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Assessment of water exploitation indexes based on water accounting.

PhD Thesis

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ASSESSMENT OF WATER EXPLOITATION INDEXES BASED ON WATER ACCOUNTING.

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JULY 2016

To my family

When the well is dry, we will know the worth of water.

Benjamin Franklin

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Many thanks to everyone.

ABSTRACT

New European policies established in the Blueprint (EC, 2012) propose the use of water accounting for the allocation and reservation of water resources. This course correction contrasts with the calculation of water balances that has been used since the last century in Spain for this purpose. According to the European Commission (EC, 2015) the difference between the two approaches is the inclusion of the economic component. This argument is indisputable, but it would also add that both "asset accounts" and the physical supply and use tables require a type of information that had not been considered until now. In view of this new challenge, the use of hydrological and water resources management models is essential.

This thesis aims to implement a methodology for the transition between water balances and water accounting considering the special characteristics of the Mediterranean basin (with a high degree of regulation and the use of unconventional resources). In the same line, it raises the need for the definition of an indicator to assess the performance of a water resources system taking into consideration the origin of the water resources as a measure of the degree of stress suffered by the systems.

This thesis is presented by publications and seeks to address the methodologies and indicators used to date in the planning and management of water resources. First, the state of the art is analyzed in the first publication of the thesis, as detailed in Annex 1. The second publication, analyzes the key elements for formulating water balances that will determine, to a large extent, results obtained, as detailed in Annex 2. The third publication, in Annex 3, tries to explain how in those basins where the use of water resources is close, or even higher, to their availability, the use of balances based solely on variables such as rainfall and temperature are not sufficient. And due to the high regulation of water resources they should also include the results of water management models. This approach contrasts with the proposals made by the countries of northern Europe focused mainly on hydrological models.

In order to address the water accounting approach a pilot case located in the Andalusian Mediterranean basins was analysed. This work is presented in the fourth publication, reproduced in Annex 4. This initial analysis has served to

highlight the need to develop a complementary software that allows unify the results of hydrological and water management models for calculating water accounts. The development of this software, which has been called AQUACCOUNTS, and its application to a general case with all the detail required in water resources planning has been published in the fifth article presented in Annex 5, taking the Júcar River Basin as a case study. From these results, a classification of water exploitation systems was carried out according to their degree of stress. These results were compared with the ones in Annex 2 which proposes the use of the indicator of exploitable water resources and which has been obtained with the traditional water balances approach.

Finally, Annex 6 includes the last publication of this thesis focused on the effects of climate change in the Po River Basin (Italy) by using water accounting. This work has served to identify those key elements within the simulation models and opens the door to improve them within the approach proposed by the SEEA-W.

This thesis aims to collaborate with those responsible for European policies in water resource planning for the application of those methodologies and tools appropriate to each territory.

RESUM

Les noves polítiques europees establides en el Blueprint (EC, 2012) proposen l'ús de la comptabilitat de l'aigua per a l'assignació i reserva dels recursos hídrics. Esta correcció del rumb (o canvi de paradigma) contrasta amb el càlcul de balanços que s'ha utilitzat des del segle passat a Espanya per a aquesta finalitat. Segons la Comissió Europea (EC, 2015) la diferència entre ambdós plantejaments es troba en la inclusió de la component econòmica. Este argument és indiscutible, però caldria afegir a més que tant les "asset accounts" com les taules físiques d'ús i subministrament requerixen un tipus d'informació que fins ara no s'havia considerat. A la vista d'este nou repte, l'ús dels models hidrològics i de gestió dels recursos hídrics es fa imprescindible.

Amb esta tesi es pretén dur a terme una metodologia que permeta la transició entre els balanços hídrics i els comptes de l'aigua tenint en compte les especials característiques de les conques mediterrànies (amb un elevat grau de regulació i l'ús de recursos no convencionals). En esta mateixa línia es planteja la definició d'un indicador que tracte de discutir el comportament conjunt d'un sistema de recursos hídrics i que tinga en consideració l'origen dels recursos empleats com a mesura del grau d'estrés dels sistemes.

Esta tesi es presenta per compendi de publicacions i tracta d'abordar les metodologies i indicadors utilitzats fins a la data en la planificació i gestió dels recursos hídrics. En primer lloc s'analitza l'estat de l'art que constituïx la primera publicació de la tesi, tal com es detalla en l'Annex 1. La segona publicació, analitza els elements clau per a la formulació de balanços que determinaran, en gran manera, els resultats obtinguts, tal com es detalla en l'Annex 2. La tercera publicació, en l'Annex 3, tracta d'explicar com en les conques on l'aprofitament dels recursos és pròxim o inclús superior a la seua disponibilitat, l'ús dels balanços basats únicament en variables com la precipitació i la temperatura no són suficients, sinó que a causa de l'alta regulació dels recursos ha de recórrer-se a més als models de gestió. Este plantejament contrasta amb les propostes plantejades pels països del nord d’Europa centrats principalment en el models hidrològics.

Per a abordar el tema s'ha partit d'un cas pilot localitzat en les conques mediterrànies andaluses. Este treball es presenta en la quarta publicació, que es

reproduïx en l'Annex 4. A partir d'aquest anàlisi inicial, es va veure la necessitat de desenrotllar una ferramenta complementaria que permetera unificar tant la informació de partida com els resultats dels models hidrològics i de gestió per al càlcul de la comptabilitat de l'aigua. El desenrotllament d'esta ferramenta, que ha sigut denominat AQUACCOUNTS, i la seua aplicació a un cas general amb tot el detall requerit en planificació s'ha publicat en el quint article que es presenta en l'Annex 5, sent la Demarcació Hidrogràfica del Xúquer el cas d'estudi. A partir dels resultats obtinguts s'ha dut a terme una classificació dels sistemes d'explotació segons el seu grau de desenrotllament comparant-se amb els resultats obtinguts en l'Annex 2 que proposa l'ús de l'indicador de recursos explotables i que s'ha obtingut amb les metodologies tradicionals de balanços.

Finalment, l'Annex 6 arreplega l'última publicació d'esta tesi en què s'analitzen els efectes del canvi climàtic en la conca del riu Po (Itàlia) per mitjà de l'ús de la comptabilitat de l'aigua. Este treball ha servit per a identificar aquells elements clau dins dels models de simulació i obri les portes a una millora dels mateixos dins de l'enfocament plantejat pel SEEA-W.

Esta tesi pretén col·laborar amb els responsables de les polítiques europees en matèria de planificació per a l'aplicació d'aquelles metodologies i ferramentes més adequades a cada territori.

RESUMEN

Las nuevas políticas europeas establecidas en el Blueprint (EC, 2012) proponen el uso de la contabilidad del agua para la asignación y reserva de los recursos. Esta corrección del rumbo (cambio de paradigma) contrasta con el cálculo de balances que se ha venido utilizando desde el siglo pasado en España para dicho fin. Según la Comisión Europea (EC, 2015) la diferencia entre ambos planteamientos se halla en la inclusión de la componente económica. Este argumento es indiscutible, pero habría que añadir además que tanto las “asset accounts” como las tablas físicas de uso y suministro requieren un tipo de información que hasta ahora no se había considerado. A la vista de este nuevo reto, el uso de los modelos hidrológicos y de gestión de los recursos hídricos se hace imprescindible.

Con esta tesis se pretende llevar a cabo una metodología que permita la transición entre los balances hídricos y las cuentas del agua teniendo en cuenta las especiales características de las cuencas mediterráneas (con un elevado grado de regulación y el uso de recursos no convencionales). En esta misma línea se plantea la definición de un indicador que trate de discutir el comportamiento conjunto de un sistema de recursos hídricos y que tenga en consideración el origen de los recursos empleados como medida del grado de estrés de los sistemas.

Esta tesis se presenta por compendio de publicaciones y trata de abordar las metodologías e indicadores utilizados hasta la fecha en la planificación y gestión de los recursos hídricos. En primer lugar se analiza el estado del arte que constituye la primera publicación de la tesis, tal y como se detalla en el Anexo 1. La segunda publicación, analiza los elementos clave para la formulación de balances que determinarán, en gran medida, los resultados obtenidos, tal y como se detalla en el Anexo 2. La tercera publicación, en el Anexo 3, trata de explicar cómo en las cuencas donde el aprovechamiento de los recursos es cercano o incluso superior a su disponibilidad, el uso de los balances basados únicamente en variables como la precipitación y la temperatura no son suficientes, sino que debido a la alta regulación de los recursos debe recurrirse además a los modelos de gestión. Este planteamiento contrasta con las propuestas planteadas por los países del norte de Europa centrados principalmente en los modelos hidrológicos.

Para abordar el tema se ha partido de un caso piloto localizado en las cuencas mediterráneas andaluzas. Este trabajo se presenta en la cuarta publicación, que se reproduce en el Anexo 4. A partir de este análisis inicial, se vio la necesidad de desarrollar un software complementario que permitiese unificar tanto la información de partida como los resultados de los modelos hidrológicos y de gestión para el cálculo de la contabilidad del agua. El desarrollo de este software, que ha sido denominado AQUACCOUNTS, y su aplicación a un caso general con todo el detalle requerido en planificación se ha publicado en el quinto artículo que se presenta en el Anexo 5, siendo la Demarcación Hidrográfica del Júcar el caso de estudio. A partir de los resultados obtenidos se ha llevado a cabo una clasificación de los sistemas de explotación según su grado de desarrollo comparándose con los resultados obtenidos en el Anexo 2 que propone el uso del indicador de recursos explotables y que se ha obtenido con las metodologías tradicionales de balances.

Por último, el Anexo 6 recoge la última publicación de esta tesis en la que se analizan los efectos del cambio climático en la cuenca del río Po (Italia) mediante el uso de la contabilidad del agua. Este trabajo ha servido para identificar aquellos elementos clave dentro de los modelos de simulación y abre las puertas a una mejora de los mismos dentro del enfoque planteado por el SEEA-W.

Esta tesis pretende colaborar con los responsables de las políticas europeas en materia de planificación para la aplicación de aquellas metodologías y herramientas más adecuadas a cada territorio.

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1. INTRODUCTION

1.1 RESEARCH MOTIVATION

Water is vital for the life of all who inhabit our planet representing an essential resource from a biological, environmental, social and economic point of view. What makes water so valuable is its random nature and its irregular distribution in space and time. This hydrological variability explains why river flows are recorded when they are not required or where they are not necessary. The spatial irregularity of water resources forces the need to develop expensive transportation and distribution networks such as channels and pipes and on the other hand, river flows are spread unevenly across the year. Further, in some regions water resources vary year-on-year, consequently, the alternation of wet periods and dry periods requires the building of costly hyper-annual regulation works.

Water scarcity regions know a lot about this and Spain is a clear example. While in countries with a direct dependence on rainwater to supply water demands a reduction in precipitation during some weeks can originate a drought, in others like in Spain, droughts can prolong for years. This reason explains the ancient tradition of hydraulic works in Spain (Estrela and Vargas, 2012) that can be understood by the following milestones:

- Spain is the fifth country in the world in terms of its number of large dams, just behind China, the USA, India and Japan (INE, 2008).
- Tibi reservoir, which is located in Alicante and was built between 1579 and 1594, is the most ancient reservoir in Europe still in operation today, just behind romans reservoirs (iAgua, 2015).
- Ebro River Basin Authority (RBA), the entity in charge of the water resources planning and management of the district, was created in 1926.
- The period 1991–1995 has gone down in history as the worst drought period in recent times in Spain. Consequently, since then drought management was incorporated in the water resources planning issues instead of being considered as an emergency (Estrela, 2006).

One of the main objectives in the XXI century is associated with the sustainable use of water ensuring that water supplies are guaranteed for all users in terms of quantity and quality. But which is the amount of water available for the different uses in a river basin? To date, the methodology used in water resources planning and management is focused on water balances. At first glance, the calculation of water balances seems simple as it involves comparing water resources with water requirements. In practise, it is more complex due to several reasons such as insufficient and poor quality of data.

In order to reach the sustainable use of water, the main objectives of the European Union (EU) Water Framework Directive (WFD) (EP, 2000) included the achievement of the ''good status" for all water bodies, the approval of the water management plans based on river basins, promoting the application of pricing policies and public participation. The transposition of the WFD into Spanish regulation was done through the Spanish Guideline of Water Planning (IPH referred to its Spanish acronym) (MAGRAMA, 2008) which was used for the River Basin Management Plans (RBMP) drafting. One of the major challenges faced in the RBMP was the water balance setting taking into account the existing water rights and the compliance of the environmental requirements. Despite the high regulation of water resources demand supplies are not always guaranteed due to the random nature of river flows. In this sense, the IPH determines if water supplies are considered satisfied by employing a reliability criterion which varies according to the type of use (urban, industrial or agrarian). This fact represents another practical consequence of water balances for the purpose of water allocation and reservations, in such a way as new water allocations in the river basin will depend on the availability of water resources.

Faced with the difficulty of achieving the "good status" for all water bodies in 2015, the Blueprint to safeguard Europe's water resources (EC, 2012) symbolizes another turn of the screw towards the improvement of water resources in terms of quantity and quality. In order to involve other sectors such as fishing, renewable energy production or transport, and to measure the influence of each water user to the overall economy the Blueprint proposes the use of water accounting as a tool for improving water management. But, what is the difference between the previous water balance and the new proposed water accounting approach? According to the guidance (EC, 2015) water balance is defined as "the numerical calculation of the inputs to, outputs from, and changes in the volume of water in the various components of the hydrological cycle, within a specified hydrological unit and during a specified time unit, occurring both naturally and as a result of the human induced water abstractions and returns". By contrast, water accounting "integrates physical and economic information related to water consumption and use, to achieve equitable and transparent water governance for all water users and a sustainable water balance between water availability, demand and supply". A priori both approaches seem similar since both methodologies are based on a water balance approach (Molden and Sakthivadivel, 1999) but with a different format and water accounting also considers economic information.

There are several water accounting frameworks developed around the world and the United Nations Statistics Division (UNSD) proposes the System of Environmental Economic Accounting for Water (SEEA-W) (UNDS, 2012). The main interest of the SEEA-W framework is to provide a standard methodology allowing policymakers to compare results between different periods and territories. But building water accounts is a complex task. As noted by Dimova et al. (2014) although the simplicity of SEEA-W concepts, its implementation involves collecting a huge variety of data. Due to this handicap, simulation models are required in order to estimate the different components of the water cycle. Moreover, Tilmant et al. (2015) point out that there is no standard process to develop water accounts, nor any agreement on how to present them.

When faced with this new paradigm, it is required to adapt the requirements of European policies into a more standardized methodology to avoid preconditions that may determine the results. Despite the willingness to adapt the current approach to the new requirements of European policies, the principle of subsidiarity should be borne in mind, since there is not any one-size-fits-all solution (EC, 2012). In this way, each Member State could apply the measures and approaches that best fit with its territory (Berbel and Gutiérrez-Martín, 2013).

To do this, this thesis proposes the use of Decision Support Systems (DSS) which represent a powerful tool, providing more analytical and well-informed decisions (Andreu et al., 2006). For the purposes of this thesis it has been required the use of several modules of a DSS: hydrologic models, water allocation models and hydroeconomic models.

1.2 CASE STUDY

The Jucar River Basin District (RBD) has been selected as the case study of this thesis. As noted by Ferrer (2012) Jucar RBD is affected by water scarcity, repeated drought episodes and overexploitation, as many other river basin districts in Mediterranean region. An overview of the case study is presented considering the following aspects: territorial area, geographical and climatic features, water resources, water uses and water infrastructures.

1.2.1 JUCAR RBD TERRITORIAL AREA

The Jucar RBD (43,000 km^2) is located in the eastern part of the Iberian Peninsula in Spain and it is formed by the aggregation of several river basins that flow into the Mediterranean Sea. It extends from the mouth of the Cenia River, including its basin in the north, and the mouth of the Segura River, in the south. It includes territories from 4 regions: Aragon, Catalonia, Castilla La Mancha and Valencia. The three main rivers in the existing Jucar RBD are Jucar River, Turia River and Mijares River.

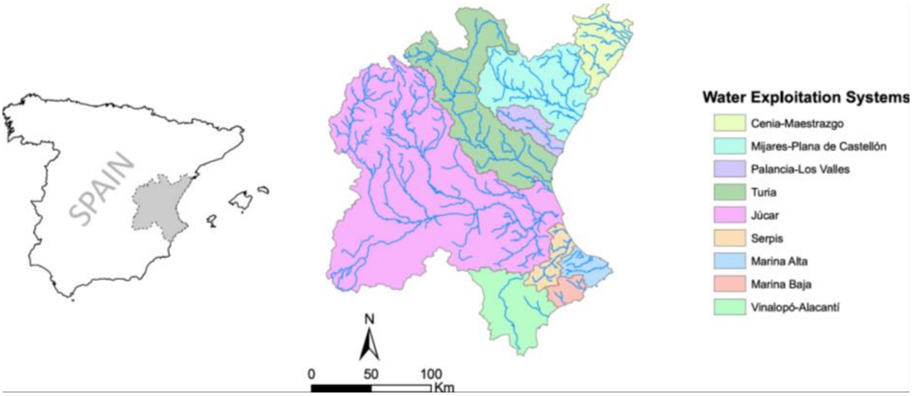


Fig. 1.1: Location of the Jucar RBD in the Iberian Peninsula
(Source: Annex 5)

The Jucar RBD comprises 9 water exploitation systems (see figure 1.1) which are described below:

The Cenia-Maestrazgo Water Resources System (1,875 km^2) is located in the north of the province of Castellon, its altitude ranges from 1000 m until the level of the Mediterranean Sea. It includes the entire river basins of Cenia, Valviquera, Servol, Barranco de Agua Oliva, Cervera, Alcalá and San Miguel rivers and coastal sub-basins.

The Mijares-Plana Castellon Water Resources System (5,466 km^2) comprises Mijares, Seco, Veo and Belcaire rivers, and nearby coastal sub-basins.

The Palancia-Los Valles Water Resources System (1,159 km^2) comprises Palancia river basin as a whole and coastal sub-basins, being in an area located between 1,550 m and the Mediterranean Sea.

The Turia Water Resources System (6,913 km^2) comprises Turia River as a whole, as well as the gorges of Carraixet and Poyo, and nearby coastal sub-basins.

The Jucar Water Resources System (22,378 km^2) includes the own Jucar river basin as a whole, also including the area and services served by the Jucar-Turia Channel and including coastal sub-basins between the Gola de El Saler and the limit of the municipalities of Cullera and Tavernes de Valldigna. This system includes the endorheic basin of Pozohondo.

The Serpis Water Resources System (990 km^2) includes the entire river basin of the Serpis, Jaraco and Beniopa rivers and coastal sub-basins. The highest peak is reached in the birth of Vallaseta River, at 1,462 m.

The Marina Alta Water Resources System (839 km^2), in the north of the province of Alicante, includes the entire river basin of Girona and Gorgos rivers and coastal sub-basins between the northern boundary of the municipality of Oliva and the left bank of Algar River.

The Marina Baja Water Resources System (583 km^2), is situated in the province of Alicante, between 1,100 m and the Mediterranean Sea; it includes the entire river basins of Algar and Amadorio rivers and coastal sub-basins between Algar River and the southern boundary of Villajoyosa municipality.

Finally, the Vinalopó-Alacantí Water Resources System (2,786 km^2) is located in the southern part of the province of Alicante, and comprises the entire river basins of Monnegre, Rambla de Rambuchar and Vinalopó, including coastal sub-basins between the northern boundary of El Campello municipality and the boundary of Segura River Basin.

1.2.2 GEOGRAPHICAL AND CLIMATICAL FEATURES

Physiographically, in the Jucar RBD two major areas are distinguished: an inland mountainous area and a coastal littoral zone. The highest peak, Peñarroya, is located in the Iberian System, with an altitude of 2,024 m; other high geographical dimensions are Javalambre (2,020 m), Caimodorro (1,921 m) and Peñagolosa (1,813 m). Between the coastal plains highlights Oropesa-Torreblanca, Castellon and Sagunto, Valencia-La Ribera, Favara-Gandía-Denia.

The Jucar RBD's climate is a typical Mediterranean climate with warm summers and mild winters. The maximum temperatures are recorded during the months of July and August, coinciding with the dry season. The average annual temperatures range between 14 and 16.5°C. The annual average rainfall is about 500 mm, there is nevertheless a great spatial variability with values of 300 mm in the southern regions, while in other areas precipitation reaches values greater than 750 mm. Also, during the months of October and November precipitation events of great intensity and short duration may occur, commonly known as "cold front".

1.2.3 WATER RESOURCES

304 surface water bodies within river category have been defined in the area of the Jucar RBD. This water bodies can be classified according to their nature in natural, heavily modified or artificial. Moreover, in the field of the Jucar RBD, 19 surface water bodies within lake category, 11 of them have been defined as natural and 8 as heavily modified, as can be observed in figure 1.2:

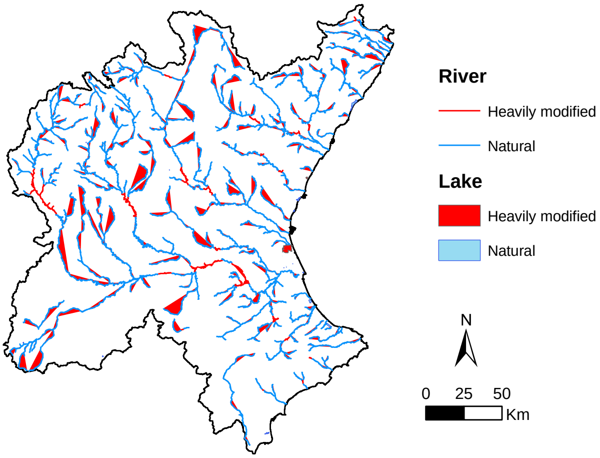


Fig. 1.2: Surface water bodies (river and lakes category) in the Jucar RBD (Source: self-made)

In the territory of Jucar RBD, 90 groundwater bodies (GWB) and 26 impervious water bodies or local aquifers have been defined, as we observe in figure 1.3).

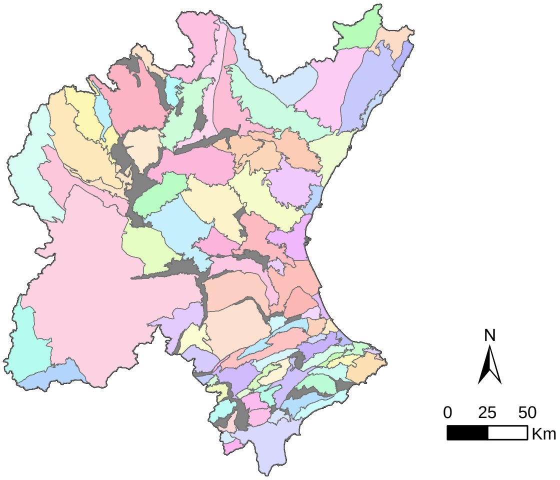


Fig. 1.3: Groundwater bodies in the Jucar RBD (Source: self-made)

The riverbeds located in the principal fluvial network have marked Mediterranean streamflows regime. This is characterized by dry periods in summer and the growth of water flows in autumn. The rainfall in the basin generates an average annual streamflows of 3111 hm^3. The spatial and temporal irregularity of rainfall is accentuated in the case of streamflows. This fact is the reason why the territory of Jucar RBD is subjected to significant periods of droughts, as those produce in the years 1994-1995 or 2004-2008. Moreover, water resources in Mijares, Turia and Jucar rivers are characterized by a marked reduction in the recorded streamflows during the 1980-2009 period (Pérez Martín et al., 213). Table 1.1 shows the average total streamflows in naturalized regimes for the period 1980/81-2011/12.

Water Exploitation System	Average of total natural streamflows (hm^3/year) 1980/81-2011/12
Cenia-Maestrazgo	143
Mijares-Plana de Castellón	326
Palancia-Los Valles	63
Turia	472
Jucar	1.605
Serpis	200
Marina Alta	164
Marina Baja	68
Vinalopó-Alacantí	69
Total Jucar RBD	3.111

Table 1.1: Summary of the total natural streamflows in the Jucar RBD (Source: Jucar RBA)

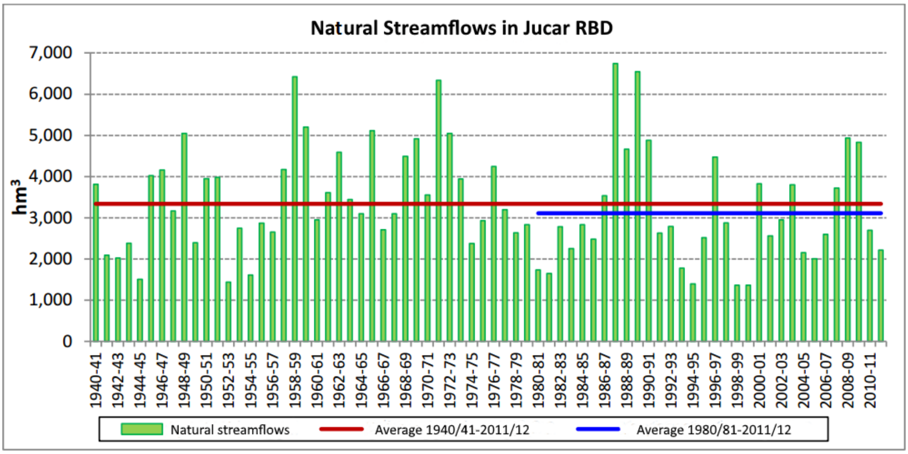


Fig. 1.4: Total natural streamflows time series of the Jucar RBD (Source: Jucar RBA)

Unconventional resources represent new sources of resources used in recent decades, such as the desalination of seawater or brackish water, and the reuse of treated wastewater (Ferrer, 2012). The incorporation of these new resources has led to the resolution of specific problems of water availability in some cases and, generally, has also increased the efficiency in the use of water resources, increasing the level of reliability. Direct reuse of treated wastewater is highly relevant from a quantitative point of view in the territory of Jucar RBD. It should be noted that only the direct reuse of wastewater near the coastline really represents an increase in the resources availability, hence water resources are available to be used that may otherwise not be profitable. The treated wastewaters in the innermost areas of Jucar RBD discharge into rivers forming natural contributions to the resources available to downstream users.

1.2.4 WATER DEMANDS

According to municipal registers, the permanent population in the area of Jucar RBD is over 5 million inhabitants (year 2009), being the population density about 119 inhabitants/km^2, higher than the Spanish average (89 inhabitants/km^2). Analysing the population distribution by water exploitation system, the Turia system is the most populated due to the location of the metropolitan area of Valencia, followed by Jucar system where the cities of Albacete, Cuenca and the regions of La Ribera Alta and La Ribera Baja are located; Vinalopo-Alacanti system, where the main cities are Alicante and Elche; Mijares-Plana de Castellón, with Castellón and Villarreal cities.

The total water demand in the Jucar RBD, is about 3230 hm^3/year, whereof 79% corresponds to agrarian sector and 17% is used to meet urban demands. The Jucar system presents the higher water demand, as we observe in table 1.2. The spatial distribution of water requirements is presented in figures 1.5, 1.6 and 1.7.

It is important to highlight that the total water demand in the district is slightly higher than the total natural streamflows obtained for the period 1980/81-2011/12 and presented in table 1.1.

Water Exploitation System	Urban demand (hm^3)	Agrarian demand (hm^3)	Industrial demand (hm^3)	Recreational demand (hm^3)	Total demand (hm^3)
Cenia-Maestrazgo	18	84	1	< 1	103
Mijares-Plana de Castellón	55	232	13	1	301
Palancia-Los Valles	14	74	7	< 1	95
Turia	145	459	31	2	637
Jucar	140	1414	56	1	1611
Serpis	31	82	5	< 1	118
Marina Alta	30	54	< 1	1	85
Marina Baja	26	34	< 1	2	62
Vinalopó-Alacantí	93	106	18	2	219
Total JRBD	552	2539	131	9	3231

Table 1.2: Summary of the water demands in the Jucar RBD (Source: Jucar RBA)

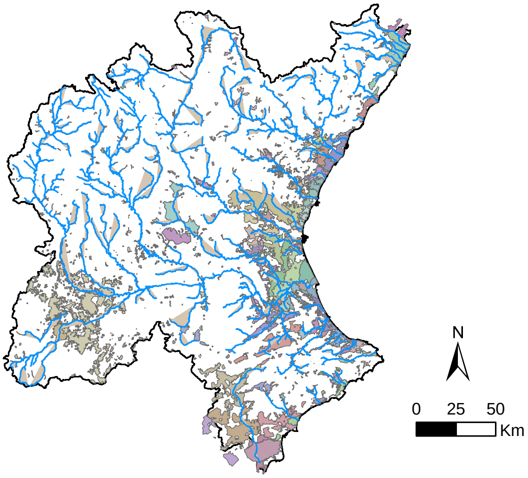


Fig. 1.5: Agrarian requirements in the Jucar RBD (Source: self-made)

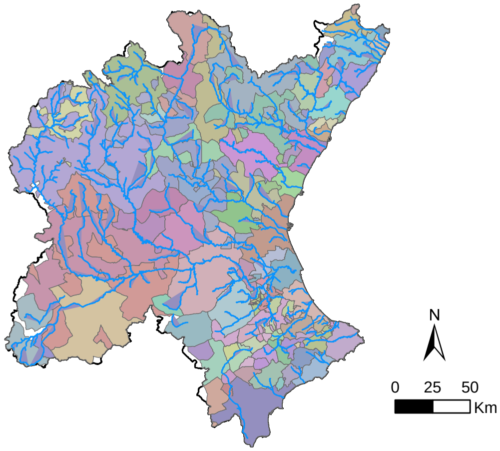


Fig. 1.6: Urban requirements in the Jucar RBD (Source: self-made)

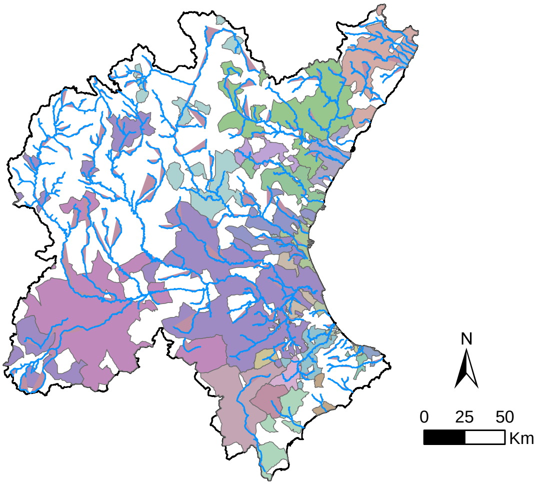


Fig. 1.7: Industrial requirements in the Jucar RBD (Source: self-made)

Figure 1.8 shows the main irrigated crops in the Jucar RBD. It highlights the importance of citrus growing, representing almost half of the irrigated area. The second largest group are the cereals for grain (wheat and barley) with 12% of the irrigated area; and the third largest group are the crops of maize and sorghum, with the 6% of the irrigated area. It should be noted that, the area dedicated to cereal represents about the 22% (including cereals for grain, maize and rice).

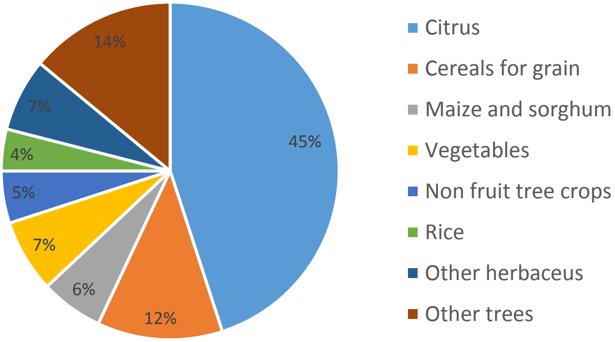


Fig. 1.8: Irrigated area distribution in the Jucar RBD
(Source: Jucar RBA)

1.2.5 WATER INFRASTRUCTURES

Regulation of surface water in Jucar RBD is performed by more than 17 large reservoirs with a total capacity of 3300 hm^3. The main reservoirs for basins are:

- In Jucar system: Alarcon (1112 hm^3), Contreras (874 hm^3), Tous (maximum capacity of 340 hm^3) and Cortes (116 hm^3), along with Forata (37 hm^3) in the Magro and Bellus (69.2 hm^3) in the Albaida River, both tributaries of the Jucar River.
- In Turia system: Benageber (228 hm^3), Loriguilla (71 hm^3), Arquillo de San Blas (22 hm^3) and Buseo (7.2 hm^3).
- In Mijares system: Arenos (maximum capacity 130 hm^3), Sichar (49.2 hm^3) and Maria Cristina (19.7 hm^3).
- In Marina Baja system: Amadorio (16 hm^3) and Guadalest (13 hm^3).
- In Serpis system: Beniarrés (29.5 hm^3)
- In Cenia system: Ulldecona (11 hm^3)
- In Palancia system: El Regajo (6.6 hm^3).

Figure 1.9 shows the geographic location of the main reservoirs in Jucar RBD.

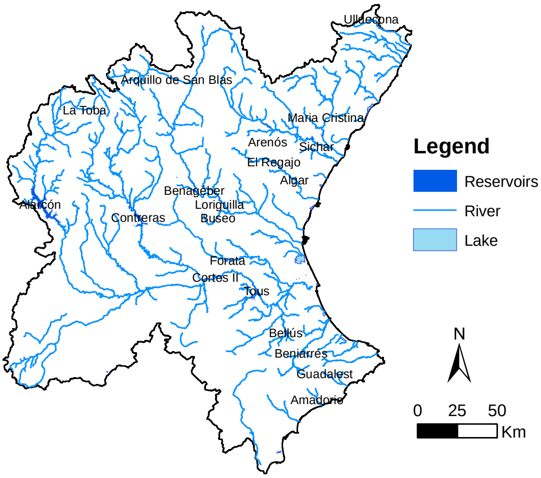


Fig. 1.9: Main reservoir in the Jucar RBD
(Source: self-made)

The main canals in the Jucar RBD are shown in figure 1.10 and table 1.3:

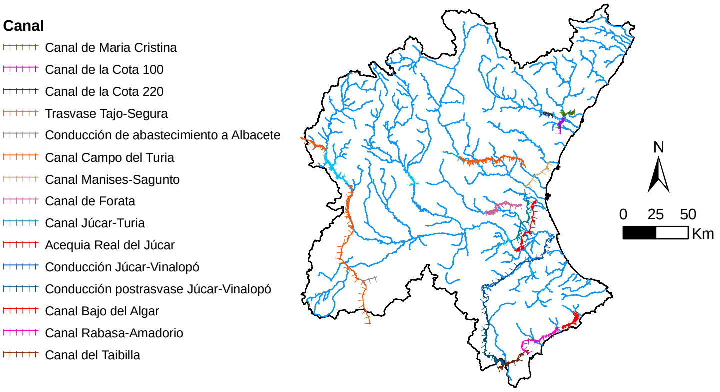


Fig. 1.10: Main canals in the Jucar RBD
(Source: self-made)

Name	Length (km)
Canal Campo del Turia	72.9
Canal Jucar-Turia	58.2
Acequia Real del Jucar	55.3
Canal Rabasa-Amadorio	48
Canal de Forata	39.4
Real Acequia de Moncada	32.7
Canal Manises-Sagunto	29.5
Canal Bajo del Algar	27.6
Acequia de Escalona	17.1
Canal Cota 100	16.7
Acequia de Carcagente	10.1
Canal Cota 220	9.2
Acequia de Sueca	5.5
Acequia de Cuatro Pueblos	4.9
Acequia de Cullera	4.8
Acequia Real de Antella	1.4

Table 1.3: Summary of the main canals in the Jucar RBD

For more information about the Jucar RBD, consult the web page of the Jucar RBA (www.chj.es).

