts should be reported.

Integrated management of water resources is mainly driven by three operative criteria (Mujeriego, 2007): 1) diversification of the alternatives applied to guarantee the global solution, 2) use of a balanced combination of structural and management approaches that increase capabilities and possibilities to fulfill supply and demand issues in space and time, 3) systematic planning infrastructures and management approaches such that the technical and economic objectives are reached, and the debate, revision, and acceptance by users are obtained, including the agents in charge of the preservation and restoration of the environment.

In any case, it is essential to optimize integrated management of surface water and groundwater resources, including treated wastewater and desalinated water. Improper management of water supply and demand can contribute to magnification of the effects of water scarcity (Rijsberman, 2006; Lecina *et al*., 2009).

In situations of water scarcity, possible alternatives to the lack of surface and groundwater resources are: improved water conservation and increased water use efficiency, implementation of intelligent territorial planning, intensified wastewater treatment and use, treatment of low quality water, desalination of sea water or other salt water, and the promotion of interregional water transfers.

In order to determine the key aspects of adequate water planning and management in the presence of drought and water scarcity it is necessary to remember some of the conclusions from Cabrera and Babiano (2007) and Cabrera and Roldán (2009): a) integrated management of all resources is essential for any water management policy, mostly for periods of drought and water scarcity; b) water resource planning should consider drought and water scarcity years as a base reference, along with the current hydrological series. They should also consider different climate change scenarios, which point to higher frequency and intensity of drought periods; c) water resource management should be performed in the framework of the hydrographic basin and in compliance with the plans developed in the corresponding hydrographic area, which are vital organizational structures for managing drought rationally; d) the water distribution system should be reviewed in such a manner that the rights of private use are more intensively and dynamically restricted to the fulfillment of planning objectives established in the WFD. In addition, it should facilitate and promote the generation of exchange centers: e) proper water resource management and, particularly, management of drought or other situations of water scarcity, requires an accurate system of indicators for characterizing, anticipating, and monitoring drought and water scarcity, as well as the efficiency of the management approach from the beginning; f) water reuse is an essential component of IWRM, mostly in coastal areas. It can highly contribute to increasing the amount of local water resources for irrigation (crops and gardens), infiltration, and aquifer storage in these areas, with a higher supply guarantee than conventional resources; g) sesalination, which has progressed significantly in recent years, is still a very expensive technology to be considered a primary water source. In addition, several social, environmental, and technological issues must be overcome; h) an important issue in IWRM is the relationship between water and energy. This should be considered especially in the following activities: purification and wastewater treatment, water conservation strategies, conventional water resource assignation, desalination, and processes for obtaining plant biomass to generate biofuel.

Meeting and reducing demand. The agricultural aspect

Improvement and consolidation of irrigable areas and water conservation

Consolidation of irrigable areas is any type of action or a part of an action with the aim of improving water use deficiencies and soil resources and reducing or eliminating environmental impacts (Hernández *et al*., 2010).

Improvement of irrigated areas is any modification of the elements, organization, infrastructure, equipment, etc., of an irrigable area for improving performance (Hernández *et al*., 2010).

The idea of «water conservation» is part of the concept of sustainable development and demand management, and the concepts of «efficient water use» and «water conservation» refer to the same idea but with nuances in meaning. Modernization, rehabilitation, improvement, and consolidation of irrigable areas are usually related to the concept of water saving. These actions usually have a main objective of water saving, although, strictly speaking, it is not a requirement. Thus, it is important to be able to estimate the real water conservation obtained. This water conservation is often overestimated, mostly when analyzing issues related to global hydrological efficiency on a river basin scale (Lecina *et al*., 2009). The concepts and criteria proposed by Burt *et al.* (1997) make it easier to estimate water conservation through these actions. These authors stated that the identification and quantification of different water uses depends on the scale (plot, farm, irrigable area, distribution system or basin), and on the time interval considered. These authors characterized water uses depending on three criteria: 1) recovery, 2) utility or profitability, and 3) the logic of assigning water for this use.

The results of this analysis (Burt *et al.,* 1997) show that the possibilities of water conservation on the plot level are limited. There is a wide range of options to act on, from obvious actions such as saving water through runoff and deep percolation recovery to actions that aim at reducing consumption through deficit irrigation, changing crop patterns (crops with low water requirements), or reducing the irrigable area.

It is also important to point out that saving water at the plot level through these actions has the following characteristics:

1) There are regulated flows supplied with a specific level of guarantee.

2) Flow is distributed to the hydrant in the plot, which can be used downstream or upstream of the hydrant. For the latter, it is not necessary to distribute flow with the water distribution network. Thus, the operational quality of the water distribution network and the service to other users are improved.

3) Sometimes these flows have to be pumped to reach the plot with enough pressure. Therefore, in these cases water conservation implies energy conservation. The water saved does not have any risk of quality loss due to farming usage, thereby contributing to decreasing the potential environmental risks of irrigation.