1.3 OBJECTIVES

The main goal of this thesis is to develop a conceptual framework, which includes methodology and tools, in order to build water balances for stressed river basins. Using the System of Environmental-Economic Accounting for Water, this work also claims to introduce the definition of water exploitation indexes that describe the state of a river basin.

The above general objectives might be subdivided in a series of more specific purposes, which are the following:

- Review of the state of the art of water scarcity and drought indexes in water resources planning and management.
- Development of a tool capable to build water accounts from hydrological and water management models.
- Acquisition of the economic costs of water.
- Application and verification of the proposed methodology to a stressed river basin.
- Classification of river basins according to their degree of water stress.

1.4 STRUCTURE OF THE THESIS

This thesis is structured in four sections and six annexes. The first section involves the introduction and it includes the research motivation, a brief description of the case study and the main objectives. The list and a brief summary of each of the publications, which are part of this research, is presented in section two. The third section contains the results obtained during this research, the discussion about the significance of the findings in comparison with other similar works and the possible improvements in the methodology. Finally, section four includes the concluding remarks and the future research lines.

On the other hand, each of the six annexes corresponds to the research papers described in section two.

2. PUBLICATIONS

This thesis is a compendium of research papers, including four scientific papers published in peer review journals indexed in the Journal Citation Report (JCR) and two participations in international conference published in Conference Proceedings. They are the following:

- **Pedro-Monzonís, M.,** Solera, A., Ferrer, J., Andreu, J. and Estrela, T., 2016. Water accounting in stressed river basins based on water resources management models. Sci Total Environ 565, 181-190 doi:10.1016/j.scitotenv.2016.04.161

- **Pedro-Monzonís, M.,** Jiménez-Fernández, J., Solera, A., and Jiménez-Gavilán, P., 2016. The use of AQUATOOL DSS applied to the System of Environmental-Economic Accounting for Water (SEEAW) J. Hydrol 533, 1-14, doi:10.1016/j.jhydrol.2015.11.034

- **Pedro-Monzonís, M.,** Solera, A., Ferrer, J., Estrela, T. and Paredes-Arquiola, J., 2015. A review of water scarcity and drought indexes in water resources planning and management, J. Hydrol. 527, 482-493, doi:10.1016/j.jhydrol.2015.05.003

- **Pedro-Monzonís, M.,** Ferrer, J., Solera, A., Estrela, T. and Paredes-Arquiola, J., 2015. Key issues for determining the exploitable water resources in a Mediterranean river basin, Sci Total Environ, 503-504, 319-328, doi:10.1016/j.scitotenv.2014.07.042.

- **Pedro-Monzonís, M.,** Ferrer, J., Solera, A., Estrela, T., Paredes-Arquiola, J., 2014. Water Accounts And Water Stress Indexes In The European Context Of Water Planning: The Jucar River Basin. 16th Conference on Water Distribution System Analysis, WDSA 2014. In Procedia Engineering 89, 1470-1477 doi: 10.1016/j.proeng.2014.11.431

- **Pedro-Monzonís, M.,** Del Longo, M., Solera, A., Pecora, S., Andreu, J., in press. Water accounting in the Po River Basin applied to climate change scenarios. 2nd International Conference on Efficient and

Sustainable Water System Management towards Worth Living Development, 2EWaS 2016.

A brief description of the contents and the relation with the achievement of the research objectives defined is presented in the following subsections.

2.1 A REVIEW OF WATER SCARCITY AND DROUGHT INDEXES IN WATER RESOURCES PLANNING AND MANAGEMENT

This research paper, which corresponds with Annex 1, aims to review the state of the art related with the central themes of this work that are water scarcity and drought indexes in water resources planning and management.

To date, a huge amount of water indexes related to different approaches, such as weather forecasting, water productivity or drought management have been defined by scientists and researchers. In most cases, these indexes are used as a threshold to determine the features of a region or to trigger an action. A priori, there is not a single index suitable for all cases. In this sense, it is required to use different indexes in accordance with the proposed objectives.

In this publication several indexes have been classified according to their use. In this way, indexes are organized in three categories that are:

- Drought and water scarcity indexes. These indexes serve to identify and classify the types of droughts. They are also used for the implementation of anticipation measures. An example of the application of measures to reduce drought impacts is the case of the National Drought Indicator System in Spain.
- Indicators derived from water accounting. They characterize the pressures on water resources, allowing a general description of the river basin and paying attention to the impact of each water user to the total monetary value of water resources in a territory (Tilmant et al., 2015).
- Performance indexes. Traditionally, these indexes are used to assess the capacity of a water resources system to meet its demands. They are also used for purposes of resource allocation along with simulation models in order to evaluate the status of the water resources system in different scenarios.

Whatever the case may be, the combined use of these indexes supports the decision-making process.

2.2 KEY ISSUES FOR DETERMINING THE EXPLOITABLE WATER RESOURCES IN A MEDITERRANEAN RIVER BASIN

This publication, which corresponds with Annex 2, tries to describe the key issues for establishing the methodology for calculating the Exploitable Water Resources (EWR) in a Mediterranean river basin, as an indicator of water availability. As noted by (UNDS, 2012), this indicator depends on the management and infrastructure development of the territory, and it is not possible to obtain it as a result from water accounting approaches.

This work is in line with the traditional approaches used in Spain for water resources planning and management. Its obtainment is supported by two key pillars which are water balances and the use of a reliability criterion for assessing the compliance with water supplies. The EWR is calculated as the maximum demand that can be satisfied in compliance with certain levels of supplies. Different possible combinations between the origin of streamflow time series, the reliability criteria and the length of the simulation period have been taken into consideration. Predictably, the findings show a wide dispersion, being necessary that decision-makers resolve the methodology required to determine the EWR in a river basin.

2.3 WATER ACCOUNTS AND WATER STRESS INDEXES IN THE EUROPEAN CONTEXT OF WATER PLANNING: THE JUCAR RIVER BASIN

This publication, which can be found in Annex 3, emphasises the need to consider jointly the use of hydrological models and water allocation models to apply water accounting approaches.

In this sense, the purposes of hydrological models are to quantify the hydrological cycle, estimating variables such as precipitation, actual evapotranspiration, surface and groundwater runoff, soil moisture, and aquifer recharge, among others. Conversely, water resource management models are used to assess the behaviour of a water exploitation system for given scenarios.

They include all the necessary elements for describing the water management, such as reservoirs, hydraulic connections, aquifers, demand centres, unconventional resources, environmental requirements or operating rules, among others.

In order to reinforce this idea, several drought indexes were applied by using precipitation data and the volumes of water stored in reservoirs obtained as a result of a water allocation model, respectively. The findings demonstrate that the single analysis of precipitation is not enough in stressed river basins as Mediterranean ones.

2.4 THE USE OF AQUATOOL DSS APPLIED TO THE SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING FOR WATER (SEEA-W)

This publication, which corresponds with Annex 4, is a pilot case for the acquisition of water accounts and the calculation of several indicators derived from their results. The accounting approach considered is the System of Environmental-Economic Accounting for Water (SEEA-W). It is focused on physical supply and use tables as well as on asset accounts, leaving aside the monetary terms.

This work has provided the basis for the development of a tool capable to build water accounts by using hydrological and water management models, as proposed in the objectives of this thesis. In order to have all the necessary information required by the SEEA-W, it was required the building of a hydrological model with EVALHID module (Paredes-Arquiola et al., 2012) from AQUATOOL DSS (Andreu et al., 1996).

The case study is the Velez River Basin, located in the Mediterranean Andalusian River Basin District, in Málaga. As first contact, the approach is applied to a small river basin in order to validate the results easily. In this case, the size of this river basin is inversely proportional to their pressures and their water management issues. The existence of a great number of economic activities in the Vélez River Basin is explained by the geographic, geomorphologic, climatic and socio-cultural context of this area. Agriculture constitutes the main economic activity together with urban settlements along the basin and the coast and to guarantee these demands the basin is highly regulated. Therefore, this area of study is an excellent example of highly pressured basin with lots of hydrological information to analyse aspects of water management.

2.5 WATER ACCOUNTING IN STRESSED RIVER BASINS BASED ON WATER RESOURCES MANAGEMENT MODELS

This research paper, which corresponds with Annex 5, serves to close this thesis. This work has allowed the fulfilment of the objectives proposed in this thesis. Among them are the development of AQUACCOUNTS module within the AQUATOOL DSS (Andreu et al., 1996), the acquisition of the economic cost of water services and the application and verification of the proposed methodology to a stressed river basin such as Jucar RBD.

Moreover, despite these findings have not been published, this research has allowed the acquisition of a classification of river basins according to their degree of water stress based on the results of water accounting.

2.6 WATER ACCOUNTING IN THE PO RIVER BASIN APPLIED TO CLIMATE CHANGE SCENARIOS

This publication, which can be found in Annex 6, aims to analyse the impact of climate change in the Po River Basin (North of Italy) using the SEEA-W within current water accounting approaches.

The methodology employed consists on a modelling chain with four consecutive stages: 1) a module for the climate which is composed by the following elements in cascade: RCP 4.5 scenario, global climate model, regional climate model and bias correction; 2) a rainfall-runoff model (TOPKAPI)(Liu and Todini, 2002) which uses the output variables of the climate module; 3) a water resources management model (RIBASIM) (Delft Hydraulics, 2006) for simulating the behaviour of the system during varying hydrologic conditions, and 4) the building of the required databases to organize the information and to obtain the asset accounts.

This work represents a first step in the development of water accounts, highlighting the necessity of new improvements in the chain model in order to consider all the information required by the approach such as the changes in the volumes of reservoirs and lakes, the evaporation and the supply to groundwater demands, among others.

3. RESULTS AND DISCUSSION

This section summarises the main findings of this thesis, which are included in the Annexes. These results derive from water resources systems analysis, which is understood as the analytical study of the water resources in a river basin in order to improve decision-making processes and identify the best alternatives from other possible ones. It includes all the necessary elements required to describe a river basin, including water resources, infrastructures, water demands and environmental requirements, among others.

As water resources systems become complex due to the high number of infrastructures and water requirements, the use of water resources models is required in order to identify the system's performance.

- Hydrological models enable us to obtain the river basin water resources in a natural regime, describing the water cycle. These models estimate variables such as precipitation, actual evapotranspiration, soil moisture among others. Some examples are SIMPA (Estrela and Quintas, 1996), EVALHID (Paredes-Arquiola et al., 2012) and PATRICAL (Pérez-Martín et al., 2014) models, which were used in this thesis.
- Water balance models enable us to obtain water allocations over a period of time, allowing the simulation of management possibilities for complex large-scale water resources systems. They include both the natural and the anthropogenic elements that constitute the water resources system and may require the results obtained with a hydrological model as an input. They include the main features of the system such as rivers and aquifers, reservoirs and canals, existing uses represented by the demand centres, the use of returns and other unconventional resources, and environmental constraints or operating rules. SIMGES model (Andreu et al., 1996) is an example of water allocation model, which was used in this thesis.
- Hydroeconomic models attempt to represent regional scale hydrologic, engineering, environmental and economic issues of water resources systems (Harou et al., 2009).

The approaches used in water resources systems analysis have changed in the past decade. It is required to add water accounting approaches to the traditional water balance methods. According to EC (2015) water balance is defined as "the numerical calculation accounting for the inputs to, outputs from and changes in the volume of water in the various components of the hydrological cycle, within a specified hydrological unit and during a specified time unit". EC (2015) also describes water accounting as an approach that "integrates physical and economic information related to water consumption and use, to achieve equitable and transparent water governance for all water users and a sustainable water balance between water availability, demand and supply".

3.1 TRADITIONAL WATER BALANCES

As mentioned before, water balances are essential tools in water planning as they explain the situation of the river basin in general terms. Whatever the type of water balance used, either at river basin scale or at water exploitation system scale, in both cases the main difficulty lies in estimating the available resources. Examples are the different methodologies used so far for their preparation and compiled in the documents: *Tres casos de planificación hidrológica* (MMA, 2000a), *Libro blanco del agua en España* (White Paper on Water in Spain) (MMA, 2000b) and *Estudio del impacto del cambio climático en los recursos hídricos* (MAGRAMA, 2012). In all of them, water balance models were based on optimization techniques.

This estimation depends directly on the baseline scenario considered and the index used to define the state of the water exploitation system (see figure 3.1). The elements that define the scenario are: (1) the topology of the scheme, (2) the quantification of the water resources, (3) the criteria used for determining the availability of water resources and (4) the reliability criterion used to define the state of the system.

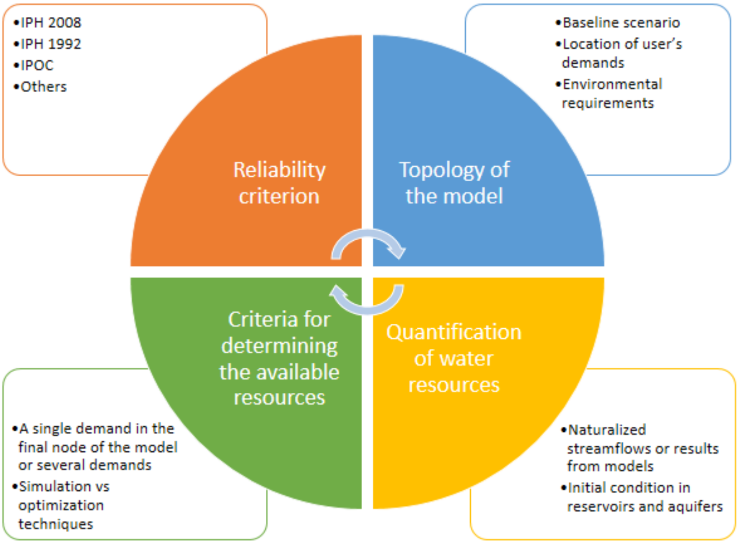


Fig. 3.1: Scheme of the approaches to define water balances

With regard to the topology of the scheme, the baseline scenario may represent the current complexity of the system with different levels of detail, a simplified version with demand elements in each of the nodes, or demands elements located in specific areas. At this stage, environmental requirements may be also considered.

Regarding the quantification of water resources, the most common approaches use time series of naturalized streamflows or streamflows time series obtained from models. The latter can be rainfall-runoff models, models focused on climate change estimations or statistical ones. Another important factor to consider is the definition of the initial condition in reservoirs and aquifers, which will largely influence the resource estimations.

The available resources are assimilated as the maximum demand that can be served to satisfy the system's requirements. In this sense, the scheme can include a single demand at the end of the water exploitation system or several demands spread in the scheme. The results also vary depending on the system management, in other words, if the operating rules and concessional aspects are taken into account (by using a simulation model), or if an optimized system is used (by using optimization models).

Finally, regarding the reliability criterion, this has changed according to the different Spanish Guidelines of Water Planning. The current criterion (MAGRAMA, 2008) establishes that for objects of water resource allocation and reservation, urban requirements are satisfied if the deficit in one month is not superior to 10% of the corresponding monthly demand and if in 10 consecutive years, the sum of deficits is less than 8% of the annual demand. Equivalently, agrarian requirements are satisfied when the deficit in one year is not superior to 50% of the corresponding demand; for two consecutive years, the sum of deficit is not superior to 75% of the annual demand; and in ten consecutive years, the sum of deficit is not superior to 100% of the annual demand.

In the case of the three aforementioned examples of water balances, each of them is characterized by:

- *Tres casos de planificación hidrológica* (MMA, 2000a). This approach uses time series of naturalized streamflows and uses as a reliability criterion based on the annual deficit in 1, 2 and 10 consecutive years. Regarding urban requirements, the deficits are limited to 10, 16 and 30% respectively. In the case of agrarian supplies the limit of these deficits are 50, 75 and 100%. It uses an optimization model, which increases demands on specific points of the scheme.
- *Libro blanco del agua en España* (MMA, 2000b). It employs both naturalized streamflows time series and time series from SIMPA model (Estrela and Quintas, 1996). As a reliability criterion it requires a reliability of 100% for urban supplies and the maximum annual deficit in 1, 2 and 10 consecutive years limited to 50, 75 and 100%. Moreover, it uses a simplified optimization model of the river basin, which includes a demand element in each node of the scheme to be increased from upstream to downstream.
- *Estudio del impacto del cambio climático en los recursos hídricos* (MAGRAMA, 2012). It uses streamflows times series obtained by rainfall-runoff models and estimations of climate change streamflows. It employs a simplified optimization model of the basin in which a single demand located at the end of the system is increased. And it uses the same reliability criterion considered in the document *Libro blanco del agua en España* (MMA, 2000b).

3.2 WATER ACCOUNTING

In accordance with the scope of water resources protection established by the WFD and due to the difficulty of achieving the “good status” of all water bodies required by 2015, the Blueprint to safeguard Europe's water resources (EC, 2012) aims to solve the obstacles that hinder the protection of European water resources. The Blueprint is based on extensive public consultations in which citizens, stakeholders, Member States and other institutions have participated. Among its objectives are (i) improving the application of current EU water policy, (ii) further integration of water policy objectives with other policies and (iii) improving important aspects of the WFD related to water efficiency. Regarding this latter, water accounts are proposed as the tool to achieve the target of water efficiency. Water accounting is a methodology that presents information on water resources linking environmental and economic issues of water supply and use (Vardon et al., 2007). As noted by Godfrey and Chalmers (2012), it covers a wide range of formats for reporting water information, being the System of Environmental-Economic Accounting for Water (SEEA-W) (UNDS, 2012) the most commonly used.

SEEA-W framework includes the inland water resource system, which is comprised by surface water, groundwater and soil water. In relation to the economy, it is represented by abstractions, imports, exports and returns of the most relevant economic agents. SEEA-W tables are presented in flow accounts or asset accounts. Flow accounts represent the water flows in physical units within the economy and between environment and the economy, and asset accounts measure stocks at the beginning and the end of an accounting period. The classification of industrial economic activities used in SEEA-W is the International Standard Industrial Classification of All Economic Activities (ISIC) (UN, 2008). The major disadvantage in the application of SEEA-W approach is the obtainment of the economic information required, as this information is traditionally presented at administrative scale and in natural years, not in hydrological years. On the other hand, it requires such amount of information that makes difficult its application.

The proposed methodology is described in figure 3.2 as a modelling chain composed of three stages: (1) a rainfall-runoff model, (2) a water balance model and (3) an economic balance. A detailed description of the methodology can be found in Annex 5. So, in this way, the conjunctive use of the rainfall-runoff model and the water balance model enables us to obtain the asset accounts and, the results of the water balance model are used to calculate the physical supply and use table. Moreover, the estimation of the water service costs, being understood as all services which provide abstraction, storage, treatment and distribution of water and the wastewater collection and treatment facilities (WATECO, 2002) is done through an economic balance.

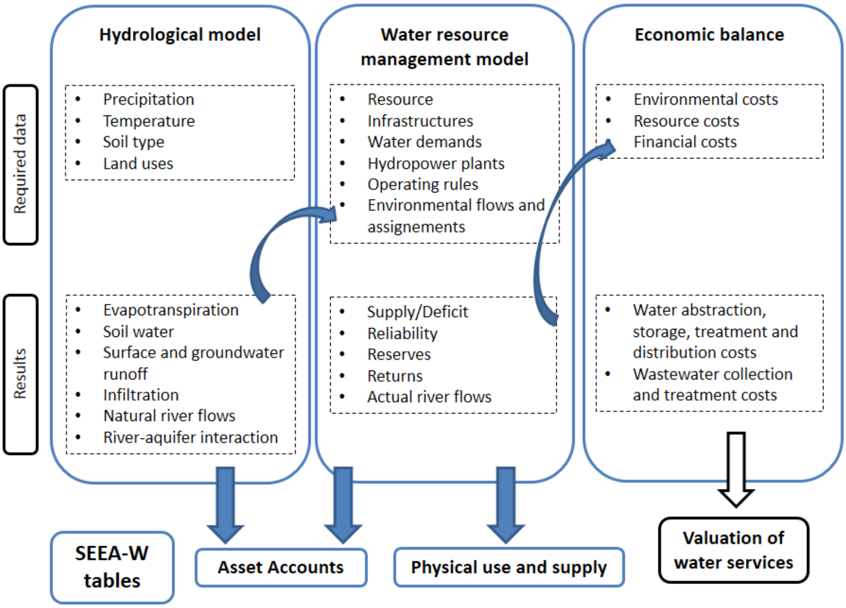


Fig. 3.2: Scheme of the approach to obtain SEEA-W tables by using different types of models related to water resources management (Modified from Annex 5)

The following sub-sections describe the application of water resources management models to obtain the exploitable water resources, asset accounts, the physical supply and use tables, the water services costs and the acquisition of indexes derived from water accounting.

3.3 EXPLOITATION INDEXES BASED ON BOTH APPROACHES

3.3.1 EXPLOITABLE WATER RESOURCES

The indicator of exploitable water resources (EWR) describes water availability in a river basin. As noted by UNDS (2012), EWR is defined as “the part of the water resources considered to be available for development under specific technical, economic and environmental conditions”. This indicator is not derived from water accounts and its calculation is proposed in Annex 2 as “the maximum demand that can be served by the system satisfying the officially established reliabilities and the environmental requirements”.

The acquisition of the EWR in Jucar river basin was conducted with a specific simulation model of the water exploitation system developed with SIMGES module. Jucar RBA used this model during the drafting of the Jucar RBMP (BOE, 2016) in order to assess water resources allocation and reservation. The figure below shows the details and complexity of the water exploitation system itself.

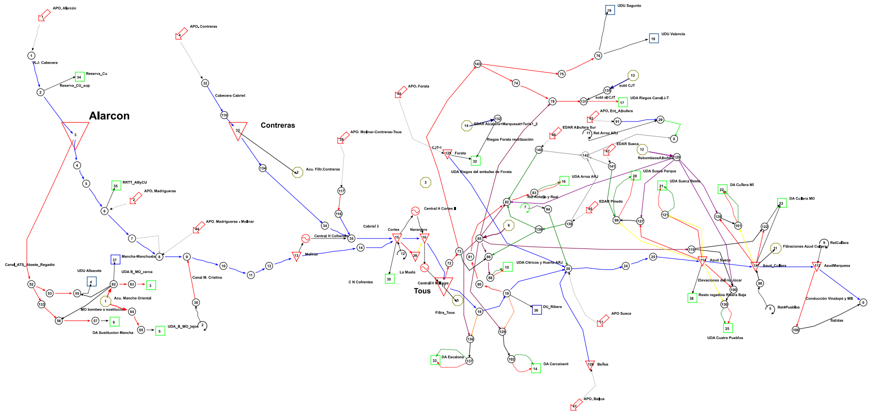


Fig. 3.3: Scheme of the Jucar Water Exploitation System with SIMGES (Source: Jucar RBA)

The estimation of the EWR is influenced by three aspects:

- The origin of the streamflows time series. Two sources of data were considered: on the one hand the EWR were obtained by using naturalized streamflows and, on the other hand, the streamflows time series came from a stochastic generation model.

- The reliability criterion to consider satisfied the supply to all water users. Two criteria were taken into account: the IPH reliability criterion (MAGRAMA, 2008) and the efficiency indicators defined by (Martin-Carrasco and Garrote, 2007).
- The length of the simulation period. During the latter 30 years, Jucar River Basin has registered an important reduction in its natural streamflows (Pérez-Martín et al., 2013) with the consequent reduction in water availability. For this reason, two possible results were obtained depending on if the simulation period was 1980-2009 or it was 1940-2009.

The reference scenario corresponds to the time horizon 2009, which includes environmental requirements, considered in the previous Jucar RBMP (BOE, 2014). This model takes into account the main infrastructures and demands of the Jucar water exploitation system, which differ from the total requirements of Jucar River Basin detailed in table 1.2. The total supplies in the reference scenario amount to 1103 hm^3/year. In order to assess how much the supply could increase, five groups of new water users were incorporated to the original model showed in figure 3.3. The location of these water users was made taking into consideration the strategic points in the river basin as it is detailed in Annex 2. An iterative process, executes the simulation model analysing the possibility of increasing these new demands. The final result is achieved when the maximum demand is obtained while fulfilling the required reliability criteria.

The table below shows the additional volume that the system is capable to supply by satisfying the established reliability criteria. In the case of the synthetic series, the figures in table 3.1 are the average values obtained after simulating 100 files of streamflow time series for the period 1980-2009 and 100 files for the period 1940-2009. Given these results, we can make some appreciations:

- When using the IPH reliability criterion (MAGRAMA, 2008), the maximum availability of water resources is registered in the lower stretch of Jucar River in Huerto Mulet gauging station. However, when using the efficiency indicators (Martín-Carrasco and Garrote, 2007) as the reliability criterion, the maximum availability of water resources is registered in the Cabriel River headwater (see figure 8 from Annex 2).

- The results obtained using synthetic time series show that the series generated by stochastic processes (autoregressive moving average (ARMA) model) do not maintain all the statistical resemblance with historical time series in natural regime that would be desirable. In this regard, and particularly for the period 1940-2009, it should be taken into account that the ARMA model is not able to generate a drought as long as the droughts registered. In practice, this prevents the appropriate conservation of drought properties that are measured according to the criteria based on the worst supplies.

		Historical data		**Synthetic series**	
		1940/41-2008/09	**1980/81-2008/09**	**1940/41-2008/09**	**1980/81-2008/09**
Criterion	IPH 2008	57,42	19,34	216,52	25,38
	Efficiency indicators	451,20	93,73	623,01	184,64

Table 3.1: Additional EWR (hm^3/year) obtained for the considered scenarios

As showed in figure 8 from Annex 2, eight radial graphs represent each of the eight scenarios considered. Each of these charts has 10 axes representing the demand elements included in the simulation model and in which the additional EWR obtained is shown. The results obtained with the simulation of the historical streamflow time series and the IPH criterion (MAGRAMA, 2008) show that the system is capable of delivering the same volume of water resources in the middle and upper basin area and, this resource increases in the lower section. Using the efficiency criterion (Martín-Carrasco and Garrote, 2007) it is found that the maximum additional water resource availability is given for a seasonal demand located at the headwaters of the Cabriel River (AD Contreras). With respect to the synthetic streamflow time series, the charts show the average value and a band representing the confidence interval of the standard deviation. In many cases the value achieved by the latter is even higher than the average value, in which case the term average minus standard deviation is not represented.

The following Box-Whisker plots present the results obtained in the simulations with synthetic streamflow time series. In the case of the 1980-2009 period, the median value of the additional exploitable water resources is zero for both reliability criteria. Moreover, in the case of efficiency criteria for many of the locations the third quartile is also zero, showing a strong asymmetry (see figure 3.4 and figure 3.5). The results observed for the 1940-2009 period are quite different. Figure 3.6 and figure 3.7 show that the maximum additional EWR is located in the lower stretch when considering IPH criterion (MAGRAMA, 2008) or it is located in the headwater when considering the efficiency indicators (Martín-Carrasco and Garrote, 2007).

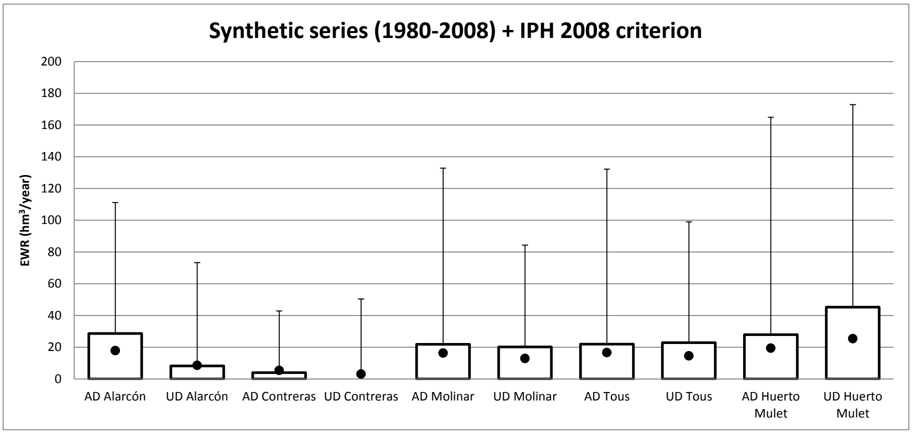


Fig. 3.4: Box-Whisker plot for the assessment of the EWR (hm³/year) by using synthetic time series, IPH criterion and 1980/81-2008/09 simulation period

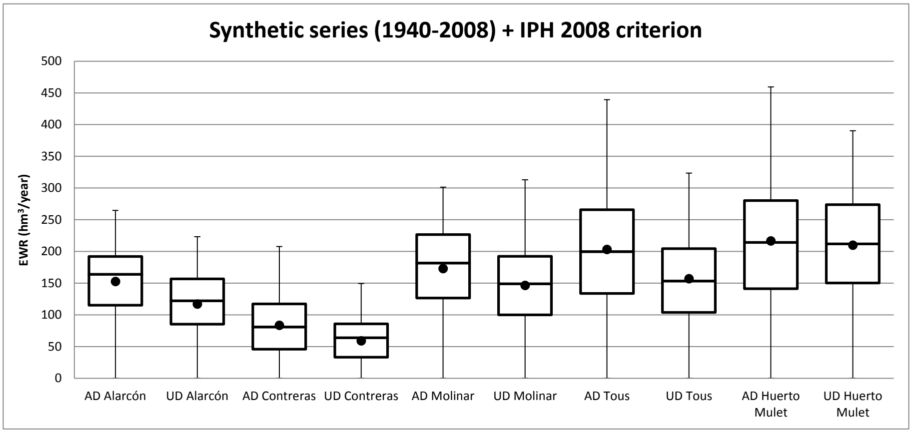


Fig. 3.5: Box-Whisker plot for the assessment of the EWR (hm³/year) by using synthetic time series, IPH criterion and 1940/41-2008/09 simulation period

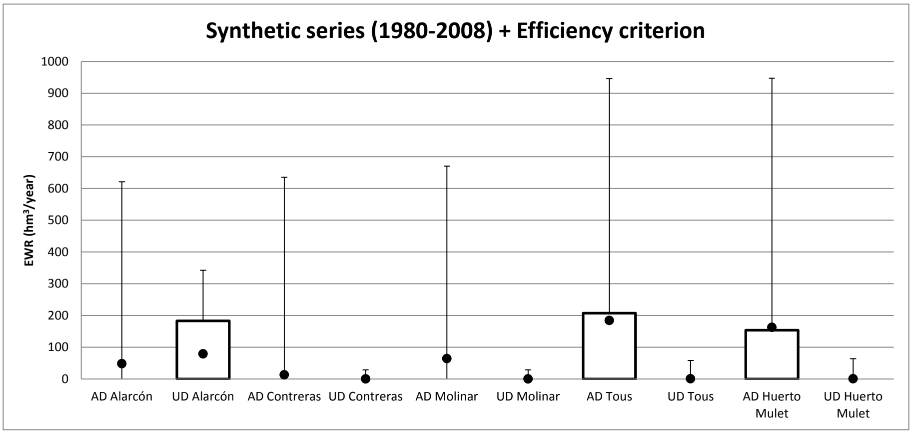


Fig. 3.6: Box-Whisker plot for the assessment of the EWR (hm³/year) by using synthetic time series, efficiency criterion and 1980/81-2008/09 simulation period

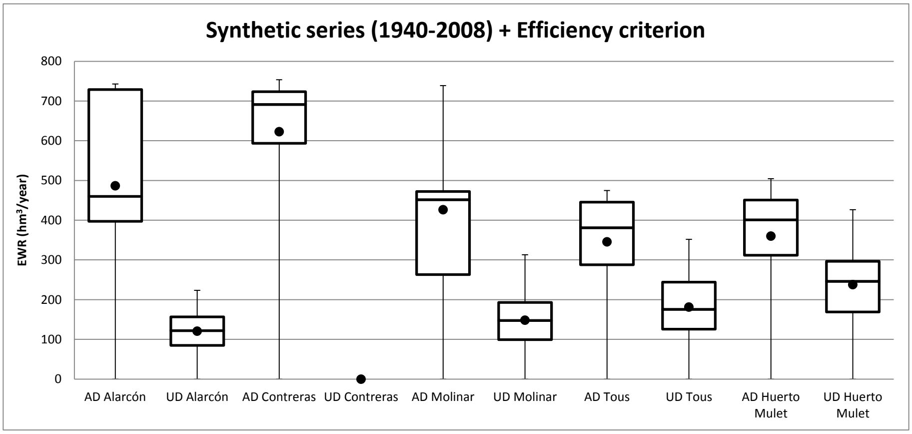


Fig. 3.7: Box-Whisker plot for the assessment of the EWR (hm³/year) by using synthetic time series, efficiency criterion and 1940/41-2008/09 simulation period

The results obtained are very different, in view of the graphs and tables presented. In many cases, the availability of water resources is determined by the hydrology, the infrastructure and the location of the existing demands. In this sense, it would be risky to provide a single value representing the EWR in Jucar water exploitation system, since, as it has been shown, it depends primarily on its calculation methodology. In addition, any changes in the regulation of reservoirs, the incorporation of new measures for reuse or sharing resources with other systems, would require a new resource assessment and the acquisition of different values of the water resource availability.

3.3.2 ASSET ACCOUNTS, PHYSICAL AND USE TABLES AND WATER SERVICES COSTS

In order to obtain SEEA-W tables, a water balance model of the case study was developed using SIMGES module from AQUATOOL DSS. This model includes all the necessary information linked with water resources, water requirements and infrastructures. It incorporates 28 artificial reservoirs and 18 lakes, 20 hydropower stations, 210 water users and 116 groundwater bodies. An in-depth description of the water balance model is included in Annex 5. Figure 3.8 shows the scheme of the SIMGES simulation model of the Jucar RBD, in which the detail and complexity of the system are identified.