It is important to highlight that some modernization actions could lead to increased water consumption, such as cases in which the total irrigable area could not be irrigated because of low distribution system efficiency, or an increased coefficient of uniformity, which reduces losses, or even the establishment of crops with higher water requirements. In these cases, the benefits of actions would be linked to an increase in evapotranspiration.

The objectives of the Program for the Improvement and Consolidation of Irrigable Area in Spain are described in the National Irrigation Plan (BOE, 2002; Royal Decree 329/2002 of April 5). These objectives focus on improving the quality of life of farmers and promoting more rational use of water for irrigation by means of new technologies, mainly in areas with limited water resources.

For improving and consolidating irrigable areas, the PNR proposes the following types of actions: a) repairing existing hydraulic infrastructures; b) modification of the distribution and transportation systems; c) changing irrigation systems. Moreover, complementary actions such as: 1) improvement of water regulation and control capacity, of the drainage network, and rural roads, 2) organization of land tenure, 3) water consumption control (installation of flow meters), 4) improving water management.

One of the main problems with structural modernization is the high costs and the need for correct analysis of the results, which is not always properly done (Ortega *et al*., 1999).

Finally, in the controversy on the effects of improving and modernizing of irrigable areas for water conservation, it is necessary to emphasize that there is an agreement on the environmental improvements derived from the improvement of irrigation infrastructures (Ortega *et al*., 2002; Causapé *et al*., 2004, 2006; Clemmens *et al*., 2008; Lecina *et al*., 2009), particularly when these actions are linked to overall improvements in the water use area (including management, irrigation scheduling, availability of irrigation advisory services, among others) (Ortega *et al*., 2005).

Measures to promote water saving in irrigation

Some of the measures for potential water conservation in irrigation are (Roldán, 2007): to measure and price the water consumed; to design, manage, and adequately maintain irrigation infrastructure; to review administrative agreements; to improve demand management by irrigation scheduling through irrigation advisory services; to study the use of irrigation management indicators and benchmarking techniques for water user association management; to perform more research on irrigation issues at the plot level; to promote the use of new information and remote sensing technologies; to increase training and information to farmers, mainly on new technologies and sustainable development techniques; and to evaluate the agricultural and economic efficiency and productivity of the water supplied for irrigation.

Some additional measures for water and energy conservation in irrigation are: to restructure the sector with an aim of reducing the irrigable area, mainly where there are low production rates or a high environmental impact; to improve and consolidate irrigated areas, providing the necessary tools for proper irrigation water management; to promote efficient water and energy use; to implement best management practices in farming; and to create water rights exchange centers that should be managed by the Administration.

Under this context, and in collaboration with Universities and public or private enterprises, several regions of Spain have developed Irrigation Advisory Services (IAS). The IAS is one of the best tools for optimizing water and energy demand, together with all other productive incomes, which helps to make irrigation a sustainable activity. The IAS are also the link with farmers to transfer technology and knowledge to them which, allows them to incorporate these advances into their production systems.

In addition, there are other measures related to the temporary or definitive acquisition of water rights by the Administration as a way to control demand. It is an alternative to other engineering solutions such as desalination, new reservoirs, or water transfers. In this sense, Spanish legislation allows the Administration to acquire water rights, and there are several examples of these actions that aim to alleviate cases of permanent water scarcity and drought.

The Upper Guadiana Special Plan (BOE, 2008a) is a clear example of water right acquisition by the Administration and control of water use by means of flow meters. The main objective of this Plan is to bring surface and groundwater resources to good status by correcting the structural water deficit in this area under a context of sustainable development of farming and economic uses in general. This is a clear example for other basins with structural deficit that results in problems of water demand supply.

Examples of the use of these actions in times of drought (case of temporary water deficit) are the actions that were developed by the Confederación Hidrográfica del Júcar (CHJ, Jucar Water Authority), in the Mancha Oriental aquifer during the last drought event (2005 to 2008). The severity and the temporal length of this drought caused the CHJ to bring up the possibility of compensation for temporary water rights acquisition in the midreaches of the Jucar River due to environmental issues.

These measures, qualified as «soft measures» by several authors (Allan, 2003; Rijsberman, 2006), should be considered and evaluated to obtain definitive solutions to water scarcity problems.

New technologies applied in irrigation

The resources utilized in irrigation are: water, energy, manpower, and equipment. The combination of these resources that produces an economic optimum, depending on environmental restrictions (soil, climate, crop, plot size, among others) and the characteristics of the water supply systems should be determined.

In order to help farmers efficiently use water and energy, they should have training and continuous updates on crop water requirements, in addition to previous awareness on water conservation and some economic incentives. The type of information and knowledge can be summarized in the following key points (Tarjuelo, 2005; Hoffman *et al.*, 2007): a) to understand and control the main factors involved in the process of water application by irrigation systems; b) proper design, management, and maintenance of irrigation systems and other infrastructures; c) to apply irrigation scheduling techniques, which indicate how much water is required and when to apply it to the crop. This is an example of the importance of Irrigation Advisory Services, such as the IAS in the Region of Castilla- La Mancha [Servicio Integral de Asesoramiento al Regante (SIAR), http://crea.uclm.es or http://www.jccm.es], which has been functioning since 1999.

In developed countries, new irrigable areas tend to use automatic irrigation systems, which lead to water conservation, lowered manpower requirements, and reduce the need for farm labour. This is causing a transformation from gravity irrigation systems to sprinkler or drip irrigation systems, depending on the type of crop and water availability. However, these irrigation systems demand more energy. Thus, improvement of the structures and water distribution systems for surface irrigation systems should be considered.

Currently, the main technological advances, classified according to irrigation system, are the following:

A) For surface irrigation systems: laser land levelling; use of simulation models, which are an important tool in the design and management of different surface systems; utilization of cutback flow techniques in border-strip irrigation systems, the use of small siphons, the surge flow irrigation method, or wired irrigation in furrow irrigation systems (Burt *et al.*, 1997; Hoffman *et al.*, 2007).

B) For sprinkler irrigation systems: mechanization and automation of irrigation events. The most common irrigation systems are center pivot systems and mixed systems (center pivot and linear moving lateral on the same machine), together with solid set systems. The most important advances are currently focused on sprinklers, with a goal of reducing the pressure head and, therefore, energy consumption; to increase the throw distance; and a higher proportion of medium drop sizes (diameter between 1.5 and 4 mm) in order to reduce drift and evaporation losses (Tarjuelo, 2005).

C) For drip irrigation systems: global automation of the system with advances in the filtration systems (low energy consumption) and hydraulic valves including command pilots for flow limitation and pressure regulation and remote activation of valves with electric or hydraulic signals. However, the most important advances are currently focused on the design of new emitters, which aim at reducing pressure requirement, maintaining a constant discharge for different pressures and reducing emitter clogging (Burt and Styles, 1999; Hoffman *et al.*, 2007).

New technologies, included in Information and Communication Technologies, have provided possibilities for irrigation that were considered impossible some years ago (Arce *et al.*, 2007). The software for irrigation management and water distribution network simulation, the improvement of regulation and control of pumping stations, etc., as well as the availability of real time crop data are some of the services that new technologies have contributed to developing. Engineering should properly implement these technologies to contribute to improving water scarcity scenarios.

Remote sensing and Geographic Information Systems (GIS) are interesting tools for planning and management of irrigable areas. They allow for monitoring the irrigated area in space and time, to control the crop pattern, and to estimate the crop water consumption of irrigable areas.

One of the most complete management models is the one that integrates users and the Administration. In addition, universities and research centers play a main role in developing and implementing the tools necessary, such as remote sensing and GIS (Neumeister *et al.*, 2007). An example of this type of model, adapted for groundwater management, is shown in Figure 2. The most important part of this model is implicit consensus between managers (mainly water authority and the regional administration) and users (farmers, urban and industrial users). The users are a key part of water management since they control and monitor water use. They also update the database that identifies the users and water consumption. Once the users are identified and their water rights are defined in function of water availability, the participation of all agents involved in the water management makes this management process clear and consensual.

This system has two parts, which are interrelated (Fig. 3): a) irrigation inventory, which contains information on each irrigated plot; and b) the decision support system tools, which allow for the analysis and management of irrigable areas through the use of calculation modules and links to other software.

Management tools for irrigable areas, which are decisive and essential for the decision making process and minimize the effects of water scarcity, should include: a) determining crop water requirements and crop fertilizing by means of tools supplied by the IAS (Ortega *et al.*, 2004b, 2005); b) real time hydraulic simulation of water distribution networks, which requires specialised software such as EPANET (Rossman, 2000), GESTAR (Aliod *et al.*, 1997) and others that use calculation algorithms to obtain flow and pressure (Moreno *et al.*, 2007a, 2008); c) regulation and management systems for pumping stations that maximize energetic efficiency (Planells *et al.*, 2005; Moreno *et al.*, 2007b, 2009a, 2010); d) determining crop patterns with optimum gross margin when subject to restrictions such as water availability by using software such as MOPECO (Modelo de OPtimización ECOnómica; Ortega *et al.*, 2004a) or AquaCrop (Steduto *et al.*, 2009); e) obtaining performance indicators to be used in techniques such as benchmarking for improving management of irrigable areas (Malano and Burton,