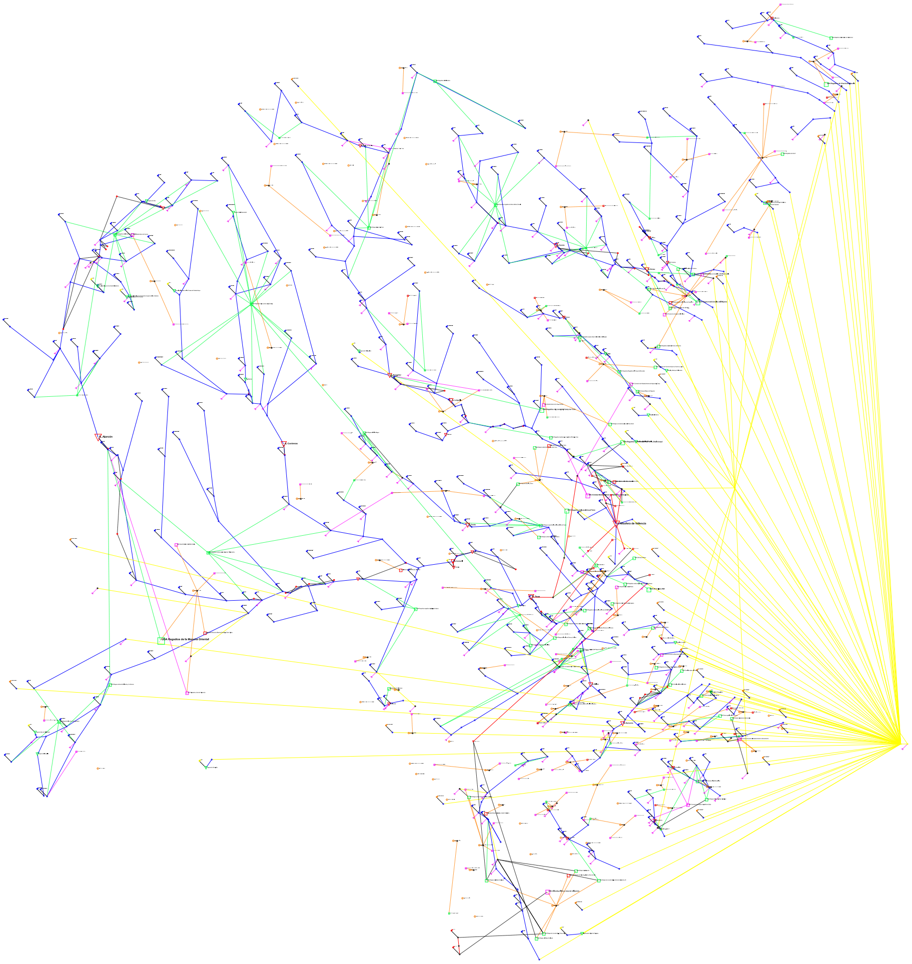
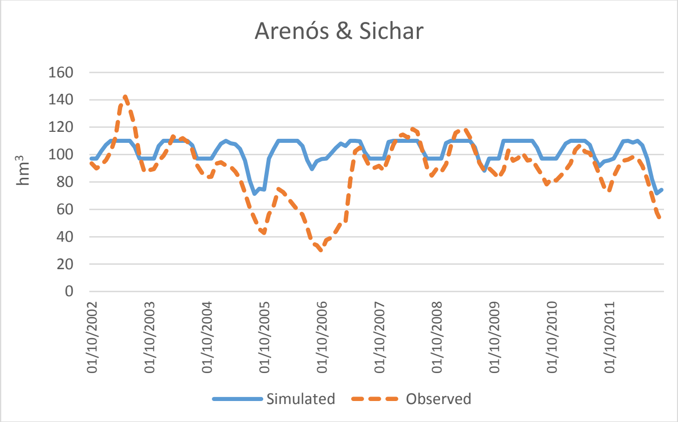
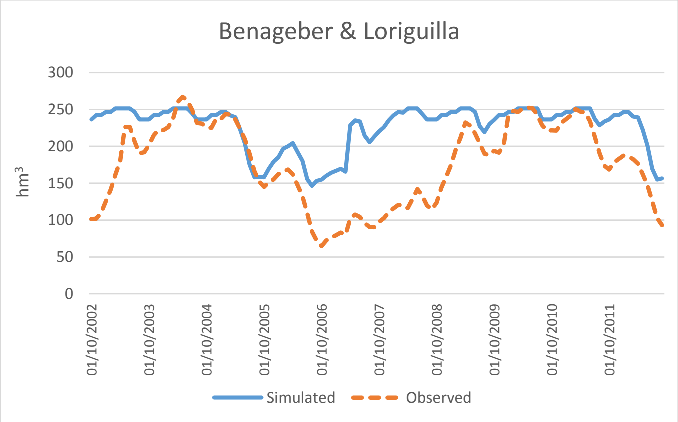


Fig. 3.8: Scheme of the water balance model of the Jucar RBD

The historical records of stored volumes in the main reservoirs of the district have been compared with the results of the water balance model for the latter ten years using 1980/81-2011/12 as the simulation period. As it is shown in the figures below, the management proposed is similar to that of recent years. It must be stressed that the initial volumes simulated in the main reservoirs of Jucar and Turia water exploitation systems differ from the historical ones. This is because the lack of resemblance between past and current water user's requirements.





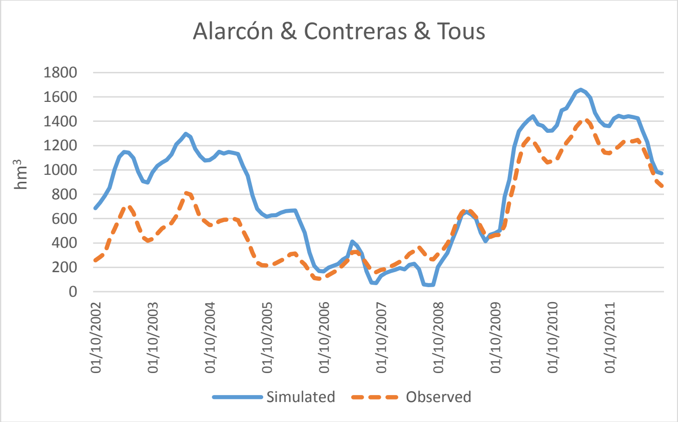


Fig. 3.9: Results from the calibration of the water balance model in the main reservoirs of the district

The table below presents the reliability criterion expressed in deficit terms, as required by IPH (MAGRAMA, 2008), for the main water users in the district. As it can be observed, the main water users have their supplies guaranteed.

		Maximum deficit (%)			
Name	**Annual demand (hm^3)**	**Monthly**	**Annual**	**2 consecutive years**	**10 consecutive years**
Mijares traditional irrigation	64	-	24	36	75
Mijares mixed irrigation	95	-	1	2	4
Turia traditional irrigation	251	-	11	15	19
Turia mixed irrigation	74	-	0	0	0
Jucar traditional irrigation	599	-	9	9	9
Jucar mixed irrigation	436	-	0	0	0
Rest of the district	1036	-	-	-	-
TOTAL Agrarian Demand	2555	-	-	-	-
Albacete	14	0	-	-	0
Sagunto	11	0	-	-	0
Valencia	147	0	-	-	8

Table 3.2: Reliability criterion (MAGRAMA, 2008) for user requirements in Jucar RBD

Asset accounts and physical and use tables

As it is described in Annex 4 and Annex 5, water asset accounts measures the reserves on surface water, groundwater and soil water in the river basin at the beginning and at the end of the accounting period and register the changes in volumes that occur during that period of time due to natural processes and human activities. Similarly, matrix of flows presents the exchanges of water between water resources, making available all the information on the origin and destination of flows in the territory. This latter assists in identifying the contribution of groundwater to the surface flows as well as the recharge of aquifers by surface runoff. In both tables, the source information of each cell may come from rainfall-runoff models and/or water balance models, as it has been described in Annex 4. Moreover, there are some values in both tables which are difficult to quantify because two possible reasons. The first reason is the fact that aggregated models do not differentiate between precipitation into artificial reservoirs, lakes or rivers (Vicente et al., 2016). The other reason is because there are flows between water resources in the environment that are unlikely or physically impossible to monitor; this is the case of precipitation into groundwater and outflows to the sea from soil water or from artificial reservoirs.

On the other hand, the physical use table is split into two sections: the first section refers to flows from the environment to the economy (like abstractions) and the second section refers to flows within the economy (like water received from other economic units). Additionally, the physical supply table is also branched into two other sections: the first one describes the flows of water within the economy (like the supply of water to other economic units) and the second one describes flows from the economy to the environment (like returns of water into the environment). In this case, in contrast to asset accounts, each cell in physical use and supply tables derives from the water balance model.

Despite the fact that SEEA-W approach is the most widely used water accounting system, some aspects should be better defined. One of them is the temporal and spatial aggregation. Results presented in Annex 5 are referred to an average year, considering the results obtained from October 1980 to September 2012. On the other hand, Annex 4 considers the asset accounts and physical and use tables obtained during the months of May 1995 and January 1996. In accordance of the objectives pursued, both options are appropriately addressed. As noted by Vicente et al. (2016), the minimum required period should be an entire hydrological year or using inter-annual average values in those areas with significant inter-annual variability. Regarding the spatial aggregation, in the case of Jucar RBD, its high spatial variability can justify the disaggregation of asset accounts and physical and use tables, which have been obtained for the entire district into individual water exploitation system tables.

Compared to the traditional water balances described in Annex 2, which have been used for water allocation and reservation in Spain, both asset accounts and physical and use tables present a higher degree of detail and complexity. That means that there are several elements that distort the final objective, which is to manage the available water resources in a just manner between all water users. In this sense, the question is if it is really required to know the volume of water stored as soil water in order to assign a new concession or to decide the annual investments in regenerated water or desalination. Even more when then main variables involved, which are precipitation and temperature, cannot be planned by managers. However, it is pertinent to take them into account to close the balance of the hydrological cycle.

Another very important matter is the organisation of industrial economic activities used in SEEA-W, which is the International Standard Industrial Classification of All Economic Activities (ISIC) (UN, 2008). In connection with this issue, the way in which results have been presented in Annex 5 differ from the ones displayed in Annex 4. In this latter the economic uses were presented according to the river basin main economic sectors, which are urban, farming, cattle raising and recreational. By contrast, in Annex 5 physical supply and use table are organised according to the ISIC. This change was due to the fact that it is necessary to have a standard classification for international comparisons between river basins. The question is if this classification is effectively useful for water resource planning and management or if this system was chosen for economic reasons. As an example, the economic importance of hydropower generation (ISIC division 35) is indisputable. But it might be more appropriate not to include non-consumptive uses in this balance. Similarly, in the case of rainfed agriculture, this latter can be decisive in economic terms in a region, contributing meaningfully to the GDP of the country (Borrego-Marín et al., 2015) but, as noted in the paragraph before, precipitation and temperature cannot be planned by water managers.

From the point of view of water planning, in order to do water accounting suitable for water resources allocation and reservation, it should take into account the environmental requirements (EC, 2015) and the possibility that deficits occur in the supplies. In the case of Spain, the IPH criterion (MAGRAMA, 2008) establishes when user’s requirements are satisfied depending on monthly and annual deficits.

Water services costs

Other results proposed by the SEEA-W approach are the hybrid and economic accounts which pretend to describe in monetary terms the supply and use of water related products. As noted by (UNDS, 2012), these tables try to identify:

a) Costs associated with their production;
b) Income generated by their production;

c) Investment in water related infrastructure and the maintenance costs; and
d) Fees paid by the users for water related services, as well as the subsidies received.

The greatest challenge posed by hybrid accounts is that the required information is often not available; being the reason why a straightforward approach based on average costs for all water services is proposed in this thesis. This proposal aims to make use of the results achieved during the assessment of cost recovery of water services, as required by WFD (EP, 2000). The components of the full water services cost are composed by environmental, resource and financial costs (WATECO, 2002) (see figure 3.10).

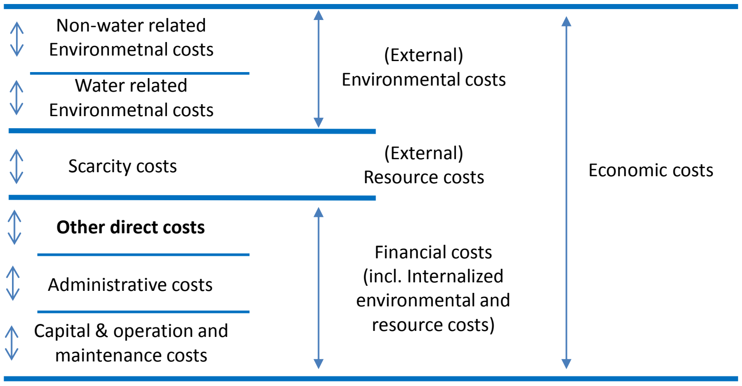


Fig. 3.10: Different types of costs considered in WFD (Source: Rogers et al. (1997))

As reported by figure 3.10, environmental costs are defined as the price to be paid for deteriorating the water bodies status. On the other hand, considering the resource costs remains a major challenge, being out of our reach. Lastly, the assessment of the financial cost rests on data from public administrations budgets for each water service. This methodology is discussed in detail in Annex 5.

For the Jucar RBD, the average cost of water services comes from Annex 9 of the Jucar RBMP (BOE, 2016) as can be seen in table 3.3. These costs rely on the origin of water resources (surface water, groundwater, reused water, desalinated water or water transfers) and on the costs of adapting water resources to their uses (agrarian, urban or industrial use). The prices for water transfers are published in (BOE, 2012) and (MCT, 2016).

Servicios del agua	Uso del agua	Volumen de agua servida (hm^3)	Coste financiero total (M€/año)	Coste ambiental CAE * (M€/año)	Costes Totales (M€/año)	Ingresos por tarifas y cánones del agua (M€/año)	Índice de Recuperación de costes totales (%)	Índice de Recuperación de costes financieros (%)	Coste financiero en €/m3	Ingresos en €/m3
Servicios de agua superficial en alta	Urbano	240.10	2.7	1	3.7	1.2	32%	45%	0.01	0
	Agricultura/ganadería	1457.90	11.6	4.4	16.1	5.2	32%	45%	0.01	0
	Industria/energía	0.00	0	0	0	0	sd	sd	sd	sd
Servicios de agua subterránea en alta	Urbano	242.90	60.3	0	60.3	60.3	100%	100%	0.25	0.25
	Agricultura/ganadería	0.00	0	0	0	0	sd	sd	sd	sd
	Industria/energía	0.00	0	0	0	0	sd	sd	sd	sd
Distribución de agua para riego en baja	Agricultura	1462.30	190.6	1.9	192.5	123.1	64%	65%	0.13	0.08
Abastecimiento Urbano	Hogares	181.90	247.7	0	247.7	228.7	92%	92%	1.36	1.26
	Agricultura/ganadería	0.00	0	0	0	0	sd	sd	sd	sd
	Industria/energía	49.80	72.4	0	72.4	66.9	92%	92%	1.46	1.34
Autoservicios	Doméstico	0.00	0	0	0	0	sd	sd	sd	sd
	Agricultura/ganadería	1095.60	270.5	50	320.5	270.5	84%	100%	0.25	0.25
	Industria/energía	136.80	17.9	6.2	24.2	17.9	74%	100%	0.13	0.13
Reutilización	Urbano (riego de jardines)	0.00	0	0	0	0	sd	sd	sd	sd
	Agricultura/ganadería	77.30	17.5	0	17.5	0	0%	0%	0.23	0
	Industria (golf)/energía	0.50	0.1	0	0.1	0	0%	0%	0.23	0
Desalación(2)	Abastecimiento urbano	2.60	18.9	0	18.9	0	0%	0%	7.23	0
	Agricultura/ganadería	0.00	0	0	0	0	sd	sd	sd	sd
	Industria/energía	0.90	6.7	0	6.7	0	0%	0%	7.28	0
Recogida y depuración fuera de redes públicas	Hogares	0.00	sd		sd	0	sd	sd	sd	sd
	Agricultura/ganadería/acuicultura	0.00	sd		sd	0	sd	sd	sd	sd
	Industria/energía	0.00	sd		sd	0	sd	sd	sd	sd
Recogida y depuración en redes públicas	Abastecimiento urbano	361.00	199.7	22.5	222.1	166.5	75%	83%	0.55	0.46
	Industria/energía	105.60	58.4	6.6	65	48.7	75%	83%	0.55	0.46
TOTALES		**3254.6**	**1174.9**	**92.6**	**1267.6**	**989**	**78%**	**84%**	**0.36**	**0.3**

Table 3.3: Summary of cost recovery analysis for water uses and services in Jucar RBD for the period 2004-2013 (constant 2012 prices) (Source: BOE (2016))

For the urban use the average cost of water is estimated in 1.38 €/m^3, 1.61 €/m^3, 2.02 €/m^3 and 7.27 €/m^3 depending whether the origin of water resources is surface water, groundwater, water transferred from other territories or desalinated water, respectively. In the case of industrial water the average costs are 0.18 €/m^3, 1.45 €/m^3 and 7.44 €/m^3 by employing groundwater, surface water, or desalinated water, respectively. The average cost of collection and treatment of used water is 0.61 €/m^3 for both urban and industrial uses. On the other hand, agrarian supplies are estimated in 0.14 €/m^3 for surface water, 0.23€/m^3 for reused water, 0.24 €/m^3 for water transferred from other territories and 0.29€/m^3 for groundwater supplies.

Based on these amounts and on the results obtained with the water balance model, the total average water services costs in Jucar RBD amounts to 1634 million € per year at constant 2012 prices, using 1980/81-2011/12 as the reference period for the determination of these figures. This value is fairly higher than the 1.268 € per year at constant 2012 prices observed in table 3.3. On the one hand, differences are due to the incidences of hydrological variables. The groundwater component obtained from simulation models is slightly higher than the observed during the period 2004-2013 and, the same goes for the volumes of reused water. On the other hand, water service costs obtained from simulation also includes the costs derived from transfers from other territories which are not included in table 3.3.

From users' point of view, knowing the water services costs can be relevant since in them is reflected the expenses born by governments. On the other hand, assessing the benefits of water services is still pending.

3.3.3 THE INDICATOR OF ECOLOGICAL STRESS FOR RIVERS

The indicator of ecological stress for rivers (ESIr) is obtained at monthly level as described in Eq. 1. This index is usually presented in a cumulative distribution function during the analysed period. EEA (2013) indicates that values of ESIr between 0-15% represent a destructive ecological stress for rivers; between 15-25% symbolize an unsustainable ecological stress; between 25-50% represent an excessive ecological stress; between 50-65% represent a risky ecological stress; between 65-90% denote a warning ecological stress and finally, ESIr values between 90-100% show the inexistence of problems in the river.

$$ESI_r = \frac{outflow}{outflow + abstractions - returns} \quad (1)$$

An example of the application of ESIr can be found at Annex 4. In this pilot case the Mediterranean River Basin District Management Plan (BOE, 2012b) considers the implementation of several environmental flows based on habitat modelling assessment and on hydrological criteria. One of them is defined in the Low Vélez Guaro River downstream the confluence of left margin tributaries. Furthermore, the application of recommended flows for the saturation of the alluvial aquifer in the left margin tributaries is also conducted. These flows are destined to recharge the aquifer and they will be used to supply the water requirements near the coast. The latter are more restrictive that the environmental ones particularly during the driest months. As a result, the likelihood of having a non-sustainable ecological stress is around 25%, in this way, the likelihood of inexistence problems in the river is 3%, displaying the high stress suffered by the system.

3.3.4 THE WATER EXPLOITATION INDEX

The Water Exploitation Index (WEI) (EEA, 2005) was defined by the European Environmental Agency (EEA) with the goal of assessing the degree of stress suffered in a river basin. This index is obtained as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources. As noted by CIRCABC (2012), values of WEI in a river basin between 0% and 20% show a situation of no stress; values between 21% and 40% indicate water stress; and values upper than 40% represent extreme water stressed river basins. Some examples of the acquisition of WEI can be found at Annex 4 and Annex 5. In the pilot case, the WEI was obtained for the period 1980/81-2006/07, and it amounted to 74%, showing a high degree of water stress in the river basin. In the Jucar RBD the values of WEI vary between 242% and 74% depending on whether or not the hydropower abstractions are considered for its calculation. In this regard, EUROSTAT (2016) confirms that the water used for hydropower generation is excluded from water abstractions for the obtainment of WEI.

The limitations of this index are remarked in EUROSTAT (2016) and detailed in Annex 1. They include:

a) Freshwater abstraction does not take into account the amount of water that returns to the environment after being abstracted, and

b) Seasonal changing conditions are disregarded when calculating the index.

3.3.5 THE WATER CONSUMPTION INDEX

Equivalently to the WEI, the (UNDS, 2012) defined the Water Consumption Index (WCI) as the ratio between water consumption and total renewable water resources. This indicator considers the returns into the environment for other uses downstream, so that WEI highlights the water abstractions and WCI is targeted towards the water consumptions. In the pilot case, the WCI amounts to 40%. Similarly, in the Jucar RBD the value of WCI amounts to 56%, softening in both cases the degree of stress in the basin.

There is another index called Water Exploitation Index Plus (WEI+) (CIRCABC, 2012) which was not applied to the case study and shares similarities with the WCI. The main feature of this index is that WEI+ is applied at monthly level. In all cases, the strengths and weaknesses of these indexes are described in Annex 1.

3.4 USES OF WATER EXPLOITATION INDEXES

Given the broad range of indexes and tools currently available in order to analyse water resources system, a first step can be its classification in order to identify the main features and to apply the most adequate approach. Taking as the starting point the results obtained in previous sub-sections, this classification aims to explain their main features, deficiencies, limitations and recommendations.

Using the results obtained in *Libro blanco del agua en España* (MMA, 2000b) for all Spanish RBD which is described in section 3.1, the following figure aims to represent, for each RBD in Spain, the relationship between the total volume of supplied demands and the origin of the water resources. This chart represents an example of the variety of river basins in Spain, and it aims to explain their main features using the similarities with the WEI which is described before. The x-axis contains the ratio between total demand and natural streamflows and the y-axis indicates the possible sources of water resource. Thus, the Jucar RBD, is represented on the right of the graphic, as its total demands represent approximately 70% its natural streamflows. The proportion of regulated water resources is about 50% of the natural streamflows. Similarly, about 85% of the resources come from regulation and pumping wells (conventional resources). The rest of the resources is associated with reuse, desalination and transfers from other river basins (non-conventional or generated resources).

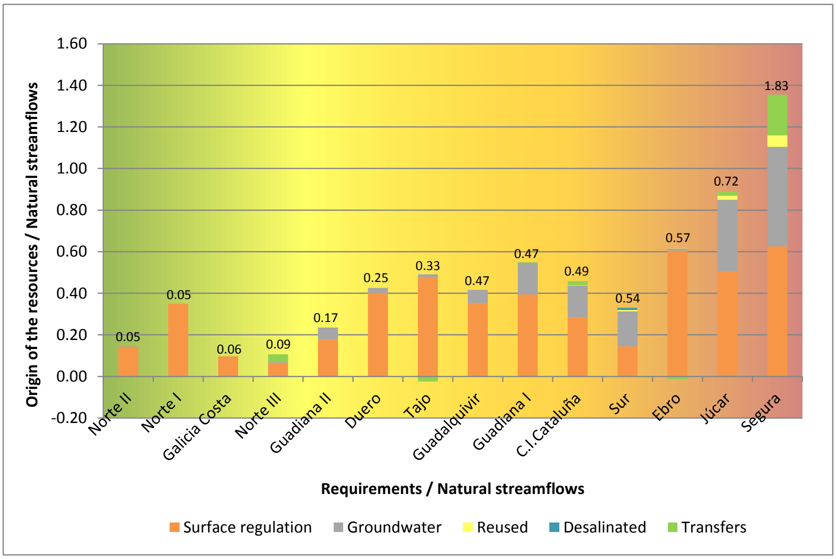


Fig. 3.11: Total demand versus generated resources for the different river basin districts in Spain. (Results derived from MMA (2000b))

In the light of the previous chart, water resources systems can be classified according to their position on the horizontal axis. Thus, systems positioned on the left of the chart are characterized by a low degree of utilization of their resources; this may be the case of systems located in humid regions. As the ratio between demands and streamflows moves to the right, systems also rise on the vertical axis, indicating that the resource is scarce and using non-conventional resources is required, with associated costs. River basin districts considered in MMA (2000) can be grouped into four areas:

- Green area. Supplies are based on water resources regulated in reservoirs. This group includes the ancient “Confederación Hidrográfica del Norte” and “Galicia Costa”. As it is observed, surface regulation is slightly higher than consumptive requirements, indicating the relevance of hydropower in these districts.
- Yellow zone. Demands are supplied with conventional resources, understood as water resources regulated in reservoirs and pumping of

groundwater. “Cuencas Internas de Cataluña” and Douro, Targus, Guadiana and Guadalquivir RBD are included in this group. Hydropower represents a crucial non-consumptive use in these RDB.

- Orange area. Other sources of resources are needed, such as reused water or desalination. This group includes “Cuencas del Sur” and Jucar and Ebro RBD.
- Red zone. This zone distinguishes systems with demands even higher than the natural resource available. This group includes Segura RBD.

Currently these observations are obsolete since this aggregation has been made from the data extracted from MMA (2000). By updating these data, the results will be different, since there has been a reduction in streamflows during the last 30 years (Pérez-Martín et al., 2013), along with the increasing use of reused water and desalination.

Continuing the last idea, an equivalent classification of the water exploitation systems in Jucar RBD is proposed based on the results of water accounting. This organisation aims to identify the main features and the degree of exploitation for each of the nine water exploitation systems, linking the total volume of water abstractions and the origin of the water resources. The x-axis contains the WEI which is obtained as the mean annual total abstractions divided by the Total Natural Renewable Water Resources (TNRWR). This latter corresponds to the maximum theoretical amount of water available on an average year in a long reference period. In other words, TNRWR represents the average annual river flows and groundwater recharge generated from endogenous precipitation, as it is not considered the existence of any river runoff and groundwater transfers between river basins. On the other hand, the y-axis indicates the origin of the water resource used for satisfying the water requirements in relative terms:

1) Total abstractions of freshwater. It takes into consideration the abstractions from surface water divided by TNRWR and, on the other hand, it considers the volume of abstractions from groundwater divided by TNRWR:
    a. Abstractions from surface water divided by TNRWR
    b. Abstraction from groundwater divided by TNRWR
2) Other economic units. It takes into account the volume of water generated by direct use of wastewater treatment, desalination and water transfers from other river basin districts:

a. Reused water divided by TNRWR
b. Desalination divided by TNRWR
c. Transfers from other river basin districts divided by TNRWR

The figure below represents the WEI obtained by water exploitation system. As it is shown, the highest intense exploitation is made in Vinalopó-Alacantí, with a WEI near to 200%, and the least exploitation is done in Cenia-Maestrazgo and Mijares-Plana de Castellón, with a WEI near to 60%. This contrasts with the WEI obtained for the whole Jucar RBD, which amounts to 74%, masking the reality in the river basin districts that conform the district.

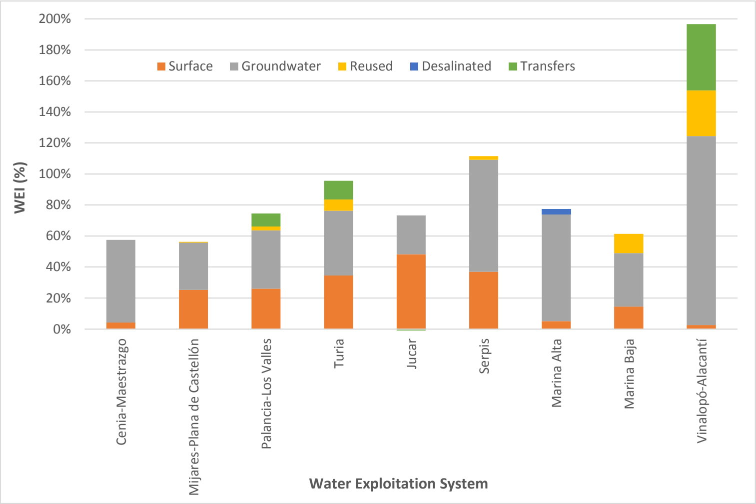


Fig. 3.12: Contribution of the origin of resources to the WEI by Water Exploitation System in Jucar RBD

Moreover, the figure shows the contribution of the origin of water used to satisfy the water requirements, expressed in terms of surface, groundwater, reused water, desalination and external transfers. In all cases, the contribution of groundwater resources is remarkable. In the case of Vinalopó-Alacantí system, the surface contribution is negligible; by contrast, the groundwater component is the most important, followed by reused water and transfers from other territories.

Another way to present these results is to organise the water exploitation systems according to their WEI, as observed in figure 3.13. As noted before, values of WEI less than 20% represent no stressed river basins, values of WEI between 21 and 40% indicate stressed river basins and values of WEI higher than 40% represent extreme water stressed river basins according to CIRCABC (2012). A new term has been added to the previous classification, this is the condition of unsustainable water stress in a river basin, defined for values of WEI higher than 100%. In the case of Jucar RBD, the large majority of its water exploitation systems are in an extreme water stressed condition, being the Vinalopó-Alacantí system in an unsustainable water stress situation. Moreover, as observed in figure 3.13, the systems located in the right of the chart are characterised by having water demands higher than their natural water availability, being required the use of reused water or water transfers in order to guarantee the supplies.

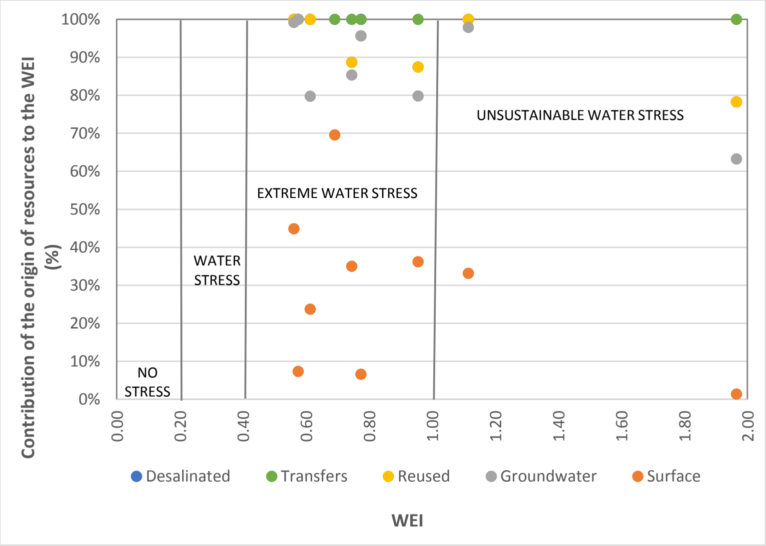


Fig. 3.13: Classification of Water Exploitation Systems according to their WEI

4. CONCLUSIONS

4.1 SUMMARY

The objective of this thesis was to analyse the methodologies and tools to build water balances in stressed river basins, trying to develop a conceptual framework in order to apply the System of Environmental-Economic Accounting for Water. This study included:

- A review of the different objectives and criteria used in water planning in relation to the development of water balances and status indicators for water exploitation systems.
- A review of the state of art of the central themes of this work such as water balances and water scarcity and drought indexes in water resources planning and management.
- Taking as a case study the Jucar River Basin, several estimations of the water resources availability were obtained depending on the origin of the series of streamflows, the length of the simulation period and the reliability criteria used to consider water requirements satisfied.
- A first approach for the development of asset accounts and physical supply and use tables was done for a pilot case study in the Vélez River Basin located in the Mediterranean Andalusian River Basin District.
- An acquisition tool called AQUACCOUNTS, was developed and integrated into AQUATOOL DSS in order to build SEEA-W tables. This tool links the main variables of the rainfall-runoff model with the results of the water balance model, enabling also the obtainment of the economic costs of water services.
- The application of the proposed approach to the Jucar River Basin District.
- A proposal of water exploitation indexes based on water accounting in order to assess the degree of stress suffered in the river basin.

4.2 CONCLUDING REMARKS

The continuous development in water resources planning and management requires the analysis and study of environmental and water resources policies on an integral approach, taking into account social and economic requirements.

With regard to the review of water scarcity and drought indexes in water resources planning and management, it has been demonstrated that there is not a single index applicable for all fields of study. The recompilation and classification of indexes proposed aims to be helpful in order to select the most appropriate index, according to the river basin particularities and the objectives of the study. In any case, the joined use of these indexes can help in the process of making better decisions.

As far as the indicator of exploitable water resources is concerned, it has been proved that, the availability of water resources depends on several factors such as the hydrology, the current infrastructure (rivers and canals) and the situation of the water users. For this reason, it would be hazardous to provide a unique value of the EWR in Jucar water exploitation system. Moreover, note that any changes in the management of water resources would require a new assessment of the EWR and the obtainment of different results.

Regarding the application of the SEEA-W approach, this research has shown the detailed degree of knowledge about the temporal and spatial evolution of the different components of the hydrological cycle and the flows between them. In this sense, from the water planning and management point of view, the incorporation of all this information is questionable due to the fact that there are some variables such as precipitation or evapotranspiration which distort the main uses in the river basins. In spite of this fact, this investigation has demonstrated the adequacy of hydrological and water allocation models for building asset accounts and physical supply and use tables. There is a need to clarify that the methodology proposed does not complete all existing issues and there are still some improvements required for the complete application of the SEEA-W approach.

Finally, it is required that policymakers make an agreement about the approach to determine water availability, either through water balances or water accounting. These methodological decisions refer:

- To the spatial and temporal aggregation of the tables. There are different possibilities such as considering monthly or annual values. These latter also could be referred to an average year, a drought year or a wet year.
- To the consideration of environmental flows. Despite environmental requirements are not explicitly considered in the tables proposed by the SEEA-W, they must be included in the approach through their inclusion in the water management models.
- To the reliability criterion. In spite of not being considered in the water accounting approach, water resources allocation and reservation requires the use of reliability criterion in order to describe if supplies are guaranteed or not.

It is noteworthy that, the Spanish Statement of Water Planning (MAGRAMA, 2008) contains a huge part of these methodological decisions, with normative status in order to guarantee consistency and comparability of the results.

4.3 FUTURE RESEARCH LINES

The thesis aims to contribute improving water resources planning and management, particularly with regard to stressed river basins with heavily regulated water resources. The work undertaken within this thesis brings attention to the need for future research in the following lines:

- In order to generalize the work done to any other river basin it is required a prior research to enrich the application of the approach proposed.
- It has also been found that there is a great difficulty in understanding the indexes by the general or not specialised public in analysis techniques. It would be interesting to make a proposal of initiatives in order to facilitate the transfer of such information to the general society.
- Improvement of the assessment of water services costs, by the use of marginal values in order to integrate them in SEEA-W tables.
- The incorporation of environmental and economic criteria for improving water allocation and reservation.
- A deep analysis and the inclusion of climate change scenarios in order to assess the impacts and measures required to mitigate it.

- Improvement of AQUACCOUNTS module, and the application to other river basins.

These aspects should enable the EU to make decisions on water in order to achieve economic, social and environmental objectives through an appropriate planning and management of water resources.

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ANNEX 1. A REVIEW OF WATER SCARCITY AND DROUGHT INDEXES IN WATER RESOURCES PLANNING AND MANAGEMENT[1]

Abstract

Water represents an essential element for the life of all who inhabit our planet. But the random nature of this resource, which is manifested by the alternation of wet periods and dry periods, makes it even more precious. Whatever the approach (water planning, water management, drought, economy), in order to maximise the profit produced by the allocation of water it is necessary an understanding of the relationships between physical variables as precipitation, temperatures, streamflows, reservoir volumes, piezometric levels, water demands and infrastructures management. This paper attends to provide a review of fundamental water scarcity and drought indexes that enables to assess the status of a water exploitation system. With the aim of a better water management and governance under water scarcity conditions., this paper also presents a classification of indexes to help decision makers and stakeholders to select the most appropriate indexes, taking as the starting point the objectives of the analysis and the river basin features.

Keywords

Water planning, water management, water exploitation system, water scarcity indexes, drought indexes

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[1] Pedro-Monzonís, M., Solera, A., Ferrer, J., Estrela, T. and Paredes-Arquiola, J., 2015. A review of water scarcity and drought indexes in water resources planning and management, J. Hydrol. 527, 482-493, doi:10.1016/j.jhydrol.2015.05.003

A1.1. INTRODUCTION

Water represents an essential element for the life of all who inhabit our planet. But the random nature of this resource, which is manifested by the alternation of wet periods and dry periods, makes it even more precious. Despite the social, economic and environmental significance that represents the lack of this resource, there is no unanimity concerning on the definition of concepts related to water scarcity, drought or water shortage in the literature (EU, 2012). As noted by Quiring (2009), this is a complex phenomenon that is difficult to accurately describe because its definition is both spatially variant and context dependent.

In general terms, water scarcity covers all aspects related to restricted water availability. According to EU (2007) water scarcity is defined as a situation where insufficient water resources are available to satisfy long-term average requirements and similarly, Van Loon and Van Lanen (2013) considered that water scarcity represents the overexploitation of water resources when demand for water is higher than water availability. Aridity, by contrast, is a climatic feature consisting of low ratio between precipitation and potential evapotranspiration (Tsakiris and Vangelis, 2005), representing a permanent phenomenon.

In the same way, the term drought has been defined in different ways. There are two main types of drought definitions: conceptual and operational. On the one hand, conceptual definitions are formulated in general terms to describe the concept of drought. According to this type of definition, as noted by Estrela and Vargas (2012), drought is a natural hazard that results from a deficiency of precipitation from expected or normal, which can in turn translate into insufficient amounts of water to meet the water needs of ecosystems and/or human activities. Whereas EU (2007) considers drought as a relevant temporary decrease of the average water availability. On the other hand, operational definitions are used to identify the beginning, end and severity of droughts. In this sense, there is no single operational definition of drought that can be used in all contexts. This is the reason why policy makers and resources planners use drought index thresholds to determine the accurate moment to implement preventive measures (Quiring, 2009).

According to the definition of drought as a natural hazard, there are different categories of droughts depending on the reference variable considered. In this study, we distinguish between three types of droughts:

i. Meteorological drought is defined as a continued shortage of precipitation. This is the drought that raises the other types of drought and usually tends to affect large areas. The origin of the lack of precipitation is associated with the global behaviour of the ocean-atmosphere system, where both natural and human factors, such as deforestation or the increase in greenhouse gases, have strongly influenced.
ii. Agricultural drought may be defined as a moisture deficit in the root zone to meet the needs of a crop, affecting the crop development and declining crop yields.
iii. Hydrological drought is defined as a period of low flows in watercourses, lakes and groundwater levels below normal. It is related to a period with a decrease in surface and groundwater water resources availability for established water uses of a given water resources system (Mishra and Singh, 2010).

As a consequence of the natural phenomenon, the terms operational drought (Sánchez-Quispe et al., 2001) and socio-economical drought (Mishra and Singh, 2010) are also used in the literature. Even though these terms do not represent a natural hazard, they can cause water shortage, understood as the deficit of water supply to meet social and environmental demands which are caused by intense drought episodes, an inappropriate use of water resources or man-made changes (Tsakiris et al., 2013). Operational drought refers to a period with anomalous supply failures (no satisfaction of water uses) in a developed water exploitation system. The causes include: the lack of water resources (hydrological drought), the excess of demand, or an inadequate design and management of the water exploitation system and its operating rules. Socio-economic drought is associated with the condition of water scarcity on people and the economic activity causing socio-economic, social and environmental impacts. In recent decades there has been an increase in the number of episodes of socio-economic drought that has led in many cases to significant economic losses, which are a consequence of the increasing pressure on water resources exerted by human activities. As noted by Tsakiris et al. (2013), it is estimated that the cost of drought in Europe during the last 30 years is 100 billion Euros. Figure

1 explains the relationship between these types of drought and the duration of the event.

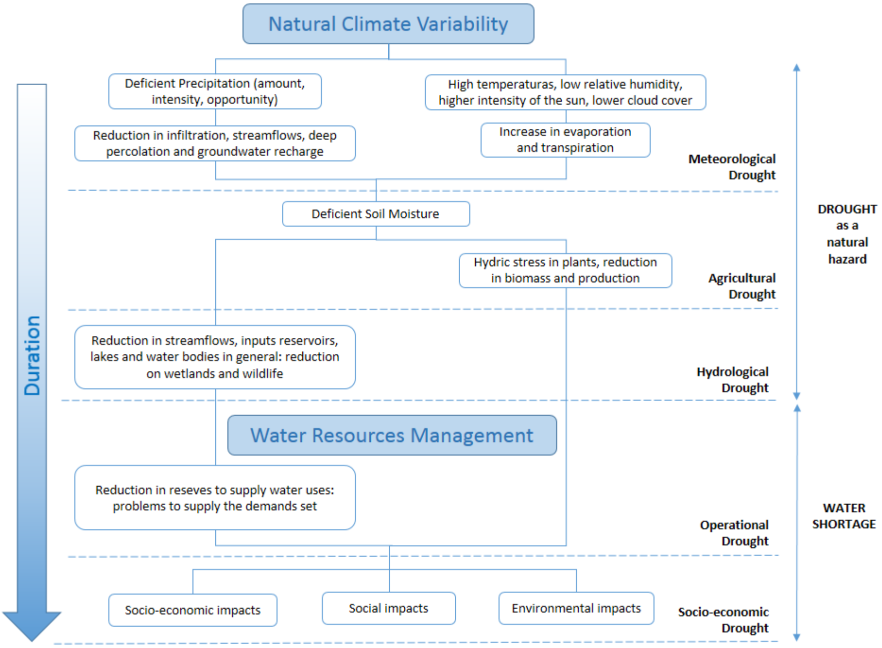

Figure 1. Relation between different types and duration of drought events (modified from Villalobos (2007))

Whatever the approach (water planning, water management, drought management, economy), society expects that policymakers and stakeholders maximise the profit produced by the allocation of water. In this sense, the use of indexes is highly relevant for decision-making processes (Lama, 2011). Before continuing, it is required to distinguish between indexes and indicators, and their use in water policies. Indexes represent an aggrupation of variables or indicators which are weighted in order to take into consideration social preferences. They are used for the development of water policies and reflect social requirements. Whereas indicators are obtained as an aggrupation of variables and expect to communicate information about the water resources system. They are based on the knowledge and scientific judgment. So, when displaying environmental information, the level of its detail would be in inverse proportion of the number of users (Vardon et al., 2012). Researchers handle a mass of information, this information is aggregated so managers and analysts use indicators and finally, indexes are used by decision-makers and wider public (see Figure 2).

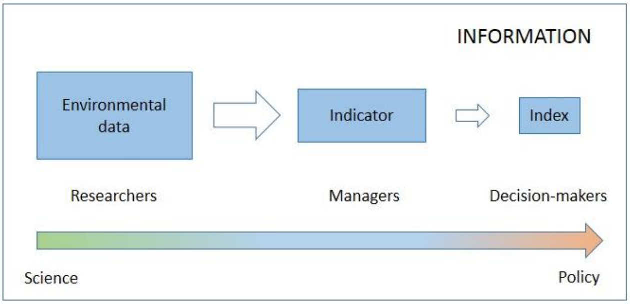

Figure 2. Aggregation of information in water resources planning and management

To date, scientists and researchers have defined a huge quantity of water indicators related to different approaches, such as water productivity, ecosystem services, weather forecasting, or drought management, as an example, Lloyd-Hughes (2014) noted that more than one hundred indexes have been proposed for use only in drought monitoring.

The target of this paper is to present a review of water indicators related to water planning and management. In order to do this, in section 2, we present a review on drought and water scarcity indexes along with indicators derived from water accounting (section 3) and performance indexes (section 4). In section 5, we propose a recompilation and classification of water related indexes in order to organise them according to the context of use, the key issue represented and the river basin features, which may be useful during the decision making process. Finally, conclusions and recommendations are presented.

A1.2. DROUGHT AND SCARCITY INDEXES

The severity of droughts is represented by drought indexes, which have been developed to detect, monitor and assess drought events (Estrela and Vargas, 2012). Several drought indexes have been defined in last decades. The most commonly variable employed in their definition is precipitation in combination with other variables such as temperature, soil moisture, etc. The most frequently drought indexes are the Palmer Drought Severity Index (PDSI) (Palmer, 1965), rainfall deciles (Gibbs and Maher, 1967), Crop Moisture Index (CMI) (Palmer, 1968), Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982); Standardized Precipitation Index (SPI) (McKee et al., 1993) or the Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis, 2005). An extended state-of-the-art review on drought concepts has been provided by Mishra and Singh (2010).

To assess water scarcity, the most commonly approaches are the water resource vulnerability index (Raskin et al., 1997), water stress index (Falkenmark et al., 1989), International Water Management Institute (IWMI) indicator (Seckler et al., 1998), critical ratio (Alcamo et al., 2000) and the water poverty index (Sullivan, 2002). An extended state-of-the-art review on water scarcity has been provided by Rijsberman (2006).

The use of water scarcity and drought indexes is not addressed only to describe or characterize the situation of a river basin, but they may also be applied in order to mitigate long-term drought risk. An example of the application of measures to reduce drought impacts is the case of the National Drought Indicator System in Spain which is described below.

A1.2.1. STATUS INDEX FROM THE NATIONAL DROUGHT INDICATOR SYSTEM IN SPAIN

Spain, as a Mediterranean country, has always presented water scarcity problems related with prolonged drought episodes. This country represents an example of an ancient tradition in water planning, where water resources are heavily regulated, being the fifth country in the world with the highest number of large dams (Instituto Nacional de Estadística, 2008). During decades, drought management in Spain was carried out as an emergency situation, being necessary the application of several Royal Decrees to mitigate the negative impacts. Due to the need of anticipation in the application of mitigation measures, it was essential to develop a system of indicators to warn when the measures have to be taken and what kind of measures were the most appropriate given the current level of risk, in other words, depending on the severity of the situation existing at any given moment.

This system of indicators consists of spatially distributed control points in the area of the river basin and collects information about reservoir storages, groundwater piezometric levels, streamflows, reservoir inflows and precipitation (MMA, 2007). Each River Basin Authority has adopted a calculation method for the definition of the drought indicator. According to these criteria, these indexes take values between 0 and 1, low values corresponds to drought conditions and values between 0.5 and 1 indicate the absence of problems related with drought. By weighting the index value in each zone we obtain an overall index value. These indexes allow us to classify the water exploitation systems into four hydrological states: normal, pre-alert, alert and emergency (see table 1). Haro et al (2014) discussed the validity of the application of this approach in any kind of system. They showed how this methodology fails at determining the drought status of within-year regulated systems, being thus necessary to adopt a different approach depending on the system's operation. Figure 3 shows the basin drought status for the water exploitation systems in late June 2014.

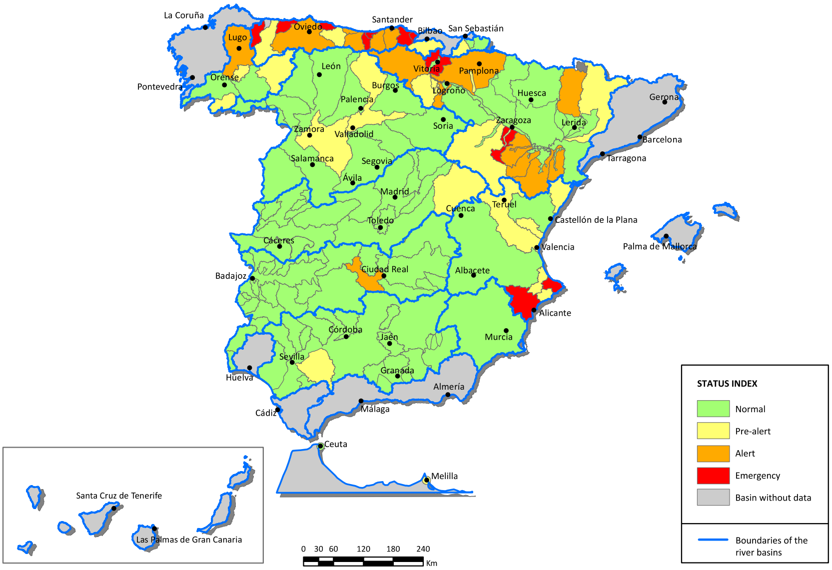

Figure 3. Basin Status Index in June 2014 (www.magrama.es)

As mentioned above, one of the main functions of the National Drought Indicator System (MMA, 2007) is the application of measures to reduce the impact of droughts based on the state of the indicators. Three types of measures are considered:

i. Strategic measures. They represent the medium and long term answer. They often require substantial investments such as construction of new reservoirs, desalination, reuse systems, etc.
ii. Tactic measures. They represent the short term response. They would be measures to promote voluntary savings for both supply and irrigation, or, accelerate the development of planned infrastructure.
iii. Emergency measures. They respond to unexpected circumstances. They are measures such as the construction of new emergency wells, the establishment of supply restrictions or prohibition of uses, among others.

The following table shows the relationship between the hydrological state of the system and the type of measure to be applied:

Status Index	Basin Drought Status	Objective	Type of Measures
0.50 - 1	Normal	Planning	Strategic
0.30 – 0.50	Pre-alert	Control-Information	
0.15 – 0.30	Alert	Conservation	Tactic
0 – 0.15	Emergency	Restriction	Emergency

Table 1. Relationship between the hydrological state of the system and type of measures to be applied

A1.3. INDICATORS DERIVED FROM WATER ACCOUNTING

Water accounting is an approach focused on the presentation of information relating to the water resources in the environment and the economic aspects of water supply and use (Vardon et al., 2007). Among its goals is to achieve a sustainable water balance and an equitable and transparent water governance for all water users (www.wateraccounting.org). As noted by Molden and Sakthivadivel (1999), their methodology is based on a water balance approach where, based on conservation of mass, the sum of inflows must equal the sum of outflows plus any change in storage. Water accounting covers a range of methods of reporting water information (Godfrey and Chalmers, 2012). Some examples of water accounting systems are the System of Environmental-Economic Accounting for Water (SEEAW) (UN, 2012) and the Water Footprint Accounting (Hoekstra, 2003).

A1.3.1. THE SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING FOR WATER

The SEEAW has been developed by the United Nations Statistics Division (UNSD) in conjunction with the London Group on Environmental Accounting (UN, 2012). Its main objective has been standardizing concepts related to water accounting, providing a conceptual framework for organising economic and hydrological information. In this sense, water accounting generally, and particularly the SEEAW, expects to become a useful tool for helping the decision-making process on issues of allocating water resources and improving water efficiency among others. In this sense, the SEEAW constitutes a structured database from which researchers may obtain many water-related indicators (UN, 2012). Each of these tables allows us to obtain the indicators of internal renewable water resources, external renewable water resources, total natural renewable water resources and total actual renewable water resources.

As noted by UN (2012), it is also possible to link the list of indicators proposed in the second World Water Development Report (UN, 2006) and the SEEAW. The cited indicators are the index of non-sustainable water use, the relative water stress index, the water reuse index, the total actual renewable water resources (TARWR) volume, the surface water as a percentage of TARWR and the groundwater development (groundwater as a percentage of TARWR). Margat (1996) proposed several indicators that could be obtained from the water accounts and expected to cover essential aspects of water availability and use. These indicators are: validity of hydrological basis, density of internal resource, concentration index of the resource, regularity index of the resource, independence of the reference territory, freedom of action index, resource per capita, exploitation index, consumption index, water resource wearing and water sanitation and purification index.

A1.3.2. WATER EXPLOITATION INDEX

Water Exploitation Index (WEI) (EEA, 2005) is obtained as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources and shows to which extent the total water demand puts pressure on water resources. The way to build the WEI indicator is by using data from SEEAW Tables 3.1, 6.1 and 6.2 (EEA, 2013). Values of WEI in a river basin between 0 and 20% show a situation of no stress; values between 21 and

40 % indicate water stress; and values upper than 40% represent extreme water stressed river basins (see Figure 4).

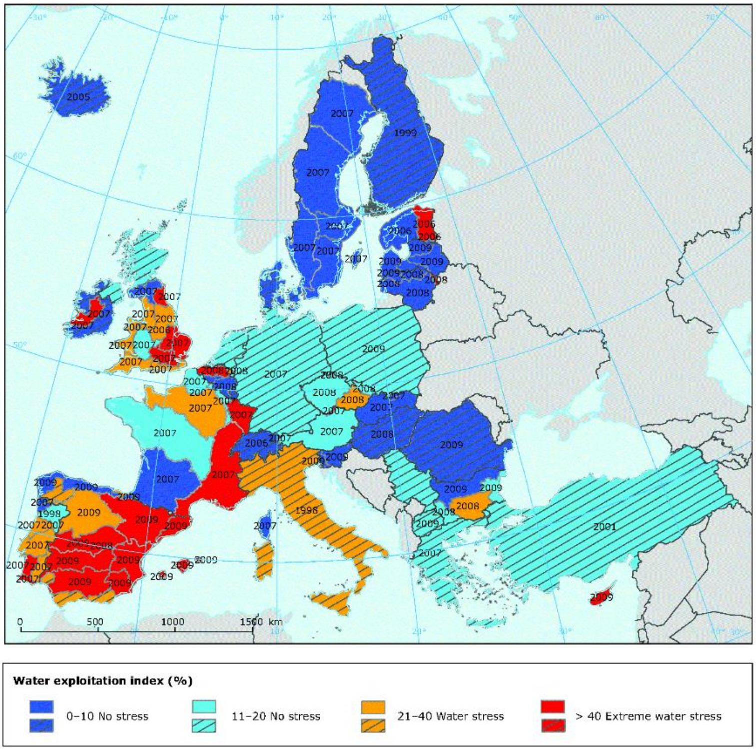

Figure 4. Water exploitation index in European Union (Source of data: http://www.eea.europa.eu/data-and-maps/figures/water-exploitation-index-2014-towards)

Despite being the index employed by the EU, there are different key issues that jeopardise the use of this index. One of them is seasonality. As it is based on annual averages it is not able to display a scarcity event at monthly scale. There may be situations in which having the same annual average of resources and demand, the pressure on the resources may be completely different due to the irregularity of resources (EEA, 2013). It is useful to analyse monthly ratios and suggest an aggregation method to describe the water stress situation in the river basin. On the other hand, the uncertainty in the assessment of demands and water resources values may result in incorrect values of the indicator.

In order to solve the limitations presented by the WEI, a modified water exploitation index called WEI+ has been defined (CIRCABC, 2012). The index focuses on the assessment of net consumption and it is defined at monthly level as follows:

$$WEI+ = \frac{(abstractions - returns)}{renewable\ water\ resources} \qquad \text{(Eq. (1))}$$

Where abstractions mean the volume of water intaken for a determined use (agrarian, urban, industrial) and returns refer to the volume of water which comes back to the environment after being used. There are two ways of addressing the renewable water resources (RWR): (1) by employing the hydrological balance equation, using precipitation (P), external inflows (ExIn), actual evapotranspiration (Eta) and change in natural storages (ΔS); or (2) by naturalisation of streamflows, using the outflows and the change in storage of artificial reservoirs (ΔSart).

$$RWR = ExIn + P - Eta - \Delta S \qquad \text{(Eq. (2))}$$

$$RWR = Outflow + (abstractions - returns) - \Delta Sart \qquad \text{(Eq. (3))}$$

Considering all these difficulties, several indicators have been considered for the presentation of water accounts (EEA, 2013). Firstly, the WEI has been normalised to reflect the entirety of resources before abstraction takes place. The nWEI is computed monthly and at sub-basin scale as follow:

$$nWEI = \frac{abstractions}{outflow + abstractions - returns} \qquad \text{(Eq. (4))}$$

Whilst environmental requirements are not explicitly considered in SEEAW tables, the ecological needs represent an important issue, in this sense, a potential indicator of ecological stress for rivers (ESIr) has been defined similarly to the nWEI:

$$ESIr = \frac{outflow}{outflow + abstractions - returns} \qquad \text{(Eq. (5))}$$

This indicator presents two problems: the first is that the denominator tends to zero if outflows are scarce; and the second problem is considering the final balance when actually there may be water bodies impacted with local withdrawals (EEA, 2013).

The third indicator represents a consumption index (WEI+c) and it is computed as follows:

$$WEI_{+c} = \frac{(abstractions - returns)}{outflow + abstractions - returns} \qquad \text{(Eq. (6))}$$

Since nWEI, ESIr and WEI+c are defined at monthly level, it is required some aggregation before their presentation. The EEA (2013) has proposed a percentile distribution to aggregate the indexes during the considered period. According to this report, mapping the indexes at 50% suggests structural water availability issues; by contrast, the 90 % indexes show there may be a recurrent water supply problem.

A1.3.3. WATER FOOTPRINT AND VIRTUAL WATER

The Water Footprint approach was introduced by Hoekstra (2003) because of the need for an indicator based in freshwater use. It is defined as the total volume of freshwater that is used to produce the goods and services consumed by an individual or community (Hoekstra and Chapagain, 2008). The water footprint allows for the differentiation of the consumed water according to its origin, distinguishing between blue water footprint, green water footprint and grey water footprint. The blue water footprint represents the consumption of liquid water available en rivers, lakes, wetlands and aquifers; the green water footprint refers to the use of rainwater stored in the soil as soil moisture which is available to plants; and the grey water footprint is defined as the volume of freshwater needed to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra, 2009).

Closely linked to the concept of water footprint is the virtual water (Allan, 1998), understood as the volume of water used in the production of a commodity, good or service. It refers to the idea that when a country imports one kilogram of a product (no matter the good or service) implicitly, this country also imports the amount of water used to produce it. Both concepts (virtual water and water footprint) are interesting in water scarcity countries because their assessment could inform the decision makers about the possibility of producing those goods most suited to local environmental conditions (Aldaya et al., 2010).

When producing the water accounting in a country, there are several terms which are not considered (Hoekstra, 2012); they do not differentiate between water uses for domestic consumption, for producing export products or water uses outside the country to support national consumptions. A scheme to obtain the national water footprint accounting is described below. The water footprint in a nation has two terms: the internal water footprint (the amount of water resources used to produce the goods and services that are consumed by national population) and the external water footprint. The first one is obtained as the difference between the uses of water within the nation minus the virtual water imported from other countries. In the same way, the external water footprint (the amount of water resources used in other nations to produce goods and services that are consumed by national population) is obtained as the virtual water imported into the nation minus the amount of virtual water exported to the other nations. This separation of components allows for evaluating the dependency ratio of water resources in a country (WD) defined as the external water footprint (WFE) divided between the national water footprint (WF) (Rodríguez et al., 2008).

$$WD\ (\%) = \frac{WF_E}{WF} \cdot 100 \qquad \text{(Eq. (7))}$$

As water footprint is composed by the set of goods and services consumed by an individual or community, it can be calculated at different levels of consumer activity (Fulton et al., 2014). So, if researchers want to use water footprint accounting as an indicator of water resources management, the best territorial unit is the river basin (Pellicer et al., 2013), even though, as noted by Zeng et al. (2012), water footprint assessment studies at river basin level are rare in the literature largely due to the lack of statistical data at this level.

The approach of water footprint has been used in the definition of the water scarcity index (Zeng et al., 2014). This index has been used to describe the severity of water scarcity in the form of a water scarcity meter to allow an easy interpretation. It has two components: the blue water scarcity index (I_{blue}) and the Grey water scarcity index (I_{grey}). I_{blue} is defined as the ratio of the water withdrawal to freshwater resources and, I_{grey} is defined as the ratio of grey water footprint to freshwater resources. A review on the indicator of water footprint for European countries has been done be Vanham and Bidoglio (2013).

A1.4. PERFORMANCE INDEXES

As noted by Hashimoto et al. (1982) the operational status of a water resources system can be described as either satisfactory or unsatisfactory. The level of a system performance was described, in Hashimoto et al (1982) research, from three different points of view: (1) how often the system fails (reliability), (2) how quickly the system returns to a satisfactory state once a failure has occurred (resiliency), and (3) how significant the likely consequences of failure may be (vulnerability).

Derived from the adoption of the aforementioned concepts, in this sub-section, several indicators are presented which describe the possible performance of a water resources system.

A1.4.1. SUSTAINABILITY INDEX

To quantify the sustainability of water resources systems, Loucks (1997) proposed the sustainability index (SI), with the aim of facilitating the evaluation and comparison of water management policies. This index is based on reliability (Rel), resilence (Res) and vulnerability (Vul) concepts. For the ith water user the index proposed by Loucks (1997) was:

$$SI^i = Rel^i * Res^i * \left(1 - Vul^i\right) \qquad \text{(Eq. (8))}$$

Sandoval-Solis et al. (2011) proposes a variation of Loucks' SI considering a geometric average of M performance criteria (Cmi) for the ith water user:

$$SI^i = \left[\prod_{m=1}^{M} C_m^i\right]^{1/M} \qquad \text{(Eq. (9))}$$

For instance, if the performance criteria are C1i= Reli, C2i= Resi and C3i= Vuli, the SI for the ith water use is:

$$SI^i = \left[Rel^i * Res^i * \left(1 - Vul^i\right)\right]^{1/3} \qquad \text{(Eq. (10))}$$

The main advantage of this index is that it allows the inclusion of other criteria according to the necessities of each territory and the use of geometric average to scale the values of SI.

A1.4.2. EFFICIENCY INDICATORS

Martin-Carrasco et al. (2013) suggests four water indexes to evaluate water scarcity at a river basin scale. The use of the efficiency indicators requires grouping the demands across several classes depending on their respective use of water. For each demand category, model results are analysed through the Demand-Reliability curve. Based on this curve, it is possible the determination of the four water indexes:

i. Demand Satisfaction Index (I_S), which evaluates the system's capacity to supply its demands
ii. Demand Reliability Index (I_R), that quantifies the reliability of the system to satisfy demands
iii. Sustainability Index (I_U), which evaluates the natural resources available for development in the system
iv. Management Potential Index (I_M), which quantifies the proportion of the demand with unacceptable reliability that is close to the acceptable level.

In systems affected by water scarcity problems, the indicators can also diagnose its causes, and anticipate possible solutions.

A1.4.3. WATER ALLOCATION INDEX

Milano et al. (2013) use a water allocation index (WAI) in order to assess the capacity of water resources to meet current and future water demands. This index is obtained by means of the quotient between water supply and water demand (%) for each year of a given period. By employing this index different water demand satisfaction classes have been defined for environmental flow requirements and the domestic sector and for the agricultural sector. Table 2 shows a classification of water demand satisfaction classes based on the WAI for environmental flow requirements and the domestic sector and for the agricultural sector.

	Very low	Poor	Moderate	High	Very high
(1)	0 < WAI < 50%	50 < WAI < 85%	85% < WAI < 95%	95% < WAI < 97.5%	WAI > 97.5%
(2)	WAI < 25%	25% < WAI < 45%	45% < WAI < 55%	55% < WAI < 75%	95% < WAI ≤ 97.5%

Table 2. Water demand satisfaction classes based on the water allocation index for (1) environmental flow requirements and the domestic sector and for (2) the agricultural sector (Milano et al., 2013)

A1.4.4. THE RELIABILITY CRITERION ESTABLISHED IN THE SPANISH GUIDELINES OF WATER PLANNING

The criterion established in the Spanish Guidelines of Water Planning (BOE, 2008) is a simple binary criteria (complies/does not comply). It indicates that for the purposes of resource allocation and reservation, urban demand is considered satisfied when the deficit in one month does not exceed 10% of the corresponding monthly demand and when in 10 consecutive years, the sum of deficits is less than 8% of the annual demand. Similarly, agrarian demand is considered satisfied when the deficit in one year does not exceed 50% of the corresponding demand; for two consecutive years, the sum of deficit does not exceed 75% of annual demand; and in ten consecutive years, the sum of deficit does not exceed 100% of the annual demand.

A1.4.5. PERFORMANCE WEIGHTED INDEX (IPOC)

The Performance Weighted Index (IPOC, in Spanish) was used in the National Hydrological Plan (MMA, 2001). This index evaluates the global performance of a water resources system by the average of the ratio between the deficit in one, two and ten consecutives years, and the acceptable deficit during the same periods for each considered demand. If there is no fault in the system IPOC is 1 and, if there is a failure in one or several demands IPOC will be greater than 1.

This index attempts to be more flexible than the reliability criterion established in the Spanish Guidelines of Water Planning (BOE, 2008), which considers that the systems fail if there is one demand that contravenes the criterion. Moreover, in order to consider the relevance of each demand or group of demands, these deficits are weighted to avoid that a failure in a non-relevant demand for the exploitation system involves the failure of the global system.

A1.4.6. EXPLOITABLE WATER RESOURCES

In order to quantify water availability, AQUASTAT (FAO's global water information system) suggests the use of the indicator of exploitable water resources. This indicator is defined as the part of the water resources considered to be available for development under specific technical, economic and environmental conditions but, despite its significance, there is disagreement in regard to the best process for calculating exploitable water resources (UNSD, 2012).

Pedro-Monzonís et al. (2015) have determined the key issues for determining this indicator in a Mediterranean river basin. In that work, the exploitable water resources have been obtained as the maximum demand that can be served in a water exploitation system while complying with the reliability criteria established by law. Once the hypothesis about the obtaining of natural streamflows and the reliability criteria for considering the supply to be satisfied is selected, the steps used to obtain this indicator are as follows: (a) select the possible places in the system where new water allocations could be required and their type of use (urban or agrarian); (b) analyse the possibility of increasing each single demand while considering the other demands as zero, and execute the simulation model. The final result is achieved when the maximum demand is obtained while fulfilling the required reliability criteria.

A1.5. CLASSIFICATION OF WATER RELATED INDEXES IN WATER RESOURCES PLANNING AND MANAGEMENT

As seen, in the literature there is a huge amount of indicators and indexes related to water. Each of them has been defined under different assumptions or conditions, so, its applicability may be adequate or not in all areas of study. The classification of water scarcity and drought indexes proposed below attempts to organise them according to the context of use, the key issue represented (aridity, water scarcity or drought), the type of drought analysed and the utility. In this sense, the context of use distinguishes between natural use, water resources planning and water allocation, and management. This distinction is done to discern on whether the considered variables to define these indexes are influenced by the management of the river basin or they are independent of human activities.

Firstly, Table 3 groups water scarcity and drought indexes in the context of natural water use due to the fact that, a priori, human activities do not have influence in variables as precipitation, temperature or potential evapotranspiration. Frequently, these indexes are used to determine drought periods, aiming to identify drought properties, such as intensity, duration and magnitude. Moreover, as a universal definition of drought suitable in all circumstances does not exist, most of these indexes are also used as an operational definition of drought, providing information about levels of severity. In this sense, Quiring (2009) indicates that the most commonly indexes used for monitoring drought and determine the operational drought definition (thresholds) are PDSI, precipitation and streamflows.

Index or Indicator	**Key issue**	**Type of drought**	**Utility**
Percent of Normal (PN)	D	M	It is calculated by dividing actual precipitation by normal (or mean) precipitation (based on 30 years of data). It can be calculated for any time scale (day, month, year).
Palmer Drought Severity Index (PDSI; Palmer, 1965)	D	A	PDSI is suitable for agricultural impacts, but it is sensitive to temperature, precipitation and the initial conditions of soil moisture.
Rainfall deciles (Gibbs and Maher, 1967)	D	M	Rainfall deciles compare monthly data of precipitation with the cumulative distribution over a long-term precipitation record. They show the likelihood of registered precipitation in a given month (i) is less than a given volume of precipitation (X).
Crop Moisture Index (CMI; Palmer, 1968)	D	A	CMI was developed to evaluate short-term moisture conditions related to agricultural droughts. It shows good results during warm seasons, but it requires weekly records of temperature and precipitation.
Standardized Precipitation Index (SPI; McKee et al., 1993)	D	M	The versatility in the aggregation period allows to observe seasonal, intermediate and long-term drought. But the index spatial aggregation covers up the significant differences between recorded rainfall in headwaters and lower basins. Also the probability distribution or the length of precipitation records affects the SPI values.

Reconnaisance Drought Index (RDI; Tsakiris and Vangelis, 2005)	A-D	A	RDI is based on the ratio between two aggregated quantities of precipitation and potential evapotranspiration. It is physically based, and it can be calculated for any period of time. This index has also been used for detecting possible climate changes of a geographical area (Tigkas et al., 2013)
Standardized Precipitation Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010)	A-D	A	SPEI is based on a water balance. SPEI is similar to the SPI, but it includes the role of temperature.

Table 3. Classification of water scarcity and drought indexes in the context of natural water use. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Secondly, Table 4 groups water indexes related to variables which may be affected by the use of water infrastructures or traditionally used in water planning for water allocation. In the case of indicators derived from water accounting, they show a current description of the river basin and allow the decision makers and stakeholders to make comparisons between the use and pressures of water resources in different regions. But, in the case of performance indexes, as water resources planning consists of the analytical study of the water resources to identify and solve the river basin problems in the long term, it is difficult to untie these indexes and the human activities. In other words, new measures are proposed aiming to improve the status of the water resources system, reflected by these kind of indexes.