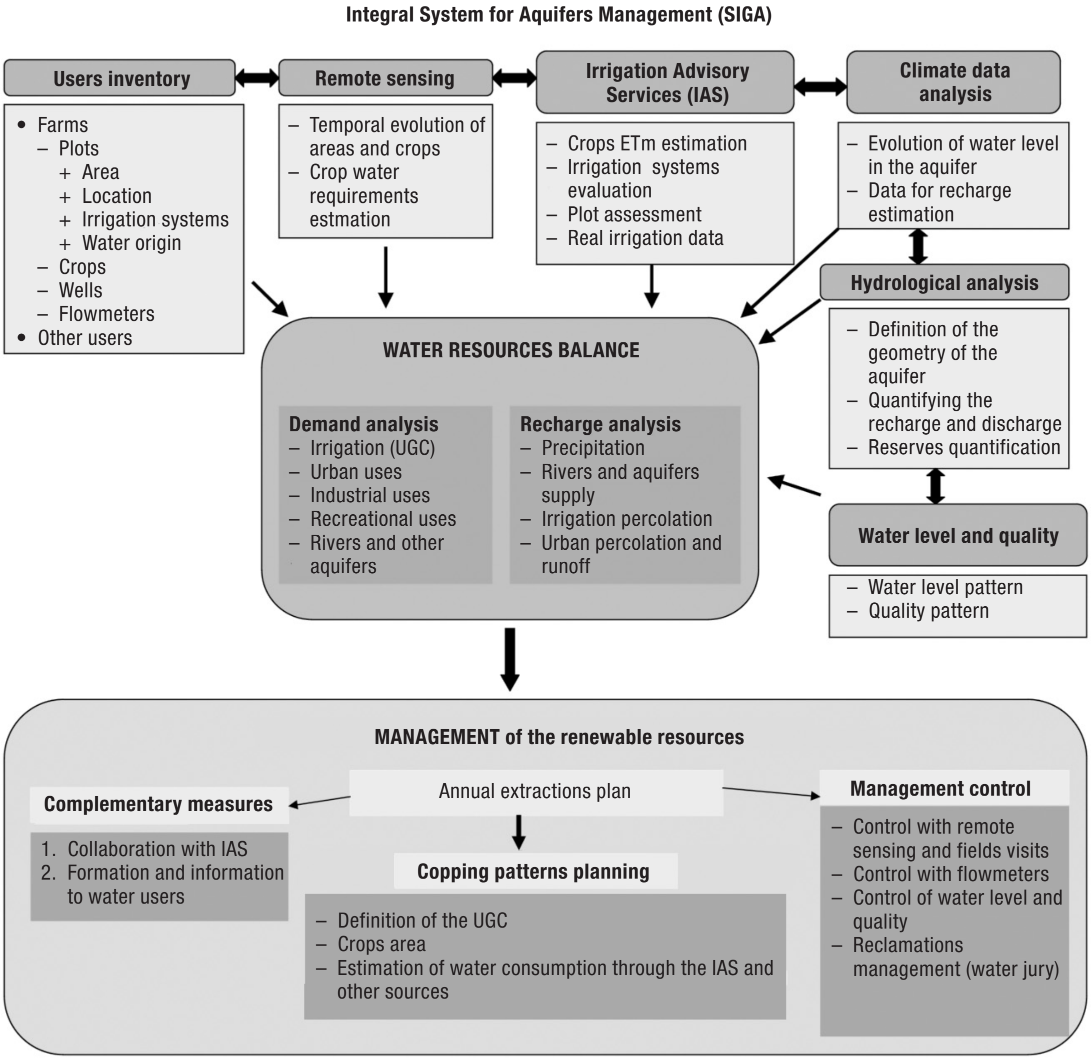

Figure 2. Flow chart of the integrated aquifer management system. UGC: Common Management Units.

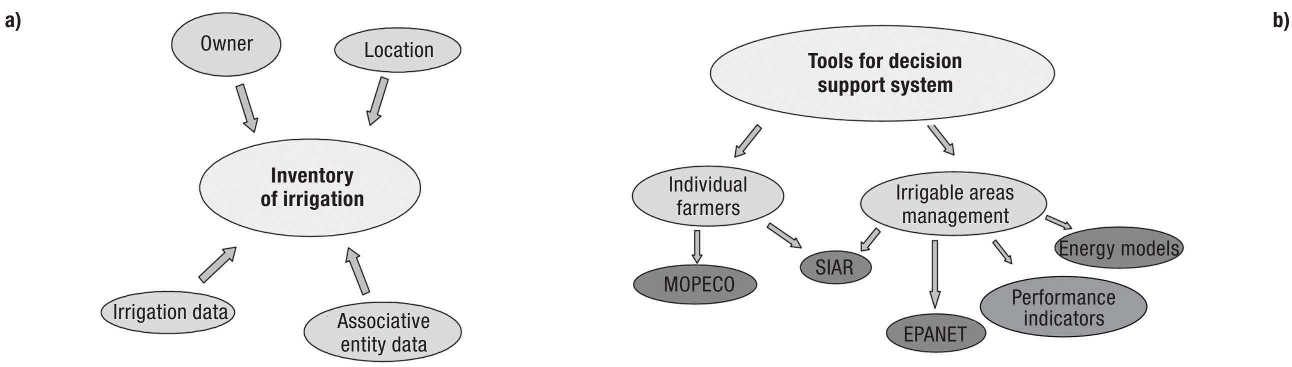

Figure 3. Diagram of a) irrigation inventory data and b) modules for calculating management improvement. MOPECO (Modelo de OPtimización ECOnómica; Ortega *et al.,* 2004a). SIAR (Servicio Integral de Asesoramiento al Regante). EPANET (Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio).

2001; Rodríguez *et al.*, 2008; Córcoles, 2009; Moreno *et al.*, 2009b).