Index or Indicator	**Key issue**	**Type of drought**	**Utility**
Normalized Difference Vegetation Index (NDVI; Rouse, 1974)	S-D	A	NDVI quantifies the water status of the vegetation through the spectral response of the vegetation cover. NDVI requires precipitation and temperatures data. The leaf water content is obtained from satellite remote sensing data.
Surface Water Supply Index (SWSI; Shafer and Dezman, 1982)	D	H	SWSI requires snowpack, streamflow, precipitation and reservoir storage.
Water Stress Index (Falkenmark et al., 1989)	S	S	Countries may be classified according to the renewable water resources per capita per year. It is easily understood and data are generally

			available. In contrast, average values may hide scarcity problems at smaller scales, it does not take into consideration the infrastructures that modify the water availability or the variations in demands among the different countries.
Water Resource Vulnerability Index (Raskin et al., 1997)	S	S	It considers scarcity as the total annual withdrawals as a percent of available water resources. It is focused on the assessment of use for being more objective than demand.
Sustainability Index (SI; Loucks, 1997; Sandoval-Solis et al., 2011)	S	S	SI was created to quantify the sustainability of water resources systems, with the aim of facilitating the evaluation and comparison of water management policies. It is defined as a geometric average of M performance criteria.
International Water Management Institute (IWMI) indicator (Seckler et al., 1998)	A	S	Represents the relation between primarily water supply (taking into account the existing water infrastructure) and the water use (evapotranspiration). Countries may be divided in physically water scarce (which will not be able to meet their future demands) or economically water scarce (should invest in infrastructures to make available their renewable resources). The disadvantage is that it is inaccessible to the wider public.
Virtual Water (Allan, 1998)	S	S	This concept indicates that the total volume of water used for a unit of production should comprise offsite water use.
Critically ratio (Alcamo et al., 2000)	S	S	It considers scarcity as the ratio of water withdrawals for human use to total renewable water resources. Among its limitations are the difficulty of distinguishing the amount of water that could be available for human use considering evapotranspiration, return flows, environmental requirements, or the possibility of the society to adapt to water scarcity.
Performance Weighted Index (IPOC; MMA 2001)	D	O	The IPOC evaluates the global performance of a water resources system by the average of the ratio between the deficit in one, two and ten consecutives years, and the acceptable deficit during the same periods for each considered demand.
Water Poverty Index (Sullivan, 2002)	S	S	Represents a weighted average of its five dimensions: access to water; water quantity, quality and variability; water uses; water management capacity; and environmental aspects. The input data are huge and expert judgments are required.

Water footprint (Hoekstra 2003, 2012)	S	S	It is defined as the total volume used to produce goods and services. It can be divided into three types: blue water footprint, green water footprint and grey water footprint.
Water Exploitation Index (WEI) (EEA, 2005)	S	S	WEI is obtained as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources. There are different key issues that jeopardise the use of this index, such as seasonality or the uncertainty in the assessment of demands and water resources.
Spanish Guidelines of Water Planning (BOE, 2008)	D	O	It has been defined for the purposes of resource allocation and reservation. It represents a reliability criteria, considering that urban demands are satisfied depending on the deficit in one month and in 10 consecutive years. Agrarian demands are considered satisfied depending on the deficit in one year, two consecutive years, and in ten consecutive years.
Dependency ratio (WD; Rodríguez et al., 2008)	S	S	Derived from water footprint. WD is defined as the external water footprint divided between the national water footprint and allows for evaluating the dependency ratio of water resources in a country.
Water Exploitation Index Plus (WEI+; CIRCABC, 2012)	S	O	WEI+ has been developed to solve the limitations presented by the WEI. The index focuses on the assessment of net consumption and it is defined at monthly level.
Normalised Water Exploitation Index (nWEI; CIRCABC, 2012)	S	S	WEI has been normalised to reflect the entirety of resources before abstraction takes place. The nWEI is computed at monthly and at sub-basin scale.
Water Consumption Index (WEI+c; CIRCABC, 2012)	S	S	WEI+c represents a consumption index and it is related to ESIr.
Ecological Stress Indicators for Rivers (ESIr; CIRCABC, 2012)	S	H-S	Whilst environmental requirements are not explicitly considered in SEEAW tables, the ecological needs represent an important issue. This indicator present two problems: the first is that the denominator tends to zero if outflows are scarce; and the second problem is considering the final balance when actually there may be water bodies impacted with local withdrawals.
Efficiency indicators	S	O	Four water indexes are defined to evaluate water scarcity at a river basin scale. In systems affected by water scarcity problems, the

(Martín-Carrasco et al., 2013)			indexes can also diagnose its causes, and to anticipate possible solutions.
Water Allocation Index (WAI; Milano et al., 2013)	S-D	O	This index represents a reliability criteria, it is obtained by means of the quotient between water supply and water demand (%) for each year of a given period.
Water Scarcity Index (Zeng et al., 2014)	S	S	The Water Scarcity Index links water quantity with water use and water pollution by human activities. It is defined as the sum of blue water scarcity index and the grey water scarcity index. It is similar to the critically ratio (Alcamo et al., 2000).
Exploitable Water Resources (Pedro-Monzonís et al., 2015)	S	O	This indicator is defined as the part of the water resources considered to be available for development under specific technical, economical and environmental conditions. It is obtained as the maximum demand that can be served in a water exploitation system while complying with the reliability criteria established by law. It requires the use of simulation models and depends on how the natural streamflows are obtained, the reliability criteria, and the places in the system where new water allocations are likely to be required.

Table 4. Classification of water stress indexes in the context of water resources planning and water allocation. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Finally, Table 5 shows the indexes related to the management stage. As expected, to solve water scarcity problems policymakers resort to water resource management, using the implementation of preventive measures in order to reduce the effects of droughts (Estrela and Vargas, 2012; Van Loon and Van Lanen, 2013). In this case too, these indexes are also used as an operational definition of drought, helping drought planners to decide when to start implementing drought measures. The importance of these indexes is crucial due to the fact that the application of specific measures are conditioned by the immediacy or the legal and administrative procedures (Ferrer and Pedro-Monzonís, 2014), and they need a clear identification of their application timing. As seen, the amount of this kind of indexes in the literature is lower than previous groups, possibly due to the fact that this index represent a practical activity more than a research activity.

Index or Indicator	Key issue	Type of drought	Utility
Standardized Reserves Index (SRI; Villalobos, 2007)	D	O	SRI shows the state of reserves in the exploitation system, checking the beginning and end of an operational drought.
Status Index from the National Drought Indicator System in Spain (PES; MMA, 2007)	D	O	The Status Index consists of spatially distributed control points in the area of the river basin and collects information about reservoir storages, groundwater piezometric levels, streamflows, reservoir inflows and precipitation. There is a relationship between the hydrological state of the system and the type of measure to be applied.

Table 5. Classification of water stress indexes related to the management stage. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Some impressions derived from the previous tables are described below:

i. Not always the classification between key issue and type of drought is easy or possible, and in some cases it could have more than one solution. The NDVI can be an example: it seems to represent clearly an agricultural drought (A) and, in fact, this is accurate when we refer to rainfed agriculture. But in irrigated agriculture, which depends on rivers or streamflows, it can represent a hydrological drought (H) or an operational drought (O) when surface water comes from artificial reservoirs.
ii. We can find in the literature many indexes related to the context of natural water use, which, in many cases, are used to identify the magnitude of drought periods. Sometimes, their usability during water resources management processes is limited. This may be due to the fact that these indexes require the definition of a threshold to identify the kind of measures to be applied according to the level of risk.
iii. There are few indexes related to the management stage. The reason may be that this is a relatively new approach which has been carried out since the last decade, and the availability of data from reservoir and piezometric levels is not vast enough to carry out a deep investigation. However, there are many indexes related to the water planning in the long term, which, in most cases, use simulation models to address the lack of data.

iv. We have also seen that, in some cases it is difficult to distinguish the key issue between aridity and scarcity. Especially in the case of water management systems, where demand is established by human beings and it could change according to decisions which sometimes are included in the analysis.

v. In connection with the different types of drought, the distinction between operational and socio-economic drought may be difficult. Especially, when operational decision such as water allocation during drought periods may originate socio-economic effects.

A1.6. CONCLUSIONS

In this paper, several water indexes have been summarized. Some of them have served to identify the types of drought (meteorological, agricultural, hydrological, operational or socio-economic), while others allow us to characterize the pressures on the water resources, to justify the allocation of new demands, or the volumes used to produce goods and services among others. This vast amount of indexes and indicators demands collecting information related to a huge variety of disciplines, representing a complex issue, and moreover, when there is no unanimity about basic terms as water scarcity and drought.

A priori, there is not a unique indicator suitable for all areas of study. In this sense, there is a clear need for using different indexes according to the proposed objectives. To do this, knowing the limitations of these indexes is crucial. That is why this paper presents a review of water scarcity and drought indexes related to water planning and management, with the aim of analysing whether they are appropriate for the climate of the region or for the objectives of the study. For this purpose, the different approaches to analyse the status of a river basin have also been reviewed. For example, in recent years, drought episodes have required the implementation of anticipation measures which have influenced the new policies for water resources management (short term) and planning (long term). According to this target, it is noteworthy that a key feature of drought management plans is the use of water drought indexes to establish a link between the current river basin status and the measures to be taken. On the other hand, indicators derived from water accounting allow a general description of the river basin, with an emphasis on water economics and the benefit of natural water and managed water. If our goal is the purposes of resource allocation it may be desirable the use of simulation models to obtain performance indexes which evaluates the status of the water resources system.

This recompilation and classification of indexes aims to be useful to select the most appropriate index, taking as the starting point the objectives of the analysis and the river basin features (a natural system or an altered system due to their water management). In any case, the combined use of all of these indicators may help in the decision-making process.

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ANNEX 2. KEY ISSUES FOR DETERMINING THE EXPLOITABLE WATER RESOURCES IN A MEDITERRANEAN RIVER BASIN[2]

Abstract

One of the major difficulties in water planning is to determine the water availability in a water resource system in order to distribute water sustainably. In this paper, we analyse the key issues for determining the exploitable water resources as an indicator of water availability in a Mediterranean river basin. Historically, these territories are characterised by heavily regulated water resources and the extensive use of unconventional resources (desalination and wastewater reuse); hence, emulating the hydrological cycle is not enough. This analysis considers the Jucar River Basin as a case study. We have analysed the different possible combinations between the streamflow time series, the length of the simulation period and the reliability criteria. As expected, the results show a wide dispersion, proving the great influence of the reliability criteria used for the quantification and localization of the exploitable water resources in the system. Therefore, it is considered risky to provide a single value to represent the water availability in the Jucar water resources system. In this sense, it is necessary that policymakers and stakeholders make a decision about the methodology used to determine the exploitable water resources in a river basin.

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[2] Pedro-Monzonís, M., Ferrer, J., Solera, A., Estrela, T. and Paredes-Arquiola, J., 2015. Key issues for determining the exploitable water resources in a Mediterranean river basin, Sci Total Environ, 503-504, 319-328, doi:10.1016/j.scitotenv.2014.07.042.

Keywords

Water availability, Jucar River Basin, exploitable water resource, water accounts, water resources systems

A2.1. INTRODUCTION

The importance of water to society is broadly recognized. As noted in the Blueprint to safeguard Europe's water resources (EC, 2012), we need to know how much water is available in order to distribute it sustainably. One of the major difficulties lies in computing water resources, as they depend on several factors, some of which are difficult to quantify. Water resources are presented in random order in the sense that they cannot be fully explained by a reduced number of physical causal factors (Marco, 1993). To assess these resources, water accounts, as defined by United Nations, have become a very powerful tool for improving water management as they provide a method of organizing and presenting information relating to the physical volumes of water in the environment, the water supply and the economy (Vardon et al., 2007). The main purpose of the System of Environmental-Economic Accounting for Water (SEEAW) (UNSD, 2012) is to provide a standard approach and therefore the possibility to compare results among different areas (Evaluación de Recursos Naturales, 2013).

Many studies have used the concept of water availability in different senses: the European Environmental Agency (EEA) (2009) considers precipitation, river flows and the storage of water in snow and glaciers as a measure of the availability of freshwater resources, while other authors (Lorenzo-Lacruz et al., 2010; Pérez-Blanco and Gómez, submitted for publication) have estimated water availability by employing drought indexes. Furthermore, Lange et al. (2007) and Sun et al. (2002, 2005, 2006) consider that regional water resource availability can be well described by water yield, defined as the difference between received precipitation and evapotranspiration, and representing the maximum water availability for natural ecosystems and human society (Lu et al., 2013).

However, not all natural resources can – or should – be considered as supplies that can be used to meet water demand (MMA, 2000). It is noteworthy that some external constraints (environmental, socio-economic or geopolitical) exist in the system itself that limit potential water use. There are also other technical restrictions that limit the use of resources. In this sense, the available resource is defined as a resource that depends on the characteristics of natural resources, external constraints and technical limitations (MMA, 2000). In other words, the concept of water availability is related to the ability of a country to mobilize water (UNSD, 2012). This concept is important because knowing the available resources of a basin will aid the planner to place a value on its growth potential in the exploitation of the system. In the same way, AQUASTAT (FAO’s global water information system) has suggested the use of an indicator of exploitable water resources to quantify water availability. This indicator is defined as the part of the water resources considered to be available for development under specific technical, economic and environmental conditions (UNSD, 2012). Unlike natural resources, whose meaning is widely accepted, there is disagreement as regards the best process for calculating exploitable water resources (MMA, 2000; UNSD, 2012). This concept is extremely important in Mediterranean countries where precipitation is scarce, evapotranspiration is intense and there is marked seasonality of the rainfall, often causing drought periods during summer (Delgado et al., 2010).

The aim of this paper is to design a scheme of conditions for determining the exploitable water resources in a Mediterranean basin. Historically, Mediterranean countries have suffered important drought periods that have caused severe impacts. Water scarcity and the frequent drought periods explain, in part, the ancient building tradition of hydraulic works (Estrela and Vargas, 2012). These territories are characterised by heavily regulated water resources and the extensive use of unconventional resources, such as desalination and wastewater reuse (Vargas-Amelín and Pindado, 2013), which is the main reason why emulating the hydrological cycle is not enough. This approach is completed by the analysis of the Jucar River Basin (Spain), which, as in other many Mediterranean basins, is currently water-stressed. To achieve this goal, the study draws on the SIMGES simulation model of water resources (Andreu et al., 1996) from the Decision Support System (DSS) AQUATOOL. As expected, the results are very different, proving the need for a standardized methodology to determine the exploitable water resources in a basin.

A2.2. MATERIALS AND METHODS

Water resources systems analysis comprises all of the necessary elements needed to describe a river basin. These elements represent the natural resources system, the socio-economic system and the administrative and institutional system (Loucks and van Beek, 2005) and include factors such as water resources, water demands, infrastructures, environmental requirements, reservoir operating rules, etc. In this sense, water resources management can be performed in different ways, among which the use of simulation models is the most reliable method. Simulation models provide information that can help improve water resources system management and planning processes (Sulis and Sechi, 2013). An extended state-of-the-art review on simulation and optimization modelling approaches has been provided by Rani and Moreira (2010). Moreover, as noted by Chavez-Jimenez et al. (2013), a system is the unit through which the exploitation of water resources may be modelled as a set of dynamically related elements that perform an activity to meet the objective of satisfying demand.

Therefore, to assess the water availability in a water resources system, it is necessary to use simulation models (see figure 1). The results obtained with the simulation models can be grouped in a water balance that represents an accounting of the inflow, outflow and storage of water during the simulation period. One such result is the time-dependent water supply. Once the time series of water supplies has been determined, it can be compared with the water demand in order to obtain the system's reliability. The indicator of exploitable water resources is linked to the reliability criteria. Therefore, if water managers accept a less severe level of reliability, it will be possible to address a larger demand than if the level were more severe. Once the reliability criteria have been selected, the exploitable water resources are obtained as the maximum demand that can be served.

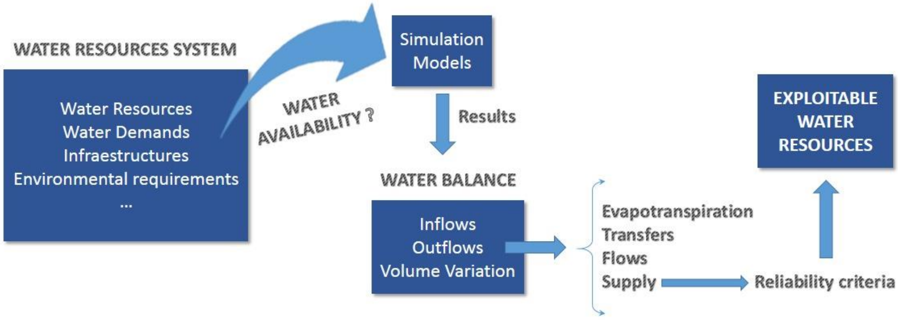

Figure 1. General scheme to obtain the exploitable water resources in a river basin

A2.2.1. WATER RESOURCES SYSTEMS ANALYSIS AND WATER RESOURCES MANAGEMENT MODELS

Water resources systems analysis consists of the analytical study of the water resources in a river basin in order to help decision makers to identify and choose one alternative from other possible ones. Quantitative and holistic knowledge of basin hydrology becomes essential as water management needs become increasingly complex (Masih et al., 2009). Molle et al. (2004) concluded that as water demands increase and more water is allocated to different uses, the management of water resources becomes increasingly complex due to a large number of interacting factors. The greater the complexity of the system is, the greater the need for a water resource management model in order to identify the system's water availability.

The planning and management of a water resources system may be simulated using SIMGES, a management simulation model in the generalized tool AQUATOOL (Andreu et al., 1996). AQUATOOL is a user-friendly DSS widely employed in Spanish water basins, as well as in other countries (e.g., Chile, Italy, Morocco, etc.). This DSS allows the definition of monthly conjunctive-use management models at the basin scale, and, as noted by Pulido-Velazquez et al. (2011), permits the simulation of management alternatives for complex large-scale systems over long time horizons. The SIMGES model can simulate the water resources system, on a monthly time scale, by a simple flow balance in a flow network in order to find a flow solution compatible with the defined constraints. Moreover, the SIMGES model allows us to define operating rules to reproduce source-demand interactions that can help improve integrated river basin management.

A2.2.2. COMPONENTS OF A WATER RESOURCES SYSTEM

Simulation models are simplified mathematical representations of water allocations over a period of time under given boundary conditions. Thus, in order to define the main elements to be included, we must distinguish between natural elements in the river basin and anthropogenic elements that produce alterations in river flows.

A2.2.2.1. Natural elements

Among natural elements we consider rivers, natural streamflows and aquifers, as well as their interactions. Natural streamflows represent the flows of a particular area of the basin corresponding to its drain point and are the most important elements for river basin management, as they represent the flows that are to be managed (Solera et al., 2010a). The random nature of streamflows requires a hypothesis to be established regarding the best way to obtain streamflow data. In this sense, it is common to use time series of naturalized streamflows, which are characterized by a number of statistical properties such as bias, seasonality and spatial and temporal correlation. Other options are to use time series obtained with a rainfall-runoff model or resorting to the use of stochastic models. In water planning, the usual practice is to analyse the system's operation over a long period of time under different hydrological conditions. However, because planning is performed for future needs, historical streamflow data will not be repeated, so it is justifiable to use statistical models for the generation of future scenarios of varying lengths (Solera et al., 2010b).

To estimate water availability, it is necessary to accept a hypothesis about how these natural streamflows will be presented, which will largely determine the results and conclusions. This paper proposes a twofold approach: a first analysis using a time series of naturalized streamflows and a second analysis employing synthetic streamflows. In the second case, a large number of stochastic time series equivalents to the naturalized ones are obtained with a stochastic generation model and then used as an input to the deterministic simulation model. In this way, it will be possible to evaluate the statistical properties of the considered options (Loucks and van Beek, 2005). The generation method employed in this study is the multivariate ARMA model (Box and Jenkins, 1976).

A2.2.2.2 Infrastructures

We consider infrastructures as all of the elements that allow water managers to operate or control the flow of water in the river basin. The most important elements are reservoirs, pumping wells and channels. As all models produce simplified representations of real-world systems (Sulis and Sechi, 2013), they must include the system's main features, such as rivers, reservoirs, aquifers, existing uses represented by the demand centres, hydraulic connections, the possibility of using returns and other unconventional resources, and the consideration or not of environmental constraints or operating rules.

To analyse water availability, a very important aspect to consider is the capacity to mobilize resources in the system. Therefore, we need to consider the existing level of technology at each moment in order to distinguish between conventional and unconventional resources. We define as conventional resources the amount of water regulated in reservoirs and groundwater pumping. Unconventional resources often include resources from direct reuse and desalination, but on account of being associated with the existing technology, these resources are a dynamic concept that varies with time. Moreover, the use of the returns of previous supplies represents a double use of water resources. This fact is essential in Mediterranean countries, where the majority of the available resources are used for irrigation, resulting in large volumes of returns. Equally important is the management of the operating system, defined as a set of operating rules for the water infrastructure system, representing another of the key aspects in the water availability. In this way, optimal water resource management can increase the availability of the system, while a deficient management inevitably reduces it.

A2.2.2.3 Demands

The purpose of water resources management is to satisfy a set of water uses. We can distinguish among several types of uses, each of which requires a certain amount of water at a certain time and place (Solera et al., 2010a). These uses may refer to environmental requirements, agricultural and urban demands, and hydroelectric and recreational uses.

Because streamflows are scattered throughout the basin, the water availability will vary depending on where water is needed. As noted by Bangash et al. (2012) water is typically allocated according to historical, institutional, political, legal, and social traditions and conditions. Likewise, if an allocation of water is assigned in a part of the basin, this allocation will modify the water availability in the rest of the basin. Furthermore, due to the seasonal variability of water resources and the limited capacity of system regulation, the allocation will vary if the demands are concentrated in different seasons.

Despite the regulation of the water resources system, we cannot be confident that all demands have satisfied their supply because it depends on the random nature of streamflows. Reliability measures the frequency or probability of success of the system by simply counting the number of days that the system was in a “satisfactory state” compared to the total simulation length (Asefa et al., 2014; Hashimoto et al., 1982); this method is traditionally used to judge whether the adoption of long-term corrective actions is necessary. Thus, having high levels of reliability means having less water resource availability and vice versa.

Two reliability criteria have been selected in order to assess the availability of water resources. The first criterion is the one established in the Spanish Statement of Water Planning (IPH, 2008), and the second is the efficiency indicators defined by Martín-Carrasco and Garrote (2007). The IPH (2008) indicates that for the purposes of resource allocation and reservation, urban demand is considered satisfied when the deficit in one month does not exceed 10% of the corresponding monthly demand and when in 10 consecutive years, the sum of deficits is less than 8% of the annual demand. Similarly, for the purposes of resource allocation and reservation, agrarian demand is considered satisfied when the deficit in one year does not exceed 50% of the corresponding demand; for two consecutive years, the sum of deficit does not exceed 75% of annual demand; and in ten consecutive years, the sum of deficit does not exceed 100% of the annual demand. On the other hand, the efficiency indicators used are (1) the demand-satisfaction index (I1), which evaluates the capability of the system to meet demand and (2) the demand-reliability index (I2), which assesses the reliability of the system to satisfy demand. The use of the efficiency indicators requires grouping the demands across several classes depending on their respective use of water. As noted in Chavez-Jimenez et al. (2013), the behaviour of the system is characterized according to the indicators I1 and I2. According to the values of I1 and I2, we can determine the intensity of the problems that can occur in the system (see Figure 2). More detailed information about the use of these indicators can be found in Martín-Carrasco and Garrote (2007).

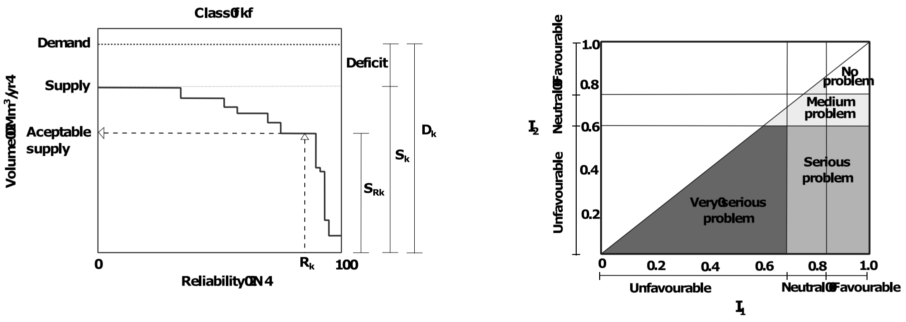

Figure 2. Demand-reliability curve (DR curve) (left) and diagnosis of severity of water scarcity problems according to indicator values I1 and I2 (right) (Chavez-Jimenez et al., 2013).

A2.2.3. CALCULATION PROCESS FOR DETERMINING THE EXPLOITABLE WATER RESOURCES

To measure water availability, the indicator of exploitable water resources will be used, which is determined as the maximum demand that can be served in a water exploitation system while complying with the reliability criteria established by law.

The steps used to obtain this indicator are as follows: (1) select a hypothesis about how to obtain the natural streamflows in the simulation model; (2) select the reliability criteria that allow us to consider the supply to be satisfied; (3) select all possible places in the system where new water allocations are likely to be required, apart from the existing demand centres; (4) define the type of use in these new places (urban use requires a uniform year-round supply, and agrarian use concentrates its supply during the harvest months) with a demand element in the simulation model; (5) using an iterative process, analyse the possibility of increasing a single demand in each step while considering the other demands as zero, execute the simulation model, and check if the adopted reliability criteria are met at each step; and (6) the final result is achieved when the maximum demand is obtained while fulfilling the required reliability criteria.

As explained in step (5) (see figure 3), the exploitable water resources are determined through an iterative process in which the model SIMGES is run with different water demand values, and the reliability criterion is analysed to compare the supply and demands. The monthly values for each demand are obtained by multiplying a definite temporal pattern (different for urban and agricultural demands) by a changing value (X). In the first iteration, X has to be a very high figure. If the reliability criterion is met when SIMGES is run, we accept the demand quantity as the exploitable water resources. However, if the reliability criterion is not met, a new demand is obtained using the bisection method until the highest demand that meets the reliability criterion is found, accepting an absolute error (E) of 0.05 hm^3/month. In the case study, the initial value for X was 200 hm^3/month, and 14 iterations were required to calculate the exploitable water resources of the system.

The results depend on the geographical area in which the demands are to be increased, either at the head of the system, in the middle section or at the mouth area, because any alteration of the system will affect the uses located downstream of such an alteration. Similarly, the timing of the use will also influence these results because it will be dictated by the type of use for which the resource is intended.

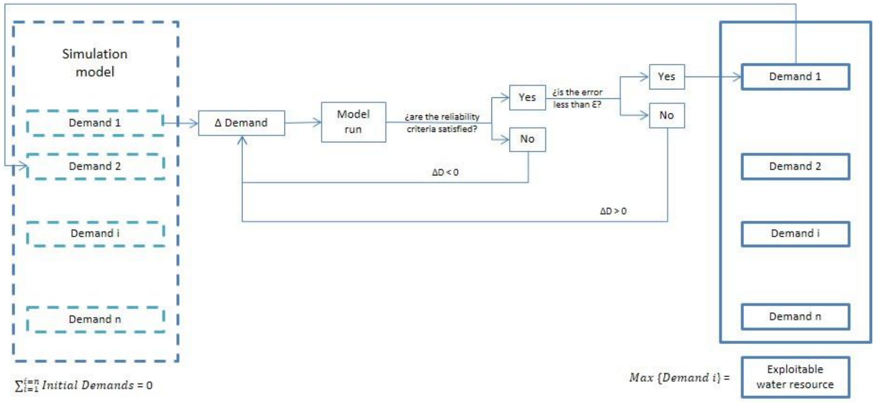

Figure 3. Iterative process

A2.3. CASE STUDY: THE JUCAR RIVER BASIN

A2.3.1. CHARACTERIZATION OF THE STUDY AREA

The Jucar River Basin is located in the eastern part of the Iberian Peninsula in Spain (see figure 4). This basin is the main principal water exploitation system of the 9 in the Jucar River Basin District, thus giving it its name. The Jucar River has a length of 497.5 km, traversing the provinces of Teruel, Cuenca, Albacete and Valencia, with its mouth at the Mediterranean Sea. Additionally, this water exploitation system includes the area and services provided by the Jucar-Turia Channel and the littoral sub-basins between the Albufera Lake and a location approximately 10 kilometres south from the mouth of the river. It is the most extensive system (22,261 km2) and provides the greatest amount of water resources in the Jucar River Basin Agency. A brief description of the study area and key issues is presented below; details can be found in Ferrer et al. (2012).

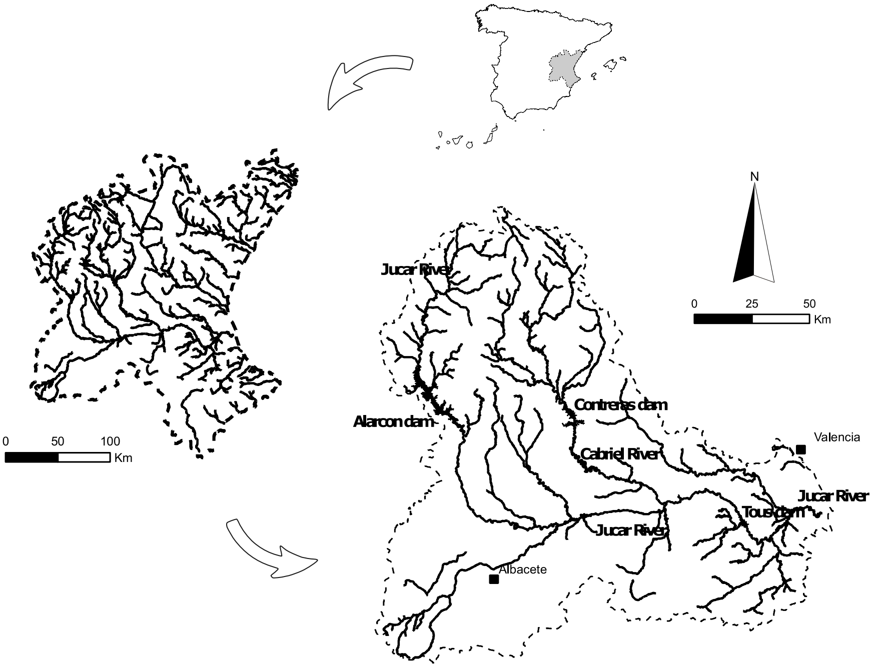

Figure 4. Location of the Jucar River Basin in the Iberian Peninsula

Physically, the Jucar River basin is described as an interior mountainous zone, with spots at high altitude and a coastal zone composed of plains. This means that 25% of the basin is at elevations over 1,000 m, while the remaining area is below this level (27% corresponds to plains below the Central plateau and 48% to plains on the Central plateau). Precipitation exhibits a high spatial variability (450 mm/year in the low basin and 630 mm/year in the north of the basin). The average precipitation is 510 mm/year, and the average temperature is 13.6°C. The average natural water resources reach 1,279 hm^3/year, representing the top limit of the renewable resources of the basin. The total population that depends on the Jucar River Basin presents a water demand of 127 hm^3/year, and the water demand for irrigated agriculture reaches 990 hm^3/year. The supply to urban areas comes mainly from wells and springs, but the Albacete, Sagunto and Valencia metropolitan areas use surface water. More details can be found in MAGRAMA (2013).

As shown in figure 5, comparing the total streamflows with the water demand for urban and agrarian use during an average hydrological year, we observe that consumptive uses and water resources are not synchronized in time. Water demands are concentrated in harvest months, while natural resources are slightly higher during winter and lower in summer. It is noteworthy that natural resources do not reduce dramatically in summer months because the Jucar River Basin is characterized by a strong interaction between surface water and groundwater. Because of this, the River Basin Authorities in charge of water management carry out a conjunctive use of surface and groundwater resources (Estrela et al., 2012). In recent decades, the environment has been an increasingly important issue. Therefore, sewage and wastewater treatment plants have been built and are in operation, including direct wastewater reuse after intensive treatment, increasing the water availability.

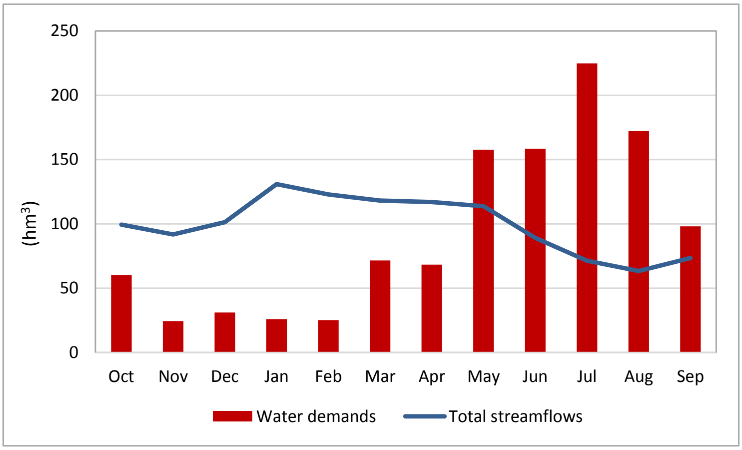

Figure 5. Total streamflows vs. water demands during an average hydrological year (1980/2008) for the Jucar River Basin. Source of data: Jucar River Basin Authority

Using the values of total natural resources (1,279 hm^3/year) and total water demands (1,117 hm^3/year) in the Jucar Water Resources System for the 1980/81-2008/09 period, a first indicator of the water balance in the system can be derived as the ratio between both values, resulting in a value of 0.87. This ratio represents a first approximation of the water exploitation index (WEI) as the ratio of total freshwater abstraction to total renewable resources. The closer this value is to 1, the greater the degree of exploitation of resources is indicated. This first indicator is not sufficient because it does not take into account agrarian returns, reuse from sewage treatment stations, or any transfers that may occur in the system. Nevertheless, it reflects the high degree of exploitation suffered by this system.

The Jucar water resources system is characterized by a marked reduction in the recorded streamflows during the 1980-2009 period (Pérez-Martín et al., 2013). Figure 6 depicts the system's total natural streamflow time series, obtained by naturalization of streamflows and used in the SIMGES simulation model employed by the Water Planning Office of the Jucar River Basin Agency. As the figure shows, there has been a significant reduction in natural streamflows throughout the past 30 years, clearly showing the existence of two periods, in which the difference between their averaged streamflows is close to 500 hm^3 per year. This fact confirms the need to differentiate among the analysis periods 1940-2009, 1940-1979 and 1980-2009.

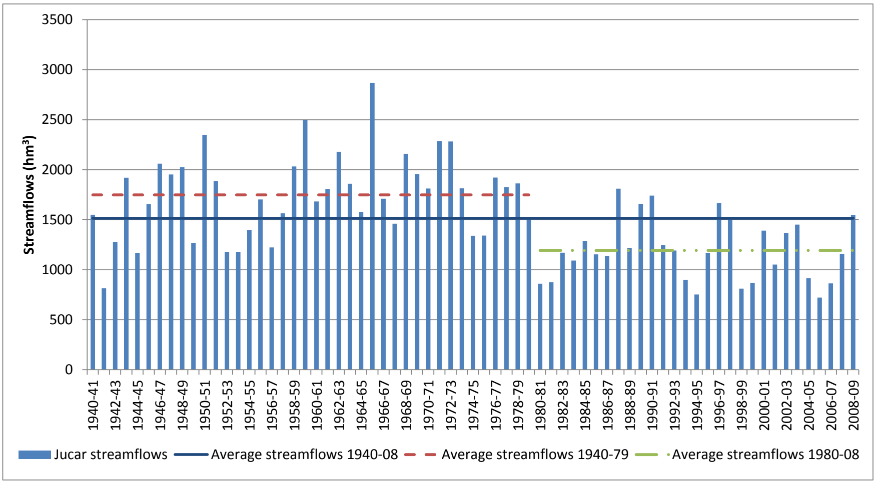

Figure 6. Total natural streamflow time series of the Jucar simulation model. Source of data: Jucar River Basin Authority

A2.3.2. SIMULATION MODEL FOR THE CASE STUDY

The first step is the construction of the simulation model for the Jucar water resources system for the current scenario. This model reflects the complex interaction among all elements in the Jucar water resources system and includes environmental requirements in order to obtain the exploitable water resources, taking into consideration the environmental objectives of the basin. To consider the current administrative concessions and operational constraints, this study draws on the SIMGES system simulation model of water resources (Andreu et al., 1996) from the DSS AQUATOOL.

Due to the special characteristics of the natural streamflows in the system, as described above, we must analyse the behaviour of the system depending on whether the simulation period covers a short period (1980-2009) or long one (1940-2009). For this reason, two multivariate ARMA stochastic models (Box and Jenkins, 1976) were calibrated using the historical data series. These models allow the generation of multiple stochastic streamflow scenarios with the same length as the historical ones. Thereby, we consider four types of streamflow time series: the naturalized streamflows during the period 1980/2008; the stochastic streamflow scenarios generated using the 1980/2008 stochastic model; the naturalized streamflows during the period 1940/2008; and the stochastic streamflow scenarios generated using the 1940/2008 stochastic model.

Based on geographical location, the exploitable water resources have been calculated at singular points in the Jucar water resources system. Figure 7 shows the scheme used to estimate the exploitable water resources, in which the detail and complexity of the system are identified. We have added to the original model five groups of demands scattered throughout the scheme, representing the strategic sites for system management. These sites correspond to the following:

- Alarcon Reservoir, located in Jucar River headwaters
- Contreras Reservoir, located in Cabriel River headwaters, tributary of Jucar River
- Molinar Reservoir. Despite not being a regulation reservoir, by locating a group of demands in this area we intend to determine the exploitable water resources in the middle reaches of the Jucar River before the incorporation of the Cabriel River.

- Tous Reservoir, located in the middle stretch of the Jucar River.
- The Huerto Mulet gauging station. This point has been selected in order to determine the water resources availability in the lower reaches of the river.

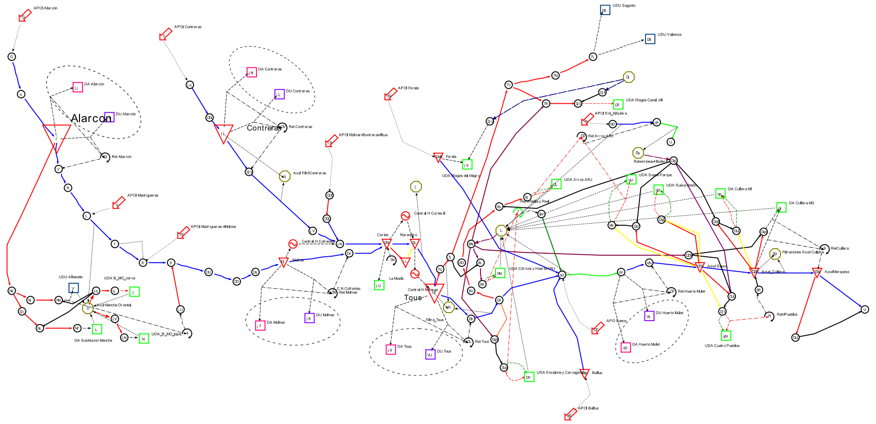

Figure 7. Jucar water resource system model used to estimate the exploitable water resources

From the point of view of the temporal distribution of water resources availability, each set of demands is composed of two elements, representing a hypothetical agricultural supply (DA) and an urban supply (DU), considering a single 20% return for agricultural use. Agricultural demands are a lower priority than the current priorities of mixed irrigation, and urban priority coincides with the priorities of the initial urban demands.

Two reliability criteria have been selected in order to assess the water availability; these include the criteria established in the Spanish Statement of Water Planning (IPH, 2008) along with the efficiency indicators defined by Martín-Carrasco and Garrote (2007); therefore, we have analysed 8 different possible combinations of the streamflow time series, the length of the simulation period and reliability criteria.

A2.4. RESULTS

The simulation model has been used to determine the water balance in the reference scenario. Table 1 shows the balance of the flows into and out of the system in the same referenced period (1980-2008). In this balance, we can perceive the different concepts employed in the model, such as resources, demands, supplies, return flows and outflows represented by average values.

WATER BALANCE OF THE JUCAR WATER RESOURCES SYSTEM (average annual values in hm^3)		**Series 1980/81-2008/09**	
RESOURCES	Inflows	1279.20	
	TOTAL RESOURCES		1279.20
DEMANDS	Agrarian	989.93	
	Urban	107.45	
	Industrial	20.00	
	TOTAL DEMANDS		1117.39
SUPPLIES	Surface water	704.20	
	Groundwater	399.40	
	TOTAL SUPPLIES		1103.59
	TOTAL DEFICITS		13.79
OUTFLOWS	Evaporation from reservoirs	81.76	
	Consumption and leaks	867.39	
	Outflows into the sea	158.24	
	Outflows into Albufera wetland	108.52	
	Transfers to Vinalopo River Basin	70.86	
	TOTAL OUTFLOWS		1286.77
VOLUME VARIATION	Reservoir volume variation	-41.39	
	Aquifer volume variation	33.83	
	TOTAL VOLUME VARIATION		-7.56

Table 1. Simplified water balance for the Jucar water resources system in the reference scenario

At this point, it would be more appropriate to refer to the results as the additional exploitable water resources because they represent the maximum demand on the system that could be supplied over the current demands, which meets the current reliability criteria required in Spanish River Basin Agencies (IPH, 2008).

Considering the geographical demand and the uncertainty of input data, a large disparity in the results can be observed. Figure 8 shows eight radial graphs representing the eight considered scenarios. Each of these graphs has 10 axes representing the new demands included in the simulation model and the calculated value of the additional exploitable water resources. The results generally show a greater availability of water resources for the long series due to the greater amount of natural resources. Moreover, the criterion used by the IPH (2008) is more demanding than the efficiency criteria because in all cases, the proceeds are greater. In addition, with the IPH 2008 criterion (IPH, 2008), the system is capable of delivering the same volume of resources in the middle and upper part of the basin, and this value increases in the lower reaches of the basin due to the high degree of exploitation in the system; however, when considering the efficiency criterion (Martín-Carrasco et al., 2007), the maximum resources are devoted to seasonal demand located at the headwaters of the Cabriel River (DA Contreras), where there are no existing demands.

With respect to the stochastic series, the figure shows the average value of the exploitable water resources and a band representing the confidence interval for the standard deviation. Thus, the water availability is affected by the reliability criteria and the length of the simulation period, as occurs with the results obtained from the historical data series calculated by naturalized streamflows. In the stochastic scenarios analysed for the short period, the results show a higher dispersion, and the standard deviation term is higher than the average value of the exploitable water resources. These charts allow the variability in the different simulated scenarios to be visualized, improving over the initial conclusions by adding a probabilistic component that considers the dispersion of exploitable water resources, as associated with a confidence interval.

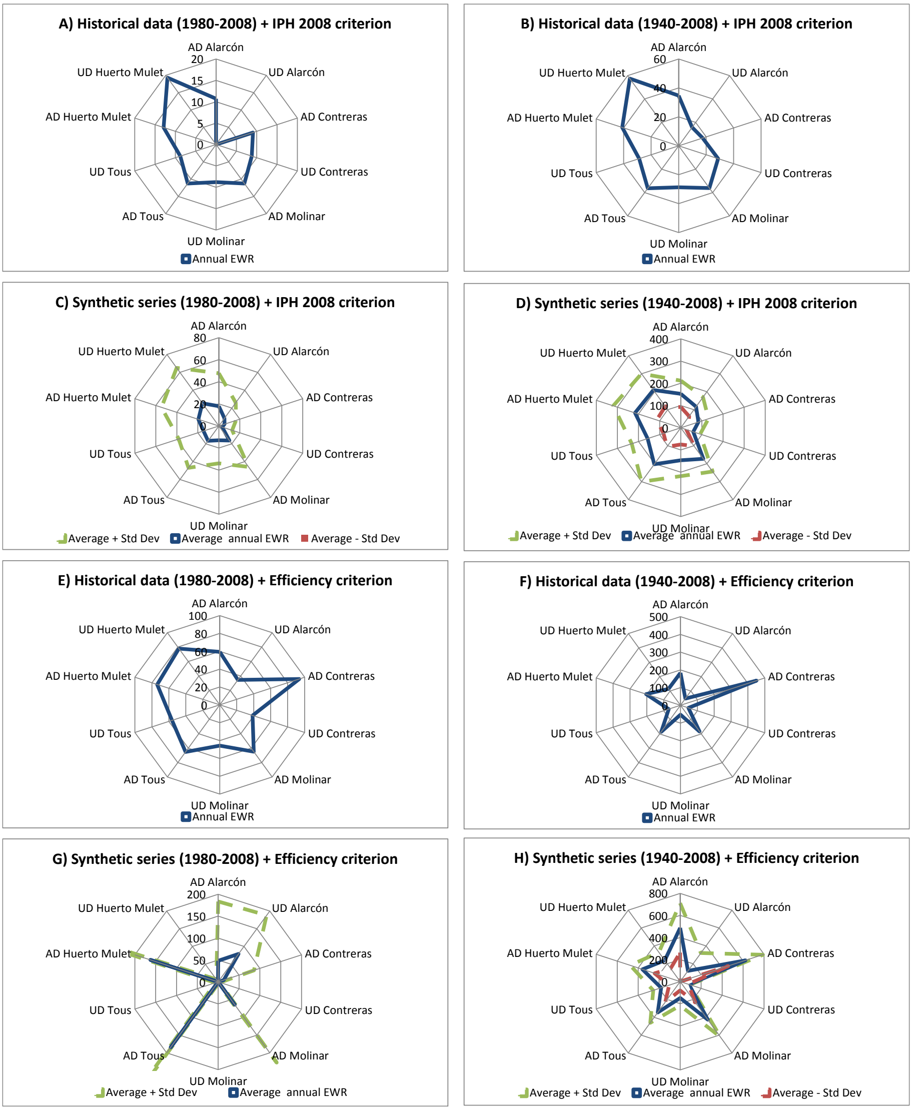

Figure 8. Location of additional exploitable water resources (hm^3/year) obtained for the considered scenarios. In the case of the stochastic streamflow time series, the figure shows the average of exploitable water resources and a band representing the confidence interval for the standard deviation [Average - Std Dev, Average + Std Dev] [UD means Urban Demand; AD means Agrarian Demand].

A2.5. DISCUSSION

Water availability has often been used in a broad context. As stated previously, this concept can be used in different senses: as precipitation, river flows and storage of water in snow and glaciers (EEA, 2009); by employing drought indexes (Lorenzo-Lacruz et al., 2010; Pérez-Blanco and Gómez, submitted for publication); or as water yield (Lange et al., 2007; Sun et al., 2002, 2005, 2006). Furthermore, water accounts have been developed in several countries (Evaluación de Recursos Naturales, 2013; Lange et al., 2007; Masih et al., 2009; van Dijk et al., 2014), and although each country has presented its account differently, there is a general agreement on the structure and scope of water accounting (Vardon et al., 2007).

The aim of this paper is to design a scheme for determining the exploitable water resources in a Mediterranean river basin, as an indicator of water availability. Knowing the water availability in a basin will aid planners in quantifying the growth potential in the exploitation of the system. Currently, new water policies are premised on the use of DSS (Bathrellos et al., 2012). DSS is a computer tool developed to help in the process of making decisions. Such methods are essential for the purpose of providing integration, sharing visions for conflict resolution and implementing sensitivity analysis and risk assessment (Andreu et al., 1996). Because this indicator is obtained as the maximum demand that can be satisfied in the water resources system using the current inflows (conventional and un-conventional water resources, transfers, etc.), it is necessary to use a model to improve the calculation and yield good decisions.

As we have seen, there are several aspects to take into consideration. First, a water balance based on average values is not enough because it masks shortage situations due to the variability in the timing of resource inputs to the system. Therefore, it is necessary to seek a management simulation that considers the temporal variability and limitations in infrastructures and regulation. In such an analysis, a monthly step time is usually sufficient because it adequately reflects the seasonal variability of rainfall and demands. Moreover, reliability criteria can be classified into two types by the way they get the fault. In the first group, the reliability is calculated using the average results obtained for a given period, and in the second group, the reliability is determined by the worst drought event. Therefore, reliability criteria compliance is highly relevant for the system because it can serve as a reference to decide whether a new allocation can be improved or an investment is necessary. In addition, in analysing the way we obtain natural streamflows for the simulation model, we must seriously consider the use of synthetic streamflows. This analysis has a long tradition of use in hydrology for temporal and spatial streamflow simulation, having been widely used as a tool for evaluating water resources systems under uncertain streamflow conditions (Rajagopalan et al., 2010), adding a probabilistic component to the analysis.

Thus, the calculation of the exploitable water resources for each combination of the three determinants considered for this case study (equiprobable natural resource estimations, length of the simulation period and reliability criteria used to consider the supply satisfied) requires iterative runs of the simulation model until obtaining the maximum allocation at the selected site that meets the selected reliability criteria by employing the natural streamflow time series considered.

Considering that we have generated 200 stochastic streamflow time series, we have identified 5 points of interest to determine the exploitable water resources in the river basin, and results are calculated using two reliability criteria, this yields a total of 57,000 determinations of the exploitable water resources, as shown in table 2. To make this calculation feasible, we have used a computation algorithm programmed using spreadsheet macros, which sequentially runs the simulation management model. Even with a fully automated process, the whole process required a computation time of 480 hours, although this time has been reduced by employing 3 computers.

Scenario	Type of series	Reliability criteria	Period Length	Number of simulations
A	Historical	IPH 2008	29 years	140
B	Historical	IPH 2008	69 years	140
E	Historical	Efficiency	29 years	140
F	Historical	Efficiency	69 years	140
C	100 stochastic series	IPH 2008	29 years	14,000
D	100 stochastic series	IPH 2008	69 years	14,000
G	100 stochastic series	Efficiency	29 years	14,000
H	100 stochastic series	Efficiency	69 years	14,000

Table 2. Number of SIMGES model runs

This assessment has been partially analysed in recent years, yielding a significant disparity in the results due to the difference in their approaches. Some examples include the distinct methodologies employed and compiled in document Three examples on water planning (MIMAM, 2000), the White Paper on Water in Spain (MMA, 2000) and the work carried out by the Centre for Public Works Studies and Experimentation (CEDEX) (2012). Additionally, water accounts have been applied in the Jucar River Basin District. Andreu et al. (2012) reported an application of General Purpose Water Accounting (Water Accounting Standards Board, 2009) to the Jucar Water Resources System. Furthermore, the Halt-Jucar-Des project has provided an opportunity to test the feasibility of applying SEEAW for determining water accounts in the Jucar River Basin District (Evaluación de Recursos Naturales, 2013).

The White Paper on Water in Spain (MMA, 2000) obtained a first approximation of the exploitable water resources for all River Basin Districts in Spain, under specific conditions, indicating the portion of the water resources that could be exploitable in natural conditions from within the amount of water resources that could be usable by building reservoirs. An interesting result obtained from this study was the fact that, in the case of the Jucar River Basin District, the volume of manageable resources without reservoirs, channels or pumping wells represents over the 34% of natural streamflows, the biggest percentage in the Iberian Peninsula, due to the existence of aquifers hydraulically connected with rivers in the basin. Furthermore, the use of dams to regulate water resources enables the exploitation of over 75% of streamflows.

The involvement of each of the key issues analysed in this paper explains the observed differences in the results of previous works related to this case study (CEDEX, 2012; MIMAM, 2000; MMA, 2000) due to the distinct approaches such as the use of optimization models (compared with the simulation model used here), the different locations of the available resources or the use of a reliability criterion based on the worst drought event. Accordingly, the key issues proposed here summarize all of these possibilities.

A2.6. CONCLUSIONS

In this paper we have analysed the key issues for determining the exploitable water resources, as an indicator of water availability, in a Mediterranean basin where emulating the hydrological cycle in the territory is insufficient. The Jucar

River Basin has been selected as case study and a calculation process has been carried out, from the general scheme presented, considering different criteria such as the origin of the streamflow time series, the length of the simulation period and the reliability criteria used to consider the demands satisfied. In view of the analyses performed, although some degree of uncertainty is always present, the results obtained show great variability. In many cases, this water resource availability is determined by hydrology, the infrastructure or the location of the current demands. It would be risky to provide a single value representing the exploitable water resources in the Jucar water resources system because, as it has been shown, the results depend crucially on the calculation methodology. Any changes in operating regulations of reservoirs and aquifers, the incorporation of new measures of wastewater reuse or resource sharing with other systems would require a new resource assessment and, consequently, yield different values of the exploitable water resources.

New water policies in the European Union are demanding more standardized management of water resources. Even so, the obtained results do not correspond exactly to those recommended by SEEAW (UNSD, 2012). Overall, a preliminary analysis of the key issues is important in the calculation of the exploitable water resources because as shown here, these preconditions will largely determine the results. In this sense, even the Blueprint to safeguard Europe’s resources (EC, 2012) recognises that the aquatic environments differ greatly across the EU and therefore does not propose a one-size-fits-all solution, in line with the principle of subsidiarity. It is necessary that policymakers and stakeholders make a decision about the methodology used to determine the water availability in a river basin. It is noteworthy that, in Spain, a large part of these methodological decisions (reliability criteria, natural streamflows time series, simulation models, etc.) are included in the Spanish Statement of Water Planning (IPH, 2008) with normative status guaranteeing consistency and comparability of the results.

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ANNEX 3. WATER ACCOUNTS AND WATER STRESS INDEXES IN THE EUROPEAN CONTEXT: THE JUCAR RIVER BASIN[3]

Abstract

Currently, water accounts are one of the next steps to be implemented in European River Basin Management Plans. One of the major handicaps lies on computing water resources availability as it depends on several factors, some of which are difficult to quantify. Building water accounts is a complex task, mainly due to the lack of common European definitions and procedures for calculating water availability. For their development, when data is not systematically measured, simulation models and estimations are necessary. The main idea of this paper is to obtain a general scheme to quantify water availability in a river basin and apply it in the European context of water planning. The Jucar River Basin, located in the eastern part of the Iberian Peninsula in Spain, has been taken as a study case. Overall, as the European Union consists of countries with different hydrology, emulating the hydrological cycle may not always be enough. Consequently, a possible procedure would be to incorporate all the elements necessary for determining water accounts within the hydrological models, or within water resources management models, or an intermediate solution.

Keywords

Jucar River Basin; water availability; drought indexes; exploitable water resources

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A3.1. INTRODUCTION

Currently, water accounts are one of the next steps to be implemented in the River Basin Management Plans in Spain [1]. In order to assess water resources, water accounts, defined by United Nations, have become a very powerful tool for improving water management, as they provide a method of organizing and presenting information relating to the physical volumes of water in the environment, water supply and economy [2]. The main interest of the System of Environmental-Economic Accounting for Water (SEEAW) [3] is to provide a standard approach and therefore the possibility to compare results between different areas [4]. In this sense, several indicators derived from the water accounts cover many critical aspects of water management under an Integrated Water Resource Management (IWRM) [3]. One of these water indicators is water resource availability.

Water availability has been often used in a broad context, when actually one of the major difficulties in water planning is determining the water availability in a basin with the aim of distributing it sustainably [5]. Many studies have used this concept in different senses: the European Environmental Agency (EEA) [6] considers precipitation, river flows and water storage in snow and glaciers as a measure of the availability of freshwater resources. While other authors have estimated the water availability by employing drought indexes [7] or the indicator of exploitable water resources [8]. Furthermore, Lange et al. [9] and Sun et al. [10] consider that regional water resource availability can be well described by water yield, defined as the difference between received precipitation and evapotranspiration, and Alcamo et al. [11] have developed the WaterGAP model to compute both water availability and water use on the river basin scale.

This concept is extremely important in Mediterranean countries. Historically, Spain, has suffered important drought periods that have caused severe impacts. Water scarcity and the frequent drought periods explain, in part, the ancient building tradition of hydraulic works in Spain [12].

The aim of this paper is to obtain a general scheme to assess water availability in a river basin, taking as study case the Jucar River Basin (Spain) whereas other Mediterranean basins it is currently water-stressed. In this sense, water accounts have been applied in the Jucar River Basin District in recent years. Andreu et al.

[13] reported an application of General Purpose Water Accounting [14] to the Jucar Water Resources System and also the Halt-Jucar-Des project [4] has provide an opportunity to test and check the feasibility of applying the SEEAW [3] to produce water accounts. From the above it follows that there is no unanimity in the methodology to determine water availability. It is necessary that policymakers and stakeholders make a decision about the methodology to determine water availability in order to include it in the policy review on water scarcity and droughts that is currently being carried out to be integrated into the “Blueprint to safeguard Europe’s water resources” [5].

The remainder of this paper is structured as follows. Section 2 lists the materials and methods used to describe water availability. This is followed by the case study in Section 3 where the methodology described is used. And finally, sections 4 discuss results and conclusions for future directions.

A3.2. MATERIALS AND METHODS

The main challenge in water accounting is related to the collection of the required data [1]. The hydrological cycle describes the movement of water in the Earth. The United Nations Statistics Division (UNDS) [3] describes it as a succession of stages: owing to solar radiation and gravity, water keeps moving from land to oceans into the atmosphere in the form of vapour and, in turn, falls back onto the land and oceans and other bodies of water in the form of precipitation. In this way, the importance of hydrological cycle lies on knowing how much water is available but, due to the difficulty of gauging the components of the hydrological cycle, the use of simulation models has become an essential tool extensively employed in last decades.

Generally, we can distinguish between two types of simulation models. The first ones are hydrological models which their main process constitutes on describing the hydrological cycle. As noted by Estrela et al. [15] these models estimate variables such as precipitation, snow, actual evapotranspiration, soil moisture, surface and groundwater runoff, aquifer recharge, volume storage in soils, etc. An example of this kind of model is Patrical Decision Support System (DSS) [16], which allows constructing hydrological cycle spatially distributed models, with monthly time step simulation; and it has been applied in different studies for the River Basin Management Plan in the Jucar River Basin District.

In the second group, we find the water resource management models, which may require the results obtained with a hydrological model as an input. This kind of model is used to assess the system behaviour for given scenarios. Their topology must include the main system features, such as rivers, reservoirs, aquifers, existing uses represented by the demand centres, hydraulic connections, the possibility of using returns and other unconventional resources, environmental constraints or operating rules [17]. An extended state-of-the-art review on simulation modelling approaches is given by Rani and Moreira [18].

We can notice that hydrological cycle simulation models enable us to assess the renewable water resources in a river basin. And water resources management models help us to know its water availability in each month of the simulation period, as they consider the existing technologies in place for abstraction, treatment and distribution of water [3] and their operating rules. In this sense, Patrical DSS will help us to analyse the influence of precipitation in the Jucar River Basin by applying several indexes such as the percent of normal precipitation and the standard precipitation index (SPI) [19]. Moreover, the monitoring of water resources in dam reservoirs will allow us to analyse the impacts of operational droughts in the water resources system.

A3.3. CASE STUDY: THE JUCAR RIVER BASIN

A3.3.1. DESCRIPTION OF THE BASIN

The Jucar River Basin is located in the eastern part of the Iberian Peninsula in Spain (see figure 1). This basin is the main, of the 9 principal water exploitation systems in the Jucar River Basin District, thus giving it its name. The Jucar River has a length of 497.5 km, traversing the provinces of Teruel, Cuenca, Albacete and Valencia, having its mouth at the Mediterranean Sea. It is the most extensive system (22,261 km^2) and with more water resources of the Jucar River Basin Agency.

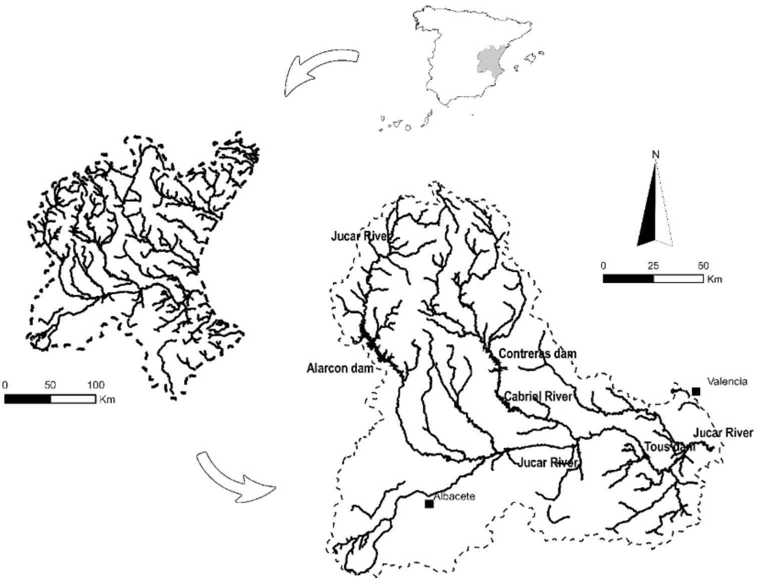


Fig. 1. Location of the Jucar River Basin in Iberian Peninsula.

Physically, the Jucar River Basin is described as an interior mountainous zone, with spots at high altitude and a coastal zone composed by plains. The average precipitation is 510 mm/year, and the average temperature is 13.6ºC. Average natural resources reach 1,279 hm^3/year that represent the top limit of the renewable resources of the basin. The total population depending on the Jucar River Basin represents a water demand of 127 hm^3/year and the water demand for irrigated agriculture reaches 990 hm^3/year. The supply to urban areas comes mainly from wells and springs, however Albacete, Sagunto and Valencia metropolitan areas use surface water. It is noteworthy that water demands are concentrated in harvest months; however, natural resources are slightly higher during the winter and go down in summer. Using the values of total natural resources and total water demands for the 1980/81-2008/09 period, a first indicator of the water stress in the system is deduced by the ratio between both values, resulting in a value of 87%. This ratio represents a first approximation to the water exploitation index (WEI) at the river basin level and it considers that a region is characterized as being under water stress, if the WEI exceeds 20%, and under severe water stress if it exceeds 40%. This first indicator is not sufficient, since it does not take into account agrarian returns, neither reuse of sewage treatment stations, nor any transfers that may occur in the system. Still, it reflects the high degree of exploitation suffered by this system.

A3.3.2. RESULTS

The most commonly employed variable for characterizing drought and consequently water availability is precipitation. The figure 2 shows the annual precipitation in Jucar water resources system for the period 1940-2009 obtained with Patrical DSS. As we can see, there has been a slight reduction in precipitation in the last 30 years. We can also see the indicator of percent of normal precipitation (PNP), considered as normal precipitation the annual average precipitation (over 510 mm/year). The main advantage of this index is that it is easily understood by the general public, and it recognizes droughts in preparatory phase before than other indexes. Among its disadvantages it is also noteworthy that this index considers a Gaussian distribution of rainfall, and another limitation arises when analyzing large regions in cohabiting both arid and wet lands.

From time series of monthly precipitation we have obtained the SPI [19]. It is considered that the system is in drought situation when the SPI value is less than or equal to -1, and the drought period is finished when SPI is positive again. According to Fernández [20], droughts can be classified according to this index: during a soft drought, SPI is in the range [0; -0,99], during a moderate drought, SPI is in the range [-1; -1,49], during a severe drought, SPI is in the range [-1,5; -1,99] and an extreme drought occurs if SPI is less or equal -2. The SPI has been calculated by adjusting the precipitation time series to a normal probability distribution.

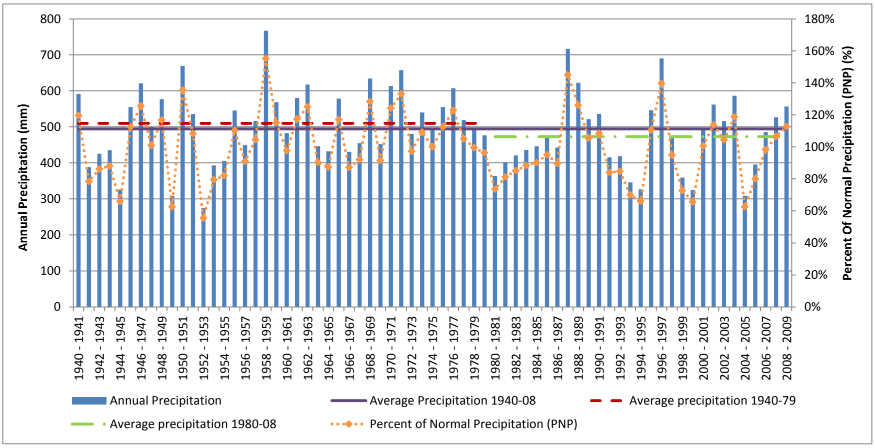
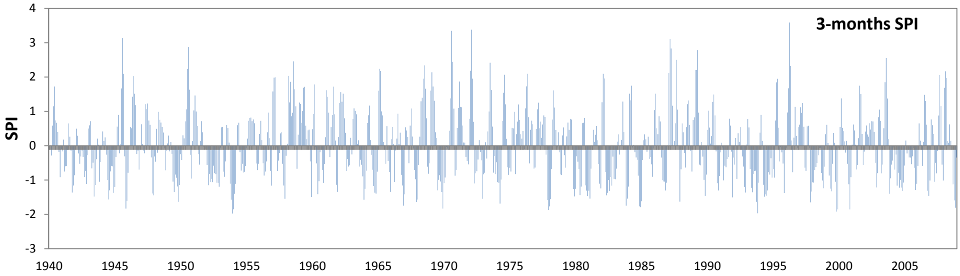
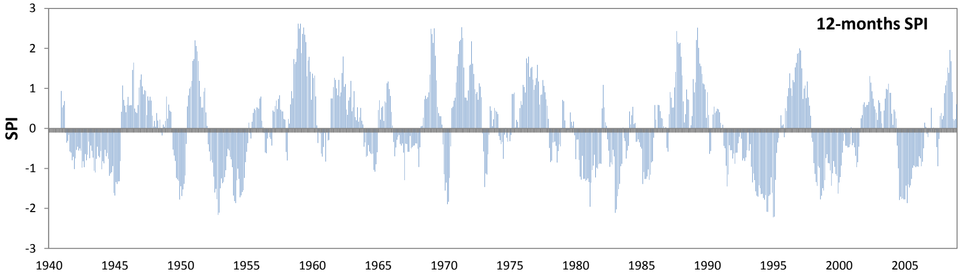


Fig. 2. Annual precipitation in Jucar water resources system for the period 1940-2008.

Figure 3 shows the evolution of the SPI over 3, 12, and 48 month intervals from 1940 to 2008. Specifying an aggregation period in defining drought is related to several basic characteristics of drought, as frequency and duration [21]. As the aggregation period is longer, the number of drought events is smaller, but these events are of longer duration. The figure shows that the longer period where the SPI is continuously negative over 48-month intervals is 1980/81-1986/87, whereas the SPI values for the same period indicates the existence of a moderate drought, while SPI over 3 month intervals indicates that the drought was extreme. The reason is that 3-month SPI is adequate for drought seasonal or short-term, 12-month SPI allows us to evaluate an intermediate drought, and 24, 36 or 48-month SPI is employed for long-term drought [21]. Moreover, the period 2004/05-2007/08 has been, so far, the most important period of drought that occurred in the Jucar River Basin. This circumstance is not directly visible in the figure, although a sequence of negative SPI is observed in this period. One aspect to be considered is the index spatial aggregation, as significant differences between recorded rainfall in headwaters and lower basins are common. A more detailed analysis would consider a regionalization that would help to characterize the spatial variability of rainfall in the river basin [21].





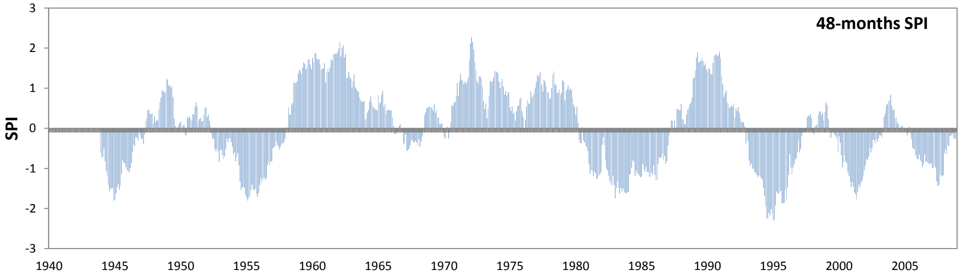


Fig. 3. Evolution of the 3-, 12- and 48-month SPI in the Jucar River Basin from 1940 to 2008.

SPI methodology can be applied to other sources of water in a water resources system as soil moisture, streamflows and storages in reservoirs [19]. The above indicators (PNP, SPI) do not consider the amount of current demands in the system. However, an indicator of operational drought itself takes into account the system needs, since it is based on data that are themselves influenced by the use made of water. A reduction of inputs results in a decrease in stored volumes, reaching more frequently the state of severe or extreme drought. A first indicator of operational drought index is the standard reserves index (SRI) [21]. This index shows the state of reserves in the system and helps explaining why in highly regulated systems, such as Jucar water resources system, in which occurs extreme drought conditions, they manifest less frequently but with a longer duration. The following chart shows the SRI in the Jucar water resources system in the main reservoirs (Alarcón, Contreras and Tous) for the period 1994/95-2008/09 once Tous reservoir became operational. It is possible to check the beginning and end of the drought periods as well as the severity levels reached according to SPI classification. As an example, the drought in the system during the period 2004/05-2007/08 was the more intense drought registered in the basin in the recorded history. But, comparing SPI and SRI results for the period 1999/00-2002/03, the charts show the existence of a severe meteorological drought but instead, the operational drought had no incidence in the system at all.