Engineering and solutions to water scarcity

Water transfers

In many areas of the world water demand has reached the limits of what the natural system can provide. In addition, the number of regions where demand exceeds water availability is quickly increasing. However, these regions usually have intense economic activity and high population densities, and are therefore important from an economic and politic point of view. Allan (2003) argued that when demand starts to reach the limits of supply, new approaches to water management should be applied. The new approaches range from conventional supply through dam building to much more holistic integrated water resource management that aims to balance environmental, social, and economic considerations in the decision-making process. Interbasin water transfers are designed to guarantee access by artificially routing water to locations where people need it. Since interbasin water transfers hydraulically connect two or more river basins, they imply an increase in the spatial scale for water management. The structures required are often huge, involving diversion construction, tunnels, and/or large pumping structures and reservoirs, which also mean high costs. The main question is whether such transfers are compatible with the concept of integrated water resource management and the conditions that should be fulfilled to make them possible.

Water transfers are always a controversial issue in regions of the world with water scarcity, as they imply possible environmental impacts and social, political and economic tension. Data on the annual volume currently transferred are not properly known, but some authors estimate it around 3,900 Mm^3 yr^{-1} worldwide (Shiklomanov, 2000). Asia alone contains 60% of the total volume transferred in the world, while in Europe 460 Mm^3 are transferred every year. This does not constitute a real solution to water scarcity problems.

Some of the debate caused by interbasin transfers as a possible solution to water deficit are (Gupta and Van der Zaag, 2008): how do interbasin transfers interfere with the concept of integrated water resources management (IWRM)? Is it indeed true (and possible) that «integrated water management» is the main principle of an interbasin water transfer project, involving both river basins, in a shared effort to attain sustainability»? (Bruk, 2001, p. S168). Are interbasin transfers compatible with the values underlying IWRM? Is it possible to carefully consider all the dimensions involved (engineering, ecology, law, economics, politics) when deciding to establish such transfers, and when operating them? Do methodologies exist to reconcile those differing dimensions within one holistic framework?

The experiences with planned and/or implemented transfer schemes have resulted in aspects such as (Gumbo and Van der Zaag, 2002; Gupta and Van der Zaag, 2008): 1) appears serious biogeochemical impacts which are difficult to predict or anticipate (Linder *et al.*, 2005), 2) problems arising in differentiating between direct and indirect costs, together with estimating benefits, which may be difficult to clarify and resolve, 3) the possibility of adequate alternatives being rejected, *e.g.* substituting virtual flows for real water flows, 4) appealing to the emotions of people, which may cause distrust of citizen towards the government and its grandiloquence, sometime associated with large political ramifications.

Many transfers can look possible despite scientific uncertainty, huge economic costs, and potentially large environmental impacts, due to the interest of engineering enterprises, politicians, and financers (Gumbo and Van der Zaag, 2002).

Based on a comparative assessment of the different multidisciplinary, political, and legal approaches for evaluating whether interbasin transfers can be justified in the context of integrated water resource management, Gupta and Van der Zaag (2008) showed that it is necessary to take the following criteria into account:

— Real water surplus and deficit: there is a real (objectively measurable) surplus in the donor basin; and there is a real (objectively measurable) deficit in the recipient basin where water is used efficiently (with the best available technology).

— Sustainability: the transfer scheme is designed to be sustainable in terms of social, environmental and economic aspects and to be adaptable to natural and social stresses.

— Good governance: the scheme is based on good governance (including a participatory approach to the decision-making process and public accountability by including the people affected).

— Balance between rights and needs: the transfer scheme respects existing (local, national, and international) rights and responsibilities without negative extra-territorial effects and other impacts on bordering countries. Nevertheless, if such impacts occur, adequate compensation measures or benefit sharing should be agreed upon. No person, family, community or state will be affected because of the transfer.

— Solid scientific principles: the transfer is based on solid scientific principles, including hydrological, ecological, and socio-economic analyses. Uncertainties and risks should be adequately identified, together with gaps in knowledge. All possible alternatives should be considered previously.

Together with these five main criteria, several issues could be incorporated in relation to temporal aspects of the decisions and the limitations for the donor basins, determining factors, political and/or legal changes, among others. It is also necessary to improve the methodologies that quantify and evaluate associated issues (Ballestero, 2004; Matete and Hassan, 2006; Jiang, 2009).

Interbasin transfers do not only increase the spatial scale of influence; they also broaden the time scale, since large hydraulic projects have an operating life that is much longer than the policies that determine their construction. The values and priorities of a society tend to change significantly over a period of 40-50 years. This period of time is the typical operating life considered in large hydraulic infrastructure projects, although in practice they last much longer. These large hydraulic infrastructures greatly influence how water resources are used in the future. This point has been made by Biswas and Tortajada (2003) and Getches (2003), with reference to the Spanish National Hydrological Plan (BOE, 2001a), in which a main issue was the transfer from the Ebro basin that was not completed when this part of the Plan was repealed.

In conclusion, large scale engineering works, such as interbasin transfers, are only justified after all (smaller scale) alternatives have been exhausted, and basically if these projects are meant to satisfy vital human needs. In any case, it seems clear that the five criteria indicated need to be satisfied if an interbasin transfer is proposed.

New water resources: desalination

Although considerable progress has been made over the past few years in desalination, it is still a marginal water source, which is too expensive to be a main source of water and may also be accompanied by social, environmental, and technologic handicaps that must be solved.

The Desalination Water Recommendations report (DWR, 2003) includes a clear and detailed description of the basic considerations to take into account for implementing infrastructure for water desalination, which are the following: 1) it is necessary to have a source of water that is environmentally acceptable, 2) it is necessary to dilute and disperse the brine produced, 3) it is convenient to have a cheap energy source due to the high consumption of these infrastructures.

On the other hand, infrastructures for seawater desalination are important infrastructures with possible environmental impacts, which should be considered together with high energy consumption.

One of the benefits attributed to desalination is a higher supply guarantee due to the diversification of water sources, mainly in arid and semiarid regions. Another positive effect is that the resources generated are managed by local entities and do not depend on other circumstances. In addition, this resource is independent of natural disasters and other threats that affect the hydrologic systems.

Desalination as a water source for urban use can supply water from resources in the area of influence, making it unnecessary to transfer water from other areas, mainly agricultural areas, since there is higher capacity of control over a region's own water. It is interesting to indicate that agricultural users are the first interested in promoting desalination as water source for urban users. Thus, political pressures to transfer cheaper water from agricultural areas to urban areas are reduced and they can also reutilize treated wastewater from urban areas. This can also avoid one of the most important problems with the use of desalted water in irrigation, the seasonal demand of this sector, since demand depends on crop water requirements.

The most conventional way to evaluate a project of desalination is to analyze the two main advantages, high supply guarantee and the quality of desalted water, and the two main disadvantages, high cost per unit volume of desalted water and possible environmental effects (Cooley *et al*., 2006).

Although desalination is currently providing an important part of total water resources in wealthy countries of the Middle East, it only represents 0.3% of the freshwater in the world (Cooley *et al*., 2006). In desalination projects it is necessary to carefully evaluate the expected benefits by considering the investment and operation costs during the operating life of the infrastructure. Financial costs, energy costs, main environmental effects, supply guarantee, and social consequences are factors that should be carefully considered.

Desalination costs are divided in two basic components: cost of recovery and operational costs. It is necessary to emphasize that the energy cost can reach 35-40% of the total, depending on the technology utilized. Therefore, it is important to analyze the potential energy savings obtained when using new energy recovery equipment (Medina, 2002; Torres, 2004; Martín and Sánchez, 2005; Medina, 2005; Martínez *et al.,* 2006).

In the international market, with proper design, integration, and management, the total cost of desalted water in large plants (40 hm^3 yr^{-1} or higher) is around €0.45 m^{-3}. In medium sized plants it is around €0.50 m^{-3}, including the cost of recovery and not considering subsidies (Martínez *et al.*, 2006).

This cost can be lower if new technologies, which are commercially available, are used for plants producing between 10,000 and 140,000 m^3 day^{-1} (Martínez *et al.*, 2006).

Currently, with the most common technology and without the new, high efficiency systems of energy recovery, energy consumption in seawater desalination is between 3.5-4.4 kWh m^{-3}. It is also estimated that a new desalination plant should not exceed 4 kWh m^{-3}, which can be much lower if the new energy recovery systems are used. The study developed by the Observatorio de Prospectiva Tecnológica Industrial (Observatory for Industrial Technology Foresight, OPTI) on water and energy for the Instituto para la Diversificación y Ahorro de la Energía (Institute for the Diversification and Saving of Energy, IDAE) highlights new technologies possible for water desalination: a) to heat the entry water using low value heat (residual) from electric generation stations or industrial processes or solar power; b) to combine inverse osmosis and electrodialysis, which allows for increasing the flux of water over the membrane and therefore reduces total energy consumption; c) to use pressure exchangers to transmit the outflow pressure to inflow; d) to develop more efficient membranes with materials resistant to disinfectants and that avoid spoiling; e) implementation of desalination plants in aerogeneration marine areas, which requires the development of pumps activated with windmills, optimization of the osmosis process to operate in a marine environment, and to obtain the solution continuously under no wind conditions; and f) application of nanotechnology for the development of new membranes for inverse osmosis.

To decide on the use of desalted water in irrigation, the added value that is obtained in each irrigable area and in each product with the use of each cubic meter should be considered. Studies on final agricultural production show that several irrigable areas have added value for each cubic meter of water used that is higher than the cost of desalted water, which would allow for its use in coastal areas and for specific products. However, different authors show varying results on this issue (Medina, 2002, 2005; Mujeriego, 2005; Ródenas and Guillamón, 2005; Torres, 2005; Martínez *et al.*, 2006).

Increase in regulation: reservoirs

Construction of large dams peaked in the 1970s in Europe and North America, and by the end of the 20th century, there were over 45,000 large dams worldwide. New dams are currently being constructed mainly in countries with periods of economic growth, *e.g.,* China now has ca. 22,000 large dams, and in semi-arid countries, *e.g.*, South Africa, Australia, and Spain, to match water demand with other demands for irrigation with stored supply (ICOLD, 1998).