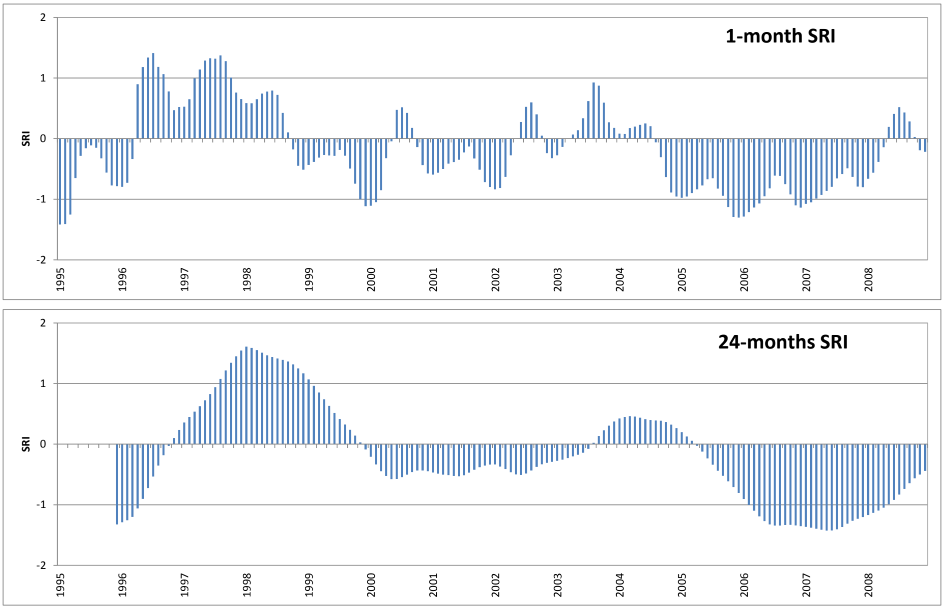


Fig. 4. Evolution of the 1-24 month SRI in the Jucar River Basin from 1995 to 2008

A3.4. DISCUSSION AND CONCLUSIONS

Worldwide studies have shown that the Mediterranean region is one of the most vulnerable areas to water crisis [22]. In this paper, several indexes have been applied in the Jucar River Basin to characterize meteorological (PNP, SPI) and operational droughts (SRI) and test their influence in water availability. Figures 3 and 4 have demonstrated that precipitation, despite being the most commonly employed variable for characterizing droughts, may not be enough. While in countries lacking water storages infrastructures, directly dependant on rainfall to supply water demands, a decrease in rainfall during some months or weeks can become a drought, in others, droughts can extend for years producing major impacts [12]. It is noteworthy that the European Union (EU) consists of countries with different physical characteristics, different hydrology, based on different productive sectors and differences both in infrastructure and demands. Not surprisingly, in the most vulnerable areas to water scarcity, it is common the use of non-conventional water resources. A clear example is the use of wastewater resources by the Member States shown in figure 5a. It is found that in countries like Spain or Italy wastewater resources are no longer seen as non-conventional resources due to its high level of implementation.

In view of these differences we have designed a general scheme for analysing water availability and consequently water accounts that should include the casuistry to justify the point of view of the EU. In figure 5b the process to obtain water availability begins with climate data, where rainfall and evapotranspiration are the main processes. This calculation continues trying to emulate the entire hydrological cycle, in which both, the estimation of the natural resources of the basin and its uses to characterize it are involved. Once the uses are known, it is possible to distinguish between natural uses and economic uses, and depending on the relationship of the latter and natural resources the WEI is obtained. Until now, that would be proposed from the EU, however, in countries like Spain, this approach is not enough.

Once renewable resources have been estimated, they are broken down between the surface runoff and groundwater. Moreover, demands can be quantified from economic uses. Depending on the characteristics of each river basin, these demands are only supplied with natural resources, or in most cases, it is necessary the operation of certain regulatory infrastructures and pumping wells that allow to use these resources when demands require it. Thus, it is no longer sufficient to consider only natural resources but it would be more appropriate to refer to these as conventional resources. Furthermore, these conventional resources could be not sufficient to serve the demands of the system; in this case we should refer to the use of non-conventional resources (wastewater reuse, desalination, transfers) which will guarantee the supplies. These two terms have been grouped by the term "generated resources" that can vary depending on the horizon scenario analysed.

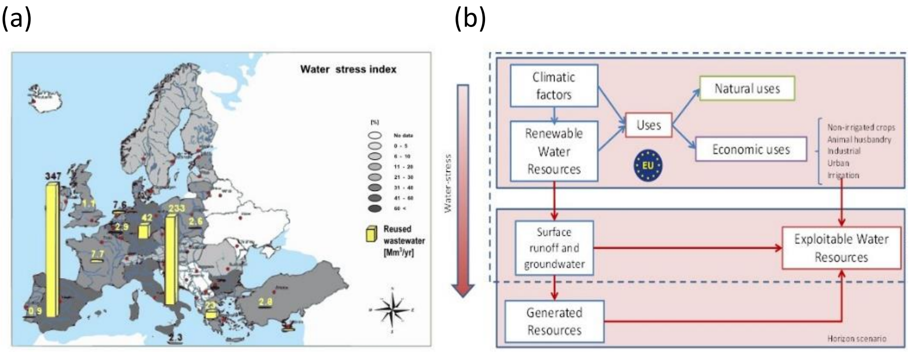

(a) (b)

Fig. 5. (a) Wastewater reuse in European Union [23]; (b) Proposal for a general scheme for the study of water availability.

Finally, water availability can be described by the use of the indicator of exploitable water resources, defined as the part of the water resources considered to be available for development under specific technical, economic and environmental conditions [3] and obtained as the maximum demand that can be served by the system satisfying the officially established guarantees and the environmental requirements [8]. To do this, emulating the hydrological cycle is not enough, and it is essential to use water resource management models. In this sense, it is necessary that EU water policies define the methodology to determine this indicator since different aspects relating to the scenario definition must be taken into consideration such as the topology, the quantification of the natural resources and the reliability criteria to know whether the demands are satisfied ([8], [17]).

These two approaches represent the two extremes in the casuistry of analyzing problems within the context of water resources. We can find cases involving both problems and even cases where the situation analyzed is in an intermediate state between both. A good procedure would be to incorporate all the elements and variables necessary for the exercise of building water accounts within hydrological models or within management models; or a mixed intermediate solution [4]. This approach needs an objective criterion for the selection or classification of water resources systems in either band of the problem that is outlined in the figure 8. In this situation, the first step may be to conduct a preliminary classification of the regions that comprise the EU in order to apply different methodologies that are appropriate to the physical and socioeconomic characteristics of each Member State. It is crucial that policymakers and stakeholders make a decision about the methodology to determine water availability in order to include it in the policy review on water scarcity and droughts that is currently being carried out to be integrated into the “Blueprint to safeguard Europe’s water resources” [5]. It is noteworthy that, in Spain, a large part of these methodological decisions are included in the Spanish Statement of Water Planning [24] with normative status guaranteeing consistency and comparability of the results.

Acknowledgements

The authors wish to thank the Confederación Hidrográfica del Júcar (Spanish Ministry of the Environment) for the data provided in developing this study and the Spanish Ministry of Economy and Competitiveness for its financial support through the projects SCARCE (Consolider-Ingenio 2010 CSD2009-00065) and NUTEGES (CGL2012-34978). We also value the support provided by the European Community's Seventh Framework Program in financing the projects DROUGHT-R&SPI (FP7-ENV-2011, 282769), ENHANCE (FP7-ENV-2012, 308438), WAMCD (EC-DG Environment No. 07.0329/2013/671291/SUB/ENV.C.1) and LIFE ALBUFERA (LIFE12 ENV/ES/000685).

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ANNEX 4. THE USE OF AQUATOOL DSS APPLIED TO THE SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING FOR WATER (SEEAW)[4]

Abstract

Currently, water accounts are one of the next steps to be implemented in European River Basin Management Plans. Building water accounts is a complex task, mainly due to the lack of common European definitions and procedures. For their development, when data is not systematically measured, simulation models and estimations are necessary. The main idea of this paper is to present a new approach which enables the combined use of hydrological models and water resources models developed with AQUATOOL Decision Support System (DSS) to fill in the physical water supply and use tables and the asset accounts presented in the System of Economic and Environmental Accounts for Water (SEEAW). The case study is the Vélez River Basin, located in the southern part of the Iberian Peninsula in Spain. In addition to obtaining the physical water supply and use tables and the asset accounts in this river basin, we present here the indicators as a result thereof. These indicators cover many critical aspects of water management, showing a general description of the river basin and allowing decision-makers to characterize the pressures on water resources. As a general conclusion, the union of AQUATOOL DSS and SEEAW will provide more complete information to decision-makers and enables to introduce these methodological decisions in order to guarantee consistency and comparability of the results between different river basins.

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Keywords

Water accounts, System of Environmental-Economic Accounting for Water (SEEAW), AQUATOOL, water resources systems

A4.1. INTRODUCTION

One of the main challenges in the XXI century is related with the sustainable use of water. This is due to the fact that water is an essential element for the life of all who inhabit our planet. In many cases, the absence of a rational water use is due to the lack of economic valuation of water resources. To improve this situation, first, the EU Water Framework Directive (WFD) (EP, 2000) established a framework for the Community action in the field of water policy. Its main objectives included expanding the scope of water protection to all waters in order to achieve their "good status", a water management based on river basins, the implementation of pricing policies and the promotion of public participation, among others. The Member States were required to implement the WFD by the river basin management plans, which had to include a description of the river basin, an inventory of water resources and demands, a register of protected areas, the regime of environmental flows, the water exploitation systems and their water balances, an inventory of pressures, the environmental targets, cost recovery, the programme of measures and the public participation. The Blueprint to safeguard Europe's water resources (EC, 2012) represents another turn of the screw towards an improvement in terms of quality and quantity of water resources. The Water Blueprint presents a three-tier strategic approach by improving the implementation of current European Union (EU) water policy; jointly analysing water policy objectives with the economic growth of other economic sectors such as agriculture, fisheries, renewable energy or transport; and improving significant aspects of the WFD related to water efficiency. To this end, water accounts are presented as a tool to achieve the objective of water efficiency. One of the targets of water accounting is, in addition to comparing results between different territories, to measure the contribution of each water user to the overall economic value of water resources in order to identify real potential water savings (Ward and Pulido-Velázquez, 2008; Dumont et al., 2013; Tilmant et al., 2015).

Currently, water accounts are one of the next steps to be implemented in the River Basin Management Plans (Hunink, 2014). In order to assess water resources, water accounts, defined by United Nations Statistics Division (UNSD), have become a very powerful tool for improving water management, as they provide a method of organizing and presenting information relating to the physical volumes of water in the environment, water supply and economy (Vardon et al., 2007). As noted by Molden and Sakthivadivel (1999), their methodology is based on a water balance approach where, based on conservation of mass, the sum of inflows must equal the sum of outflows plus any change in storage. The System of Environmental-Economic Accounting for Water (SEEAW) (UNSD, 2012) is displayed as a tool for water allocation which enables the building of water balances in a river basin. The main concern of the SEEAW is to provide a standard approach which allows policymakers to compare results between different territories and periods. But one of the weaknesses of this approach is that environmental requirements are not explicitly considered and, it is worth noting that the introduction of environmental flows may affect the existing uses in the basin. As observed, building water accounts is a complex task, mainly due to the lack of common European definitions and procedures and the difficulty of the collection of the required data. As noted by Tilmant et al. (2015), although the SEEAW is increasingly adopted, there is no unified procedure to establish water accounts, nor there is an agreement on how water accounts must be presented. Dimova et al. (2014) also indicate that although the SEEAW concepts are relatively simple, its implementation requires collecting a variety of data from numerous actors and stakeholders. Due to the difficulty of gauging the components of the hydrological cycle, the use of simulation models has become an essential tool extensively employed in last decades.

This research is framed within the Water Accounting in a Multi-Catchment District (WAMCD) project, financed by the European Union. Its main goal is the development of water accounts in the Mediterranean Andalusian River Basin District, in Spain. To achieve this goal, the study draws on several modules from AQUATOOL Decision Support System (AQUATOOL DSS) (Andreu et al., 1996), which enables the building of a water cycle simulation model and a water resources management model in order to create a database to assist the building of the physical water supply and use tables and the asset accounts presented in the SEEAW.

A4.2. MATERIALS AND METHODS

Water resources systems analysis comprises all the necessary elements to describe a river basin (Pedro-Monzonís et al., 2015a). It consists of the analytical study of the water resources in a river basin in order to help decision makers to identify and choose one alternative from other possible ones. Water planning and the Integrated Water Resources Management (IWRM) represent the best way to achieve this goal.

A4.2.1. SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING FOR WATER (SEEAW)

The SEEAW has been developed by the UNSD in conjunction with the London Group on Environmental Accounting (UNDS, 2012). Its main objective has been standardizing concepts related to water accounting, providing a conceptual framework for organising economic and hydrological information. In this sense, water accounts generally, and particularly the SEEAW, expect to become a useful tool for helping on the decision-making process on issues of allocating water resources and improving water efficiency.

SEEAW framework considers the flows between the environment and the economy. The inland water resource system is comprised by surface water, groundwater and soil water; in relation to the economy, it is represented by abstractions, imports, exports and returns of the most relevant economic agents (households, the industry involved in the collection, treatment and discharge of sewage, the industry involved in the collection, treatment and supply of water to households, industries and the rest of the world and other industries which use water in their production process). SEEAW tables related to water resources are organised in flow accounts or asset accounts according to whether they represent the water flows in physical units within the economy and between environment and the economy, or they measure stocks at the beginning and the end of the accounting period. This is further discussed in section 2.3. The classification of industrial economic activities traditionally used in SEEAW is the International Standard Industrial Classification of All Economic Activities (ISIC) (UN, 2008), although the economic uses could be classified according to the river basin main economic sectors.

A4.2.2. AQUATOOL DECISION SUPPORT SYSTEM SHELL

AQUATOOL (Andreu et al., 1996) is a user-friendly DSS widely employed by Spanish River Basin Authorities, as well as in other countries (e.g., Chile, Italy, Morocco, among others). This DSS consists of several modules allowing the analysis of different approaches in water resources systems. A brief description of the modules used in this research is presented below.

A4.2.2.1 EVALHID module

EVALHID (Paredes-Arquiola et al., 2012) is a module for the development of rainfall-runoff models in complex basins and which evaluates the amount of water resources produced. The module consists of several types of models that can be chosen depending on the available data, the complexity of the basin and the user's experience in the development and calibration of hydrological models. All available models are aggregated with semidistributed application at sub-basin scale.

The HBV model (Hydrologiska Byråns Vattenbalans-avdelning) (Bergström and Forsman, 1973) has been used in the case study. It consists of eight parameters and three state variables. The general processes of the version used of HBV model are illustrated in the figure below. This includes a module that processes the data of precipitation as rainfall or snow based on the temperature in each time step. Rainfall and melting snow are processed into the soil moisture form where the effective precipitation contributing to runoff is evaluated. The remainder of precipitation contributes to moisture on the ground, which in turn may evaporate if the content of water present within the ground is large enough. The main output of the model is total runoff in the drainage point of the basin, which consists of three components: direct runoff, interflow (fast discharge plus slow discharge) and baseflow (see figure 1). Additional information related with the HBV model can be found in Götzinger and Bárdossy (2007).

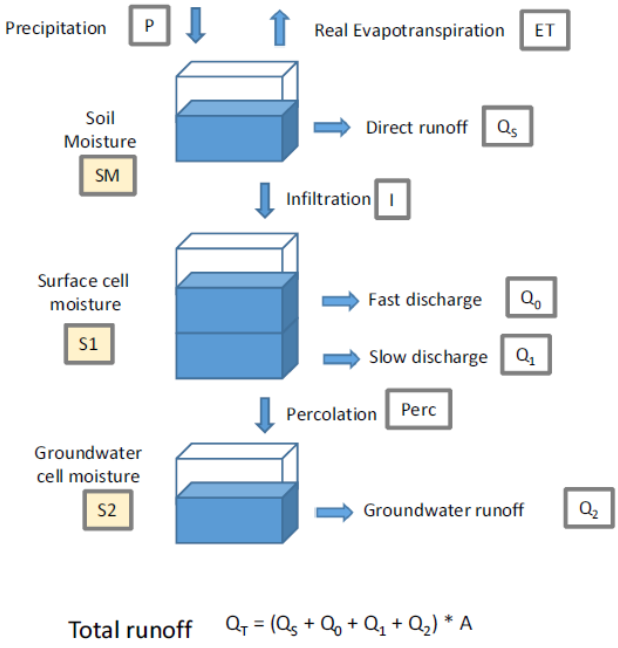

Figure 1. Schematic flow and storage of HBV model

Broadly, the necessary data for each sub-basin are the corresponding area, precipitation (P) and potential evapotranspiration (PET) time series data. The two latter ones have been obtained by using the database of Spain02 (Herrera et al, 2012), which is formed by a rough grating of 20 km2, covering the surface of Spain. This database provide the time series data of maximum and minimum air temperatures and precipitation, both with daily and monthly scale aggregation, for the period 1950-2008. As noted by Vangelis et al. (2013), since precipitation and air temperature data are the only readily available data, PET was obtained by the Hargreaves method (Hargreaves and Samani, 1985).

A4.2.2.2 SIMGES module

The SIMGES module (Andreu et al., 1996) can simulate the water resources system, on a monthly time scale, by a simple flow balance in a flow network in order to find a flow solution compatible with the defined constraints. It considers the aquifers and the relations between river and aquifer, the returns to the surface system and the infiltration to the groundwater, the evaporation and infiltration loses from reservoirs, the energy production from hydropower stations, the definition of environmental flows as well as different water use priorities. Moreover, the SIMGES module allows us to define operating rules to reproduce source-demand interactions that can help improving integrated river basin management.

A4.2.3. COMBINED USE OF AQUATOOL DSS AND SEEAW

To construct SEEAW tables, we have used a rainfall-runoff model which has been built with EVALHID module. The results are the time series of real evapotranspiration, soil storage, and infiltration, among others. So, once we select the corresponding hydrological year or period of years, we are capable of building SEEAW tables. In order to include the human actions during the planning and management of the water exploitation system, we have used EVALHID results in combination with SIMGES module. The time series of streamflows obtained with EVALHID have been introduced in a SIMGES model, and we obtain results related to water allocation such as water transfers, evaporation in reservoirs, reserves or outflows to the sea, among others, that can be managed by technicians. A scheme of this approach is shown in figure 2.

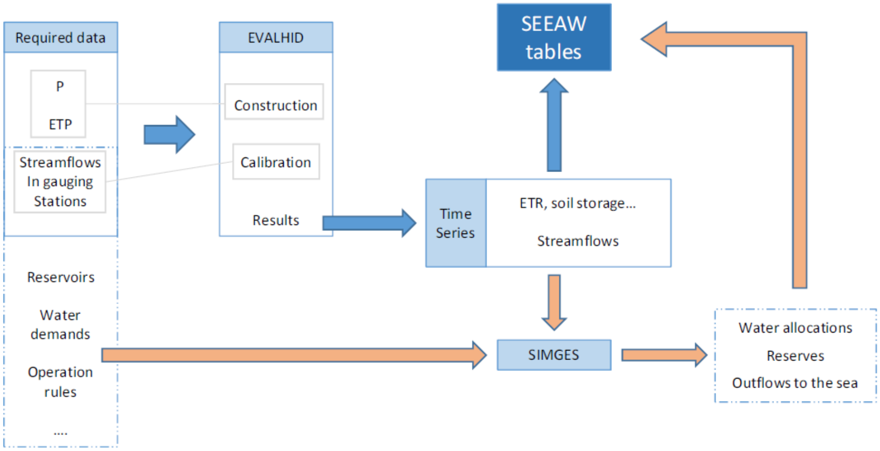

Figure 2. Process to obtain SEEAW tables by using EVALHID and SIMGES tools (Source: EC (2015))

We have developed an acquisition tool consisting of a database linked with SIMGES and EVALHID models, which enables the building of water asset accounts, matrix of flows between water resources and physical water supply and use tables at monthly scale in any month of the simulated period (1950/51-2006/07). Both programs work on a database and their results can also be dumped into the SEEAW database. All data and results are linked with their correspondent element and every element is linked with the type of elements they represent in the system. Note that each element may have several results, e. g. some of the results of a reservoir are volume, evaporation, and filtrations. In order to obtain the accumulated results in the required format of SEEAW tables, it has been necessary the building of several database queries which are linked with several spreadsheets where the tables are finally built.

Water asset accounts (see table 1) measures stocks at the beginning and at the end of the accounting period and record the changes in stocks that occur during that period due to natural causes (precipitation, evapotranspiration) and human activities (abstractions, returns). On the other hand, matrix of flows (see table 2) describes exchanges of water between water resources, providing information on the origin and destination of flows in the territory. It assists in identifying the contribution of groundwater to the surface flow as well as the recharge of aquifers by surface runoff. In both tables, the source information of each cell may come from EVALHID and/or SIMGES models.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks	▥	░	■	▤	▦	▤	
Increases in stocks		░					
2. Returns	▥	░	▥	■	▥	■	
3. Precipitation	■	░	■	▤	■	▤	
4. Inflows		░					
4.a. From upstream territories		░				■	
4.b. From other resources in the territory	▨	▨	▨	▨	▨	▨	
Decreases in stocks		░					
5. Abstraction	▥	░	▥	■	▥	■	
6. Evapotranspiration/actual evapotranspiration	▥	░	■	■	■	▤	
7. Outflows		░					

7.a. To downstream territories	🟦	░		⬛		⬛	
7.b. To the sea	⬛	░	🟦	⬛	🟩	⬛	
7.c. To other resources in the territory	🟧	🟧	🟧	🟧	🟧	🟧	
8. Other changes in volume		░					
9. Closing stocks	🟦	░	⬛	🟩	🟪	🟩	

Table 1. Water asset accounts (hm³) [Blue cells with an horizontal pattern style indicate these data come from SIMGES model, green cells with a vertical pattern style indicate these data come from EVALHID model, pink cells with a grid pattern style indicate these data come from EVALHID and SIMGES models. Orange cells with sloped pattern style indicate these data come from the matrix of flows between water resources table.]

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA. 1311 Artificial reservoirs	⬛	░	🟦	⬛	🟦	⬛	🟧
EA. 1312 Lakes	░	░	░	░	░	░	🟧
EA. 1313 Rivers	🟦	░	⬛	⬛	🟦	⬛	🟧
EA. 1314 Snow, ice and glaciers	⬛	░	⬛	⬛	⬛	🟩	🟧
EA. 132 Groundwater	⬛	░	🟪	⬛	⬛	⬛	🟧
EA. 133 Soil water	⬛	░	🟩	⬛	🟩	⬛	🟧
Inflows from other resources in the territory	🟧	🟧	🟧	🟧	🟧	🟧	

Table 2. Matrix of flows between water resources (hm³) [Blue cells with an horizontal pattern style indicate these data come from SIMGES model, green cells with a vertical pattern style indicate these data come from EVALHID model, pink cells with a grid pattern style indicate these data come from EVALHID and SIMGES models. Orange cells with sloped pattern style indicate these results are used in water asset accounts table.]

The physical use table is divided into two parts: the first part describes flows from the environment to the economy (such as water abstraction) and the second part describes flows within the economy (such as water received from other economic units). Likewise, the physical supply table is also divided into two parts: the first part describes the flows of water within the economy (such as the supply of water to other economic units) and the second part describes flows from the economy to the environment (such as returns of water into the environment). These are the classification of the economic water uses in these tables: urban, farming, cattle raising, recreational and rest of the world. This classification differs from the ISIC (UN, 2008) and is adapted to the main economic features of the river basin, where agrarian and touristic uses are the principal ones. Note that each cell in physical use and supply tables comes from SIMGES model.

A4.3. CASE STUDY: THE VÉLEZ RIVER BASIN

A4.3.1. CHARACTERIZATION OF THE STUDY AREA

The Vélez River Basin is located in the southern part of the Iberian Peninsula in Spain (see figure 3). This river basin is managed by the Mediterranean Andalusian Basin’ River Basin District (MAB RBD) which includes up to 16 subsystems (or exploitation systems). The Vélez River is included in the subsystem II.1 and it has a length of 68 km, traversing the province of Malaga. Its main tributaries are Benamargosa, Guaro, Alcaucín, Bermuza, Almanchares and Rubite rivers. The climate is subtropical Mediterranean with an average precipitation of 630 mm/year, and an average temperature of 16ºC. There is a progressive transition to a maritime Mediterranean climate as we move up to the peaks further north (García-Aróstegui et al, 2007). The hydrological regime is determined by the artificial reservoir of La Viñuela, which was completed in the mid-nineties of the last century. This system includes La Viñuela reservoir (with a capacity of 173 hm^3) and eight diversion dams to transfer the surplus flows of the basin to the reservoir. These reserves are assigned to the supply of agrarian and urban demands. In the final part of the Vélez River Basin is located the Río Vélez-060.026 groundwater body (Río Vélez GWB in figure 3). This GWB is comprised of a single detrital aquifer made up of Quaternary deltaic and alluvial sediments with an average thickness of 30 m which reaches maximums of approximately 60 m in the central part—confluence of the Vélez and Benamargosa rivers—and in the deltaic sector (Benavente et al, 2005). The hydrogeological behaviour of Río Vélez GWB is conditioned by La Viñuela Reservoir and the diversion dams, since they affect the recharge of the aquifer, and reduce considerably the vertical aquifer thickness (6 m), at 4 km from the coast, dividing the aquifer into a fluvial sector upstream and a coastal (deltaic) sector downstream (Benavente et al, 2005). When an important period of groundwater exploitation occurs, this latter feature can be advantageous, from a hydrogeological point of view, as it inhibits the saltwater wedge from intruding inland (Lentini et al, 2009).

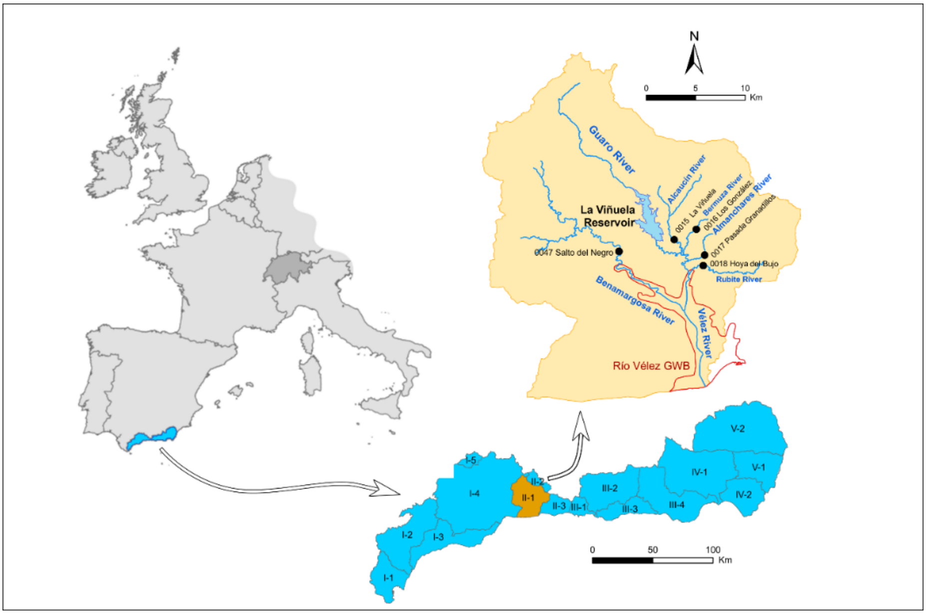

Figure 3. Location of the Vélez River Basin in the Iberian Peninsula

A4.3.2. MODELLING THE VÉLEZ RIVER BASIN BY USING AQUATOOL DSS

The first step for modelling the Vélez River Basin is the obtention of the streamflow data series from the rainfall-runoff model. The election of the calibration points has been determined by the availability and length of records in gauging stations and reservoirs. It was performed in 6 points of the Vélez system: La Viñuela Reservoir, EA 0015 La Viñuela, EA 0016 Los González, EA 0017 Pasasda Granadillos, EA 0018 Hoya del Bujo and EA 0047 Salto del Negro. Each of these gauging stations is located in the tributaries of the Vélez River. With regard to the time period used for calibration, we have reserved the first two hydrological years as warm-up period to minimize the effect of initial moisture conditions, and the last three available years are used for validation. Furthermore, the calibration period finishes in 1992 when several transfers started operation in the basin, so the alteration of gauging stations became obvious. A Visual Basic adaptation to the SCE-UA algorithm (Duan et al., 1992) has been used to import the results from EVALHID streamflows to compare with the series of observed inputs and evaluate an objective function that represents a numerical measure of the difference between the simulated response of the model and the response observed in the basin. The degree of adjustment between the observed values and the simulated ones is measured by a graphic display and the use of objective functions whose minimization is the foundation of techniques of automatic calibration parameters. The objective function used is the average of the following functions: Nash-Sutcliffe index, Nash Neperian logarithm, Pearson correlation coefficient and Average of the symmetry of the adjustment between average simulation and average observation.

Once the streamflow data series have been obtained, the next step is to introduce them in the water resources management simulation model with all the required data related to reservoirs, water demands, operation rules and environmental requirements. The latter are included as minimum flows and they are based on habitat modelling assessment, hydrological criteria and expert recommendations for the saturation of the alluvial aquifer. Figure 4 shows the scheme of the simulation model that has been built for the current scenario with SIMGES module. This model reflects the complex interaction among all elements in the system.

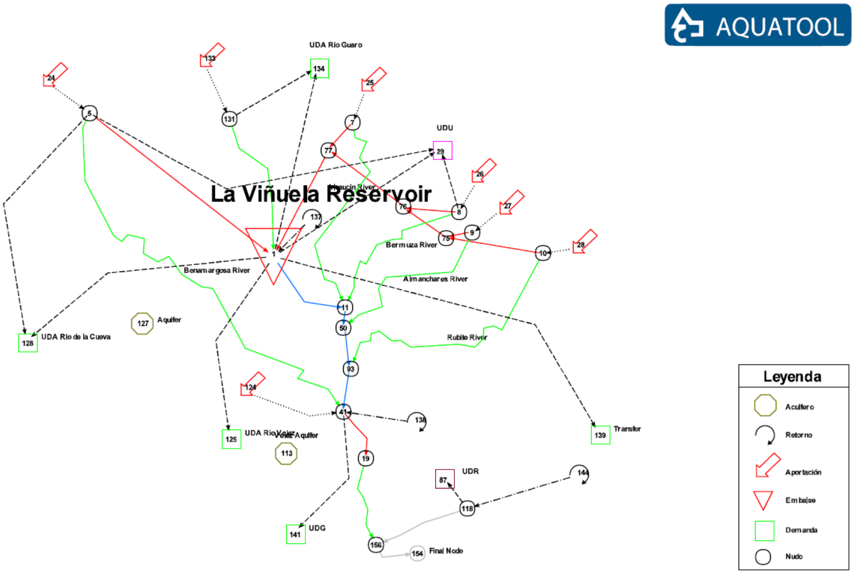

Figure 4. Scheme of the simulation model of Vélez River Basin [UDA means farming demand; UDU means urban demand; UDR means recreational demand and UDG means cattle raising demand]

A4.4. RESULTS

A4.4.1. RESULTS FROM EVALHID MODULE

EVALHID results have allowed us, on the one hand, to obtain the streamflow data series which will be used in the SIMGES model and, on the other hand, to fill in the SEEAW tables that information related to the components of the hydrological cycle which cannot be physically measured. The latter include actual evapotranspiration (ET), soil storage, infiltration to aquifers (Inf), discharge from soil to surface waters (Groundwater runoff) and discharge from aquifers to surface waters (Surface runoff). Figure 5 shows the average value of the main components of the water cycle in the average year of the period 1980/81-2006/07. As it is shown, Vélez River Basin presents warm winters and hot, dry summers; PET increases during harvest months, just when P is lower. Therefore, ET will depend on the availability of water in the basin. Table 3 shows the main statistics for each streamflow element which will be used in the simulation model.