Reservoirs are built for flood control, water storage (water abstraction for humans, industry, agriculture or shipping), energy production and boating, but in most cases multiple uses are likely, and user conflicts must be expected. The benefits and environmental impacts of reservoirs have been intensively discussed, especially for those in large rivers such as the Amazon or the Sao Francisco, Brazil, the latter with a cascade of reservoirs in the semiarid area (Biswas *et al*., 1999; Biswas, 2004). A more scientific basis for this discussion was reached with the approach of investigating and comparing predicted and realized environmental impacts of the 25 year old Amazon Reservoir Curuá-Una and also of the 21 year old Itaparica Reservoir in the Sao Francisco River, both in Brazil (Gunkel and Sobral, 2007).

Reservoirs are not just involved in energy production, but they are part of the cultural landscape: in many cases they are necessary for energy production, but they must contribute to a better quality of life, and this includes flood protection, the ecological value of the reservoir, use of the water as drinking water in many regions and use of water for different human activities, thus providing a sufficient income for those who live near the reservoir.

A multiple use, such as hydroelectric power, flood regulation, abstraction of water and fishing, must be accomplished, and the users' conflicts must be minimized by an integrated river-basin management, which means a regionally adopted land- and water management system. This system includes land use and economic development, water abstraction, land and water ecosystem dynamics and socio-economic development (Gunkel and Sobral, 2007). Goals for the integrated river-basin management are the reduction of water quality impact and guaranteeing long term water use (Straskraba and Tundisis, 1999; Tundisi *et al*., 2008), the reduction of the impact of nature, mainly on the biodiversity and soils, and from a global point of view, the reduction of greenhouse gases (GHG) emissions by oligotrophication.

Benefits of reservoirs

Without a doubt, some benefits of dams to humans include long time production of electrical energy at low cost, flood regulation to avoid periodic flooding with severe impact to people in the affected zone and water storage for periods of drought that is essential in many tropical or subtropical and arid or semiarid regions (WCD, 2000).

Further benefits of reservoirs are fishing, recreational boating, development of irrigated agriculture, aquaculture in net cages or tanks and a water supply for intensive water-consuming industries. However, these benefits need to be regarded more critically. On the one hand, water quality with specific requirements is not guaranteed, *e.g.*, contamination with sewage counteracts the use of water for agricultural irrigation. On the other hand, human activities contradict ecosystem preservation, *e.g.*, migration of people into the sub-watershed of the reservoir, promoting the development of villages, agriculture and aquaculture with its diffuse and point-source emissions (Gunkel and Sobral, 2007; Tundisi *et al*., 2008).

Challenges of reservoirs

Possible environmental impacts of a dam with a medium-sized reservoir (in the range of ten to a few hundred kilometers in length) can be evaluated using developed methods for environmental impact assessment. However, very large reservoirs, such as the Itaipú (Brazil/Paraguay), Aswan (Egypt), or Three Gorges (China), must be evaluated under consideration of further, more complex risks, and the methods for such an environmental impact assessment are not yet sufficiently developed. Reservoirs lead to some impact on nature such as the destruction of the inundated area and the inhibition of fish migration (WCD, 2000; Biswas, 2004).

The reservoir as a new man-made lake is deprived of organisms because lotic organisms cannot survive in standing water, and a new fish population must be established. Furthermore, the operational water level changes of a reservoir, amounting to several meters, lead to complete damage of the littoral zone with its fauna and flora. This results in a poorly buffered ecosystem with severe reactions to any disturbance, *e.g.*, the trophic upsurge.

Possible effects of medium-sized reservoirs can be grouped into long-range effects, reservoir upstream effects, reservoir effects and reservoir downstream effects (Gunkel *et al.,* 2003). Frequently, the following impacts to nature occur (Friedl and Wüest, 2002; Gunkel and Sobral, 2007; Tundisi *et al*., 2008):

Sedimentation of the river's suspended load in the inflow area and build up of a delta with an increased risk of flooding.

— Periodic water-level fluctuations, determined by the energy production cycle, lead to littoral erosion and damage of the littoral fauna and flora.

— The remaining vegetation in the reservoir leads to eutrophication and has an impact on boating and fishing, so that no net fishing can be performed.

— The damming effect leads to a trophic upsurge of reservoirs with significantly more eutrophic conditions than in the former river stretch.

— Eutrophication of reservoirs in hot tropical/subtropical areas owing to climate.

— The dam serves as a barrier to the stream flow with an inhibition of fish migration so that the fishery yield decreases upstream and downstream of the reservoir.

— Waterborne diseases, *e.g.* schistosomiasis and malaria, can occur more frequently.

— In the reservoir, a loss of nutrients is caused by sedimentation, and downstream during flooding no fertilization of agricultural areas will take place, which results in a decline in soil fertility and agricultural yield.

— The missing suspended-sediment load downstream of the reservoir leads to riverbed or riverbank erosion and in some cases even to erosion of the river's delta at the ocean entrance point.

Alternative resources: use of treated wastewater

The use of treated wastewater is an intrinsic component of the natural water cycle. Wastewater dumped into streams and its dilution by flowing water indirectly make it available downstream of the dumping point for urban, industrial, and agricultural uses. The direct or planned use of this type of water has a more recent origin and it implies the direct use of wastewater with different degrees of treatment. Thus, it is necessary to transport it to the point of use by a special pipe, thereby avoiding its outlet into a natural water stream. The main objective of the planned use of wastewater is to convert it into an element of the IWRM through an agreement between urban, agricultural, and recreational water users.

The large distances between new water sources and urban areas, environmental limitations for building new reservoirs and pluriannual droughts have led to proposed application of treated wastewater for uses that do not require drinkable water.

While secondary water distribution networks of treated wastewater for irrigation is very limited in Europe, this type of network is very common in California, Florida, or even Japan, where it is a common practice in water and wastewater services. In addition, the population of these cities accepts and even promotes this kind of practice.

Urban, recreational, and irrigation development, mainly in coastal areas in Spain, leads to a significant increase in water demand for satisfying domestic consumption and the increasing area of gardens and irrigation for commercial and recreational uses. Water resource management under these conditions has two complementary objectives: 1) rational water use, *i.e.* avoiding excessive water consumption, and 2) the use of treated wastewater for uses other than drinking water, mainly in garden, golf courses and agricultural irrigation, and in environmental restoration, which allows for the creation of new water rights and that avoid coastal water degradation.

Although the use of treated wastewater in inland areas does not allow for the creation of new water resources, it makes it possible to improve water management through the substitution of pre-potable water for public consumption by treated wastewater for those uses that do not require pre-potable water.

Although treated wastewater has worse quality than drinkable water, it is usually more costly to supply treated wastewater than keep a supply of drinkable water.

The production cost of urban treated wastewater for use in irrigation has two main components: 1) wastewater treatment, which should be charged to the urban centers that dumped the waste; and 2) tertiary treatment, which should be charged to the final user of the treated water. This cost depends on the type of treatment and the quality requirements of the final use. Some studies estimate for water with good quality before tertiary treatment costs at least €0.12-0.30 m^{-3}. In addition, depending on the volume of wastewater generated and the temporal pattern, it is necessary to store the water, requiring in some cases large storage capacity. Thus, it is necessary to consider the cost of water storage, which depends on the volume, the characteristics of the reservoir, and the additional treatments.

In addition, it is necessary to consider and comply with the requirements described in the legislation (BOE, 2007; Royal Decree 1620/2007 of December 7), which establish the legal regime of using treated wastewater. This legislation deals with the legal issues related with the use of treated wastewater (definitions, specific concession system, concessions, among others) as well as the permitted uses, which are classified as: urban, agricultural (with three levels of water quality), industrial, recreational (including golf courses), and environmental, together with the quality requirements for each use.

With this legislation, some uses of treated wastewater could greatly increase the cost and the energy demand compared with the previous legislation due to the requirements of more intensive treatments. The cost of these new treatments should be charged to the final users, together with the costs of controlling water quality and treatments, independently of other considerations related with the concession system, authorization, etc.

Finally, it is necessary to indicate the importance of the location of available treated wastewater and its integration into the hydrological cycle, which should follow criteria related with rational planning and management of a river basin. Thus, in coastal areas, it may be interesting to use treated wastewater, while in inland areas far from the coast, treated wastewater can become part of the water cycle and be used downstream, which are aspects that characterize the IWRM processes. Therefore, in an IWRM process it is important to use treated wastewater in coastal areas, while it is not a key issue to do so inland. In addition, in coastal areas it is more important to use water efficiently than in inland areas, although it is a common objective in any basin planning and managing process.

The most recent studies developed in Australia indicate that there are doubts about the environmental effects of desalination and awareness of possible public health problems linked with the use of treated wastewater (Dolnicar and Schäfer, 2009).

Conclusions

Engineering, together with water planning and management tools, plays an important role to avoid water scarcity problems worldwide in both, permanent water scarcity (aridity) and temporal water scarcity (drought) scenarios.

One of the best strategies to face water scarcity is the implementation of management systems, which utilize models and tools to estimate the available water resources in each region and its variation in time. Following the principles of the society, a equilibrium between the offer and demand of the water resources should be found. In addition, these models and tools permit to assign water resources to the difference usages considering social, economic, and environmental criteria.

In order to perform a proper water planning and management it is necessary a strength relationship between users and administration, making emphasis in the demand organization, which is based on the available water resources and the corresponding water assigns to the different usages.

Engineering should get involved in deciding the infrastructures to be built (reservoirs, water transfers, wasterwater and salty water treatment plants, among others), their design, development, and management with the aim of obtaining a viable water planning and management, from a technical and economic point of view.

In addition, engineering support the efficient use of water and energy, optimizing the design and management of water distribution networks together with the irrigation systems. This is of great importance since irrigation consumes more than the 70% of the water resources in the World.

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