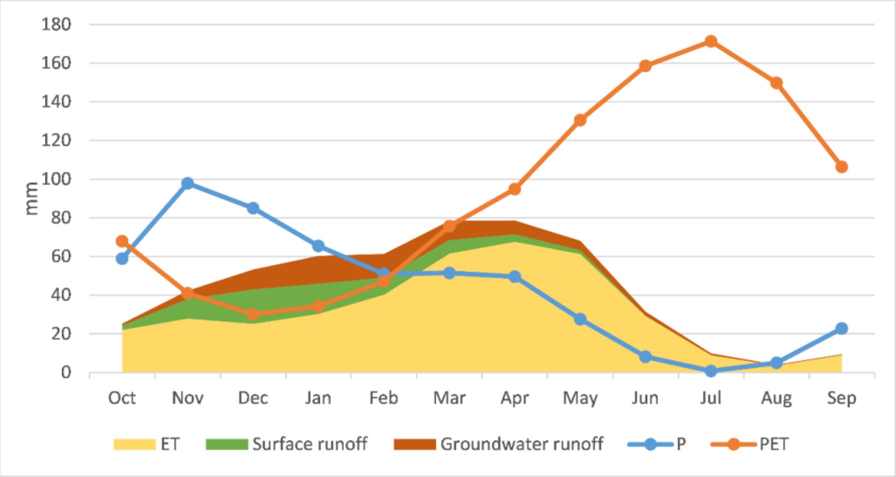

Figure 5. Representation of inputs and outputs of the EVALHID model for the Vélez River Basin (period 1980/81-2006/07)

La Viñuela Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.9	4.1	6.6	5.8	3.6	3.0	1.6	0.9	0.2	0.0	0.0	0.0	26.7
Standard deviation (SD)	2.0	5.0	9.0	9.3	4.9	3.6	2.3	1.4	0.3	0.1	0.0	0.1	23.0
Coeficient of Variation (%)	2.3	1.2	1.4	1.6	1.4	1.2	1.4	1.6	1.5	1.4	1.4	3.9	0.9
Bias	3.0	1.1	2.0	2.2	1.8	1.6	3.3	2.2	1.9	1.8	1.6	5.0	1.1
Median	0.0	1.5	2.5	1.9	1.8	1.8	0.8	0.3	0.1	0.0	0.0	0.0	22.2

Salia Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.0	0.3	1.1	1.5	1.3	0.9	0.6	0.4	0.1	0.0	0.0	0.0	6.3
Standard deviation (SD)	0.1	0.4	2.1	3.2	2.0	1.0	1.0	0.7	0.2	0.0	0.0	0.0	8.0
Coeficient of Variation (%)	2.4	1.3	1.9	2.1	1.6	1.1	1.5	1.7	1.6	1.5	1.5	2.1	1.3
Bias	3.9	1.7	2.4	3.5	2.2	1.7	3.6	2.9	2.6	2.5	2.5	4.1	1.7
Median	0.0	0.1	0.2	0.2	0.3	0.7	0.4	0.1	0.0	0.0	0.0	0.0	2.6

Bermuza Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.4	0.8	0.9	0.9	0.7	0.6	0.5	0.4	0.2	0.1	0.1	0.1	5.7
Standard deviation (SD)	0.4	0.8	0.9	1.0	0.6	0.4	0.4	0.3	0.1	0.1	0.0	0.1	3.3
Coeficient of Variation (%)	1.0	0.9	1.0	1.2	0.9	0.7	0.7	0.8	0.6	0.6	0.6	1.2	0.6
Bias	1.1	1.0	1.6	1.9	1.3	0.5	1.3	1.9	0.7	0.7	1.2	2.4	1.0
Median	0.2	0.5	0.5	0.6	0.5	0.6	0.5	0.3	0.2	0.1	0.1	0.1	4.1

Almanchares Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.0	0.2	0.4	0.6	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	2.4
Standard deviation (SD)	0.1	0.3	0.7	0.8	0.6	0.3	0.2	0.2	0.1	0.0	0.0	0.0	2.5
Coeficient of Variation (%)	2.1	1.4	1.6	1.5	1.3	0.9	1.0	1.1	1.1	1.1	1.1	1.1	1.0
Bias	3.7	1.6	2.0	2.4	1.6	1.0	2.1	2.2	2.1	2.1	2.1	1.9	1.3
Median	0.0	0.1	0.1	0.2	0.1	0.3	0.2	0.1	0.0	0.0	0.0	0.0	1.2

Rubite Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.2	0.7	1.3	1.4	0.9	0.7	0.5	0.3	0.0	0.0	0.0	0.0	6.2
Standard deviation (SD)	0.2	1.0	2.2	2.5	1.2	0.7	0.6	0.5	0.0	0.0	0.0	0.0	5.8
Coeficient of Variation (%)	1.5	1.4	1.6	1.7	1.3	1.0	1.2	1.6	1.1	1.1	1.1	2.5	0.9
Bias	2.4	2.3	2.3	2.7	2.2	1.0	1.9	2.5	1.2	1.5	1.6	3.5	1.3
Median	0.0	0.4	0.4	0.4	0.5	0.3	0.3	0.1	0.0	0.0	0.0	0.0	3.2

Benamargosa Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.5	2.2	5.7	6.7	5.0	4.1	2.7	1.7	0.6	0.3	0.1	0.1	29.8
Standard deviation (SD)	0.8	3.1	10.1	11.7	7.3	4.6	3.6	2.7	0.8	0.4	0.2	0.2	35.3
Coeficient of Variation (%)	1.7	1.4	1.8	1.7	1.5	1.1	1.3	1.5	1.3	1.3	1.3	1.6	1.2
Bias	2.6	2.8	2.4	2.6	2.3	2.1	3.2	3.0	2.9	3.0	2.9	3.2	1.5
Median	0.1	1.0	1.5	1.9	2.1	3.3	1.7	0.9	0.4	0.2	0.1	0.1	13.1

Guaro Final Stretch Streamflow

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
Average	0.1	0.5	1.2	1.4	1.0	0.8	0.5	0.3	0.1	0.1	0.0	0.0	6.2

Standard deviation (SD)	0.2	0.8	2.3	2.6	1.6	0.9	0.7	0.5	0.2	0.1	0.0	0.0	7.5
Coeficient of Variation (%)	1.9	1.7	1.9	1.8	1.5	1.1	1.3	1.5	1.3	1.3	1.3	1.9	1.2
Bias	3.3	3.2	2.6	2.8	2.4	1.7	2.8	2.8	2.4	2.5	2.5	3.9	1.5
Median	0.0	0.2	0.2	0.5	0.4	0.6	0.3	0.2	0.1	0.0	0.0	0.0	2.6

Table 3. Main statistics of the streamflow data series included in SIMGES model (hm^3)

The streamflows obtained from EVALHID module have been compared with the results of SIMPA model (Ruiz, 1998) which has been widely generalized in almost all river basin districts in Spain, and also with the respective gauging stations located along the river basin. These gauging stations are integrated in the gauging stations official network (ROEA, for its acronym in Spanish). The SIMPA model is a distributed hydrological model used for the evaluation of water resources in natural regime. It was developed by the Centre for Public Works Studies and Experimentation (CEDEX) during the drafting of the White Paper on Water in Spain (MMA, 2000). As observed in figure 6, generally the results obtained with EVALHID model present a better adjustment than the ones obtained with SIMPA model. The main reason is that EVALHID model is calibrated with more detail in all the gauging stations located in the system, so it allows obtaining a better adjustment especially in headwaters flows. The average year represented in figure 6 has been used for the calibration period.

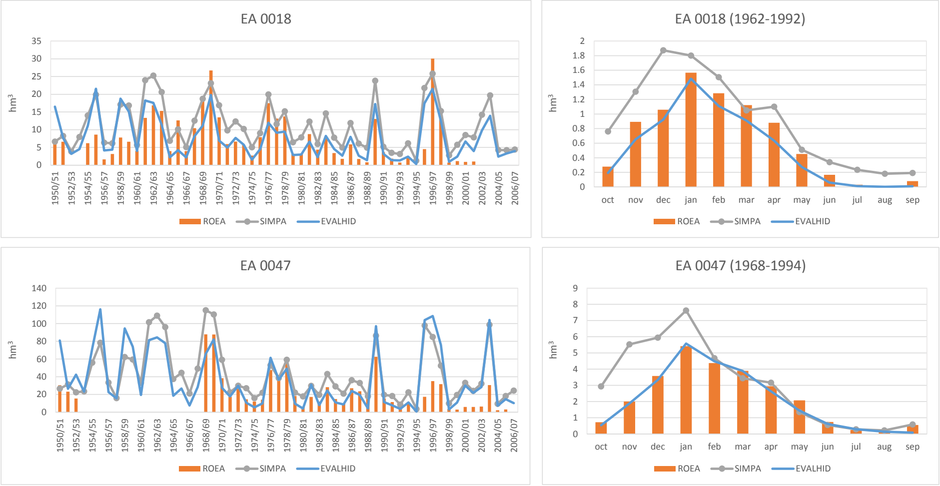

Figure 6. Comparison between EVALHID and SIMPA results with the flows registered in the gauging stations EA 0018 and EA 0047 (hm^3) (ROEA means gauging stations official network)

A4.4.2. FILLING IN THE SEEAW TABLES

One of the main objectives of the water accounting is to compare hydrological information not only at spatial dimension, but also at temporal scale. As an example of the applicability of SEEAW approach, the following tables show the water accounts tables in May 1995 and January 1996 in the case study considered. The period 1991-1995 has gone down in history as the worst drought in recent times in Spain. The month of May 1995 represents the beginning of the irrigation season in a long dry period and, on the other hand, the month of January 1996 represents one of the first few months of drought recovery. In this way, we may compare the hydrological cycle processes and the use of water in two different situations, a severe dry period and a wet period.

A4.4.2.1 Water accounts tables in May 1995

As we observe in tables 4 and 5, as a result of the drought period the volume of reserves is zero and precipitation is very low. Similarly, there is a small amount of soil water and it is mainly used in the evapotranspiration process. As the reservoir is empty, the evaporation is zero. There is an small amount of water (0.01 hm^3) that is used in downstream territories. Closing stocks are fewer than opening stocks, and as it is shown, the volume abstracted for water uses comes from La Viñuela reservoir and the intakes located in the river. The negative values of groundwater volumes at opening and closing stocks are explained by the principle of superposition (Reilly et al., 1984; Solera et al., 2010). This means that, as we do not know the volume of water stored in an aquifer, it is assumed that in natural system this volume is zero. So, any action on the aquifer caused by human activities has an effect on the piezometric levels and on its reserves. A negative value indicates a decrease in the volume of water stored in the aquifer, and a positive value indicates an increase. The main exchanges of flows between water resources are those between rivers to La Viñuela reservoir and, outflows from groundwater to river, reducing the amount of water stored in aquifers.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks	**0.00**	**0.00**		**0.00**	**-0.38**	**8.77**	**8.39**
Increases in stocks							
2. Returns	0.00		0.04		0.00		**0.04**
3. Precipitation						0.36	**0.36**
4. Inflows	0.03		0.06		0.00	0.00	**0.09**
4.a. From upstream territories							**0.00**
4.b. From other resources in the territory	0.03	0.00	0.06	0.00	0.00	0.00	**0.09**
Decreases in stocks							
5. Abstraction	0.02		0.07		0.00		**0.09**
6. Evapotranspiration/actual evapotranspiration	0.00					6.63	**6.63**
7. Outflows	0.01		0.03		0.06	0.00	**0.10**
7.a. To downstream territories	0.01						**0.01**
7.b. To the sea			0.00				**0.00**
7.c. To other resources in the territory	0.00	0.00	0.03	0.00	0.06	0.00	**0.09**
8. Other changes in volume							**0.00**
9. Closing stocks	**0.00**	**0.00**		**0.00**	**-0.44**	**2.49**	**2.06**

Table 4. Water asset accounts in May 1995 (hm^3)

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA.1311 Artificial reservoirs			0.00		0.00		**0.00**
EA. 1312 Lakes							
EA. 1313 Rivers	0.03				0.00		**0.03**
EA. 1314 Snow, ice and glaciers							**0.00**
EA. 132 Groundwater			0.06				**0.06**
EA. 133 Soil water			0.00		0.00		**0.00**
Inflows from other resources in the territory	0.03	0.00	0.06	0.00	0.00	0.00	**0.09**

Table 5. Matrix of flows between water resources in May 1995 (hm^3)

The physical use and supply tables are shown in table 6. As we observe, the main use is allocated for urban and recreational uses. Water resources employed to supply urban demands come from surface water (reservoirs and rivers) and recreational water uses are supplied by reused water. These results are interesting because the month of May represents the beginning of the harvest period and all the water supplied is assigned to urban demands, with the consequent harm to agrarian sector.

	Urban	Farming	Cattle raising	Recreational	Rest of the world	Total
1. Total abstraction	0.05				0.01	**0.06**
1.a Abstraction for own use	0.05				0.01	**0.06**
1.b Abstraction for distribution						
1.i From inland water resources	0.05				0.01	**0.06**
1.i.1 Surface water	0.05				0.01	**0.06**
1.i.2 Groundwater						
1.i.3 Soil water						
1.ii From water resources						
1.ii.1 Collection of precipitation						
1.ii.2 Abstraction from the sea						
2. Use of water received from other economic units				0.04		**0.04**
2.a Reused water				0.04		**0.04**
2.b Wastewater to sewerage						
2.c Desalinated water						
3. Total use of water	**0.05**	**0.00**	**0.00**	**0.04**	**0.01**	**0.10**
4. Supply of water to other economic units	0.04					**0.04**
4.a Reused water	0.04					0.04
4.b Wastewater to sewerage						
5. Total returns						**0.00**
5.a To water resources						
5.a.i Surface water						
5.a.ii Groundwater						
5.a.iii Soil water						
5.b To other sources						
6. Total supply of water	**0.04**					**0.04**
7. Consumption	**0.01**	**0.00**	**0.00**	**0.04**	**0.01**	**0.06**
7.a Losses from evaporation						
7.b Losses in distribution not because of leakages						

Table 6. Physical use and supply table in May 1995 (hm^3)

A4.4.2.2 Water accounts tables in January 1996

The situation in January 1996 is very different from the previous one, as observed in table 7. Opening stocks indicates that reservoir is filling up and the soil layer contains certain amount of water. The amount of precipitation and the inflows from other resources in the territory are considerable. Abstractions are higher than during the month of May of 1995 due to water availability - in spite of the fact that harvest period begins in May and water demanded by farming is higher. Evapotranspiration has grown up because the higher water availability in the soil, and the outflows also have increased. As a consequence, closing stocks are higher than opening ones, showing the recovering of the system.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks	**11.38**				**10.73**	**110.40**	**132.52**
Increases in stocks							
2. Returns	0.11		0.93		0.00		**1.04**
3. Precipitation						204.50	**204.50**
4. Inflows	72.13		101.77		71.19	0.00	**245.08**
4.a. From upstream territories							**0.00**
4.b. From other resources in the territory	72.13	0.00	101.77	0.00	71.19	0.00	**245.08**
Decreases in stocks							
5. Abstraction	0.16		1.57		0.00		**1.73**
6. Evapotranspiration/actual evapotranspiration	0.00					17.22	**17.22**
7. Outflows	0.76		101.13	0.00	30.43	138.05	**270.37**
7.a. To downstream territories	0.47						**0.47**
7.b. To the sea			24.82				**24.82**
7.c. To other resources in the territory	0.29	0.00	76.31	0.00	30.43	138.05	**245.08**
8. Other changes in volume							**0.00**
9. Closing stocks	**82.70**				**51.49**	**159.62**	**293.81**

Table 7. Water asset accounts in January 1996 (hm^3)

As we observe in table 8, the main flows between water resources are the ones between soil layer with rivers and groundwater, summing up more than

138 hm^3. As a consequence, the flows from rivers enable an increase of the volume of water stored in reservoirs.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA.1311 Artificial reservoirs			0.29		0.00		**0.29**
EA. 1312 Lakes							
EA. 1313 Rivers	72.13				4.18		**76.31**
EA. 1314 Snow, ice and glaciers							**0.00**
EA. 132 Groundwater			30.43				**30.43**
EA. 133 Soil water			71.04		67.01		**138.05**
Inflows from other resources in the territory	72.13		101.77	0.00	71.19	0.00	**245.08**

Table 8. Matrix of flows between water resources in January 1996 (hm^3)

As in the previous balance, abstractions come from surface water as table 9 shows. The main use of water is destined to urban uses and, as in the previous analysis in May of 1995, recreational water uses are supplied by reused water. The water transferred to other territories downstream has been increased in comparison with the month of May.

	Urban	Farming	Cattle raising	Recreational	Rest of the world	Total
1. Total abstraction	1.16	0.53	0.01	0.00	0.47	**2.17**
1.a Abstraction for own use	1.16	0.53	0.01		0.47	**2.17**
1.b Abstraction for distribution						
1.i From inland water resources	1.16	0.53	0.01		0.47	**2.17**
1.i.1 Surface water	1.16	0.53	0.01		0.47	**2.17**
1.i.2 Groundwater						
1.i.3 Soil water						
1.ii From water resources						
1.ii.1 Collection of precipitation						
1.ii.2 Abstraction from the sea						
2. Use of water received from other economic units	0.00	0.00	0.00	0.03	0.00	**0.03**
2.a Reused water				0.03		**0.03**
2.b Wastewater to sewerage						
2.c Desalinated water						
3. Total use of water	**1.16**	**0.53**	**0.01**	**0.03**	**0.47**	**2.20**

4. Supply of water to other economic units	0.03	0.00	0.00	0.00	0.00	**0.03**
4.a Reused water	0.03					**0.03**
4.b Wastewater to sewerage						
5. Total returns	0.90	0.11	0.00	0.00	0.00	**1.01**
5.a To water resources	0.90	0.11				**1.01**
5.a.i Surface water	0.90	0.11				**1.01**
5.a.ii Groundwater						
5.a.iii Soil water						
5.b To other sources						
6. Total supply of water	**0.93**	**0.11**	**0.00**	**0.00**	**0.00**	**1.04**
7. Consumption	**0.23**	**0.42**	**0.01**	**0.03**	**0.47**	**1.16**
7.a Losses from evaporation						
7.b Losses in distribution not because of leakages						

Table 9. Physical use and supply table in January 1996 (hm³)

A4.4.2.3 Discussion on the specific results

In general terms, as we observe in the tables, variables such as precipitation or evapotranspiration show high volumes of water, while other variables such as abstractions or outflows to the sea, which could be controlled by human actions are one order of magnitude lower than natural processes. This fact is remarkable because variables like precipitation and evapotranspiration cannot be modified during the planning and management of the water exploitation system.

A4.4.3. INDICATORS DERIVED FROM SEEAW TABLES

Indicators derived from water accounts show a general description of the river basin with an emphasis on the benefit of natural water and managed water (Pedro-Monzonis et al., 2015b) and allow decision-makers to characterize the pressures on water resources. Some of the indicators defined by United Nations (UNSD, 2012) have been applied in the case study. To show these indicators, we have selected the period 1980/81-2006/07. Internal Renewable Water Resources (IRWR) represents the average annual flow of rivers and recharge of groundwater generated from endogenous precipitation, and it can be obtained from the matrix of flows. For the selected period IRWR are 81.69 hm³/year. On the other hand, External Renewable Water Resources (ERWR) consists of river runoff and groundwater transfers between countries. This indicator is obtained from asset accounts. In the case study, for the same period ERWR are 0 hm³/year, stating that there are not any transfers from other river basins. The sum of IRWR and ERWR correspond to the maximum theoretical amount of water available for a country on an average year on a long reference period. This indicator is named Total Natural Renewable Water Resources (TNRWR) and it is 81.69 hm³/year. When referring to the maximum theoretical amount of water actually available at a given moment, this is named Total Actual Renewable Water Resources (TARWR) and for the month of May of 1995 TARWRMay 95 is 0.36 hm³ and in January of 1996, TARWRJan 96 is 204.50 hm³, both values vary greatly showing the temporal variability of renewable water resources in the basin. From the results above, we have obtained the Dependency ratio (DR) which expresses the part of the total renewable water resources originating outside the territory and it is obtained as the ratio between ERWR and TNRWR. In the case study DR is 0%. Taking into account the population size, we obtain the renewable resources per capita as the ratio between total renewable water resources and population. In the case study, this is 570 m³/person. And finally, the density of internal resources (DIR), which is 7.5 hm³/km², represents the ratio between the average internal flow and the area of the territory. United Nations (UNSD, 2012) also recommend the use of the indicator Exploitable Water Resources (or manageable resources) that represents the part of the water resources which is considered to be available for development under specific, technical, economic and environmental conditions. In this sense, it is not possible to obtain this indicator by employing water accounts. Pedro-Monzonis et al (2015a) propose a methodology for its acquisition.

As can be seen, these indicators are mainly based on the amount of water that is generated in a territory, with special attention to the resources coming from other territories. This kind of indicators may be suitable for international river basins, but the features of those territories are far away from Mediterranean river basins, as we have seen in the case study. On the other hand, the proposed indicators do not refer to the abstractions in the river basin, and they are a crucial fact in order to assess the degree of water stress suffered by water exploitation systems. In this sense, Water Exploitation Index (WEI) (EEA, 2005) may help us to know the degree of stress in the river basin. This index is defined as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources and shows to which extent the total water demand puts pressure on water resources. Values of WEI in a river basin between 0% and 20% show a situation of no stress; values between 21% and 40% indicate water stress; and values upper than 40%

represent extreme water stressed river basins (CIRCABC, 2012). For the period 1980/81-2006/07 the WEI in the case study is 73.61%, showing a high degree of water stress in the river basin. Similarly, Water Consumption Index (WCI) (UNDS, 2012) represents the ratio between water consumption and total renewable water resources. In this sense, WEI emphasizes the water abstractions and WCI is focused on the water consumptions in the river basin, taking into account the use of water returns for other uses downstream. For the period 1980/81-2006/07 the WCI in the case study is 55.84%, softening the degree of stress in the river basin.

On the other hand, we have observed that environmental needs are not explicitly considered in SEEAW tables. Likewise EEA (2013) noted that the ecological requirements represent an important issue and water accounts enable us to obtain a potential indicator of ecological stress for rivers (ESIr) (see Eq. 1):

$$ESI_r = \frac{outflow}{outflow + abstractions - returns} \quad (1)$$

As ESIr is defined at monthly level, figure 7 represents a cumulative distribution of ESIr in the case study which aggregates the indexes during the analysed period. As noted by EEA (2013) values of ESIr between 0-15% represent a destructive ecological stress for rivers; between 15-25% symbolize a non sustainable ecological stress; between 25-50% represent an excessive ecological stress; between 50-65% represent a risky ecological stress; between 65-90% denote a warning ecological stress and finally, ESIr values between 90-100% show the inexistence of problems in the river. In our case study, the likelihood of having an ESIr less than 25% (non sustainable ecological stress) is approximately 25%, and the likelihood of having an ESIr higher than 90% without any problem in the river basin is 3%, showing the stress suffered by the system.

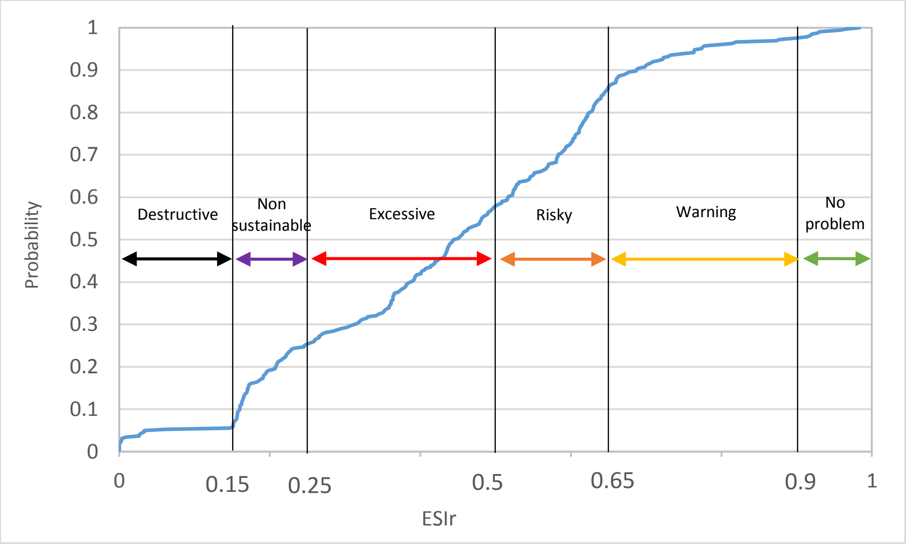

Figure 7. Cumulative distribution function of ESIr (%) in Vélez River Basin for the period 1980/81-2006/07

A4.5. DISCUSSION ON THE APPLICABILITY OF THE APPROACH

As it has been shown in this paper, AQUATOOL DSS represents a reliable tool for building physical and use tables and the asset accounts under the SEEAW methodology, allowing the collection of those parameters of water cycle that cannot be obtained by monitoring. In this sense, AQUATOOL is capable of reproducing the potential evapotranspiration for non-irrigated land, the distinction between surface and groundwater runoff, the amount of soil water, the returns to groundwater and surface water bodies which had not been possible to determine in previous works with WEAP model (Dimova et al., 2014). Even so, there are still some parameters which cannot be reproduced as the losses in distribution networks.

Although SEEAW is the most employed water accounting approach, there are some key issues that are not completely defined or should be better considered. The first handicap is the spatial and temporal aggregation. As regards the spatial consideration, water accounting may be developed in different levels of water use. Molden and Sakthivadivel (1999) defined three levels of analysis: macro level (basin or sub-basin level), mezzo level (service level) and micro level (use level). In this way, Momblanch et al. (2014) noted that water management analysis is performed at a water resource system scale, which is conceptually different to the river basin scale. So it may be possible to build SEEAW tables at a river basin scale, at water exploitation system scale or at a local scale. As regards the temporal consideration, traditionally SEEAW tables are built in a natural year concurring with economic accounts but, what about the water exploitation systems with pluriannual regulation?

We have emphasized throughout the paper the relevance of improving water efficiency. Several researches have demonstrated that more efficient irrigation technologies may cause, on the first hand, a decrease in the price of water and, as a consequence, an increase in water global use. On the second hand, they may reduce return flows, affecting downstream users and aquifer recharge. In these circumstances, the improvement in water efficiency can actually increase water depletions. This contradiction is named rebound effect or Jevon’s paradox (Dumont et al., 2013). To overcome this situation, designing water pricing policies and the revision of water rights are recommended. Measuring these effects is out of the reach of this paper but some evidence of them can be found in Ward and Pulido-Velazquez (2008) and Gutierrez-Martin and Gomez (2011).

In section 2.3 there are some dark grey cells (see table 1 and table 2) which indicate zero entries because two possible reasons: 1) aggregated models do not distinguish between these types of results, such as precipitation on artificial reservoirs, lakes or rivers; 2) there are flows between water resources that are physically impossible or unlikely, such as precipitation on groundwater or outflows to the sea from soil water or artificial reservoirs. On the other hand, the column of EA. 1312 Lakes may have the same consideration as the column of EA.1311 Artificial reservoirs, due to they may be modelled in the water resources management model with the same type of element.

As regards to the methodology in the case study, it is based on time series data of precipitation and temperatures from the Spain02 database. The data availability of Spain02 enables obtaining time series of results during the period 1950-2008, being necessary the use of other sources of information in more recent periods. Other key issue is the classification of economic users presented in the SEEAW. In most of River Basin Districts, this information is not available because this information is not specified exhaustively, and it is preferable to classify the economic users in agrarian, urban or industrial users, as presented in the case study. Asset accounts also distinguish between water flows and water in reservoirs. This differentiation is a complex task unless we use simulation models to obtain it.

A priori, among the results obtained, indicators derived from water accounts allow policymakers to compare results between different territories and periods. But, as observed, they are mainly based on the amount of water generated in a territory, with special attention to those resources coming from other territories, but without an in-depth analysis of the amount of water that it is really abstracted. In this sense, WEI and WCI represent a first approximation to the degree of water stress suffered by the system, despite being based on annual averages and not displaying the seasonality or even a scarcity event at a monthly scale (Pedro-Monzonis et al. (2015b)). The consideration of several scenarios with and without reservoirs, pumping wells, waste water reuse or desalination may be useful for the definition of new indicators related to the stress of a water exploitation system.

It is worth noting that environmental requirements are not explicitly considered in SEEAW tables. In this sense, water abstraction for supplying human populations and economic activities are substantially conditioned, especially in water scarce exploitation systems and/or drought episodes. The introduction of environmental flows in a water resources system may negatively affect the existing water uses in the basin and, in those periods when there are not enough water resources, those demands with the lowest priorities will present deficits (Pellicer-Martínez and Martínez-Paz, 2016). There is a clear need for improving water accounting approaches in order to include environmental requirements. As a first step the use of ESIr has enabled us to obtain a slight understanding of the stress suffered by the river at its mouth area, although results may improve if we analyse ESIr in every surface water body along the river basin. To deal with this issue, we suggest the use of simulation scenarios considering different environmental requirements to compare some of the values obtained in SEEAW tables among other: total abstractions and outflows to the sea.

A4.6. CONCLUSIONS

As seen, filling SEEAW tables needs a significant degree of knowledge about the temporal and spatial evolution of the different components of the hydrological cycle and the flows between them. The main conclusion obtained from this research is the fact that AQUATOOL DSS is a reliable tool that provides information enough for building physical and use tables and asset accounts under SEEAW methodology, allowing the collection of those parameters of water cycle that cannot be obtained by monitoring. EVALHID module has been used for building physical water balances in natural regime. Moreover, the combined use of SIMGES simulation model and EVALHID allows complete physical water balances in altered flow regime, taking into consideration water allocation demands, evaporation from reservoirs and water transfers among others. In the case of building water accounts were mandatory in the river management plans, it may be desirable to have a standard for SEEAW tables as it exists in other water accounting approaches such as the ISO 14046 on Water Footprint.

In this regard, society expects from policymakers and stakeholders to maximise the profit produced per unit of natural resources. This research pretends to contribute to the objectives of the “Blueprint to safeguard Europe’s water resources”. It is noteworthy that, in Spain, a large part of these methodological decisions are included in the Spanish Guideline of Water Planning (BOE, 2008) with normative status guaranteeing consistency and comparability of the results.

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ANNEX 5. WATER ACCOUNTING FOR STRESSED RIVER BASINS BASED ON WATER RESOURCES MANAGEMENT MODELS[5]

Abstract

Water planning and the Integrated Water Resources Management (IWRM) represent the best way to help decision makers to identify and choose the most adequate alternatives among other possible ones. The System of Environmental-Economic Accounting for Water (SEEA-W) is displayed as a tool for the building of water balances in a river basin, providing a standard approach to achieve comparability of the results between different territories. The target of this paper is to present the building up of a tool that enables the combined use of hydrological models and water resources models to fill in the SEEA-W tables. At every step of the modelling chain, we are capable to build the asset accounts and the physical water supply and use tables according to SEEA-W approach along with an estimation of the water services costs. The case study is the Jucar River Basin District (RBD), located in the eastern part of the Iberian Peninsula in Spain which as in other many Mediterranean basins is currently water-stressed. To guide this work we have used PATRICAL model in combination with AQUATOOL Decision Support System (DSS). The results indicate that for the average year the total use of water in the district amounts to 15143 hm^3/year, being the Total Water Renewable Water Resources 3909 hm^3/year. On the other hand, the water service costs in Jucar RBD amounts to 1634 million € per year at constant 2012 prices. It is noteworthy that 9% of these costs correspond to non-conventional resources, such as desalinated water, reused water and water transferred from other regions.

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[5] Pedro-Monzonís, M., Solera, A., Ferrer, J., Andreu, J. and Estrela, T., 2016. Water accounting in stressed river basins based on water resources management models. Sci Total Environ 565, 181-190 doi:10.1016/j.scitotenv.2016.04.161

Keywords

Water accounts, System of Environmental-Economic Accounting for Water (SEEA-W), AQUACCOUNTS, water resources systems, Jucar River Basin District

A5.1. INTRODUCTION

The EU Water Framework Directive (WFD) (EP, 2000) establishes a framework for the Community action in the field of water policy. Among its main objectives highlights the scope of water protection to all waters in order to achieve their “good status”, a water management based on river basins, the implementation of pricing policies or the promotion of public participation. For the purpose of improving the implementation and integration of water policy objectives into other policy areas, the Blueprint to Safeguard Europe's water resources (EC, 2012) aims to facilitate the WFD Common Implementation Strategy (CIS). Blueprint proposes the use of water accounts in order to meliorate quantitative water management and water efficiency in Europe, contributing to water quality objectives. In this sense, as noted by Blueprint “water accounts provide the missing link in many river basins for water management”, representing an adequate tool to support basic information in the decision-making process.

But building water accounts represents a complex task, due to the difficulty of the collection of the required data and, on the other hand, due to the lack of common European procedures (Dimova et al., 2014; Tilmant et al., 2015; Pedro-Monzonís et al., 2016). Because of the difficulty of monitoring the components of the water cycle and the water management in a territory, hydrological models and Decision Support Systems (DSSs) have become an indispensable tool to provide the required data. A DSS is a computer tool created to help decision-makers for the purpose of providing integration, screening alternatives, obtaining operation guidelines and implementing sensitivity analysis and risk assessment (Andreu et al., 1996). According to Sanz et al. (2011), modelling is generally one of the best approaches to integrate, administrate, quantify and validate hydrological information. Another important advantage of the use of DSS, is that models can be helpful in participatory and negotiation processes, as required by WFD, supporting more rational and well-informed decisions and consensus-building among different stakeholders based on a common understanding and model of the problem and socio-economic implications of solutions (Andreu et al., 1996).

Both WFD and Blueprint emphasise the need of an efficient use of water. As noted by Blueprint “not putting a price on a scarce resource like water can be regarded as an environmentally-harmful subsidy”. This requirement contrasts with the fact that, traditionally, water has been typically allocated according to historical, political, legal, institutional and social conditions (Harou et al., 2009). In this sense, one of the purposes of water accounts is to measure the influence of each water user, infrastructure and management decision to the total economic value of water resources in a given basin (Tilmant et al., 2015). Taken it into account, in many places, the available economic data do not fit the format of water accounts and, in these cases, hydroeconomic models can help provide this information, advancing on transparency and efficiency in water use (Harou et al., 2009).

If in any territory the sustainable use of water is required for ensuring the well-being of citizens, this is particularly important in stressed river basins. In those regions where water resources are most fully allocated managing water resources especially during drought periods becomes a difficult task. Decision-makers have to make an effort in order to guarantee water for human and environmental requirements, which means high investments in infrastructures exemplified by a heavily regulation of water resources and an intensive use of non-conventional resources such as reused water and desalination.

The aim of this study was to broaden the knowledge of the applicability of the System of Environmental-Economic Accounting for Water (SEEA-W) (UNDS, 2012) in stressed river basins. The SEEA-W is the most well-known approach of hybrid accounting and it is developed in many European countries, such as Italy, Greece, Germany, Slovenia, Spain and Bulgaria (Dimova et al., 2014; EC, 2015; Pedro-Monzonís et al., 2016). It has been created by the United Nations Statistic Division (UNSD) in conjunction with the London Group on Environmental Accounting. Its main purpose has been normalising concepts related to water accounting, giving a conceptual framework for organising hydrological and economic information. The SEEA-W covers five categories of accounts: (1) physical supply and use and emission accounts (representing the amount of water used and discharged back into the environment and the amount of pollutants added to water); (2) hybrid and economic accounts (linking to the economic aspects of water with the physical supply and use data); (3) asset accounts (representing a water balance and measuring stocks and their changes due to natural causes and human activities); (4) quality accounts (indicating the stock of water in terms of its quality); (5) valuation of water resources. More information can be found at (UNDS, 2012).

The Jucar River Basin District (RBD) has been selected as a case study because this region, as many other river basin districts in the Mediterranean region, suffers from water scarcity, persistent drought periods and groundwater overexploitation (Ferrer, 2012). This work represents another turn on the screw for water accounting in Jucar RBD. The Halt-Jucar-Des project (EVREN, 2012) provided an opportunity to test and check the feasibility of applying the SEEA-W in this system. Among its conclusions, to include altered regime, a mixed solution integrating hydrological models and management models was proposed as additional future steps to be taken. To guide this work, three models have been employed: 1) a GIS-based rainfall-runoff model to analyse the water cycle; 2) a water allocation model to simulate the water management; and 3) an acquisition tool to link the main variables of the rainfall-runoff model, with the results of the water allocation model and the economic data. All the data were provided by the Jucar River Basin Authority (RBA) (www.chj.es).

A5.2. MATERIALS AND METHODS

The proposed methodology (see figure 1) is represented as a modelling chain composed of three stages. The first stage lies in the hydrological model, which enables us to obtain the river basin water resources in a natural regime. This information is used in the DSS to simulate the water allocation, representing the second stage. Thirdly, once we know the amount of water allocated for the different uses we are able to link it to the economic costs. At every step of the modelling chain, we are capable to build the asset accounts and the physical water supply and use tables defined according SEEA-W approach. Moreover, an estimation of the water service costs in the district is done, being understood as all services which provide abstraction, storage, treatment and distribution of water and the wastewater collection and treatment facilities (WATECO, 2002). At this point, it is worth noting that other hydrological models and DSSs could have been implemented in order to calculate these tables. To guide this work we have used PATRICAL model (Pérez-Martín et al., 2014), SIMGES model (Andreu et al., 1996) and the acquisition tool AQUACCOUNTS explained in detail below.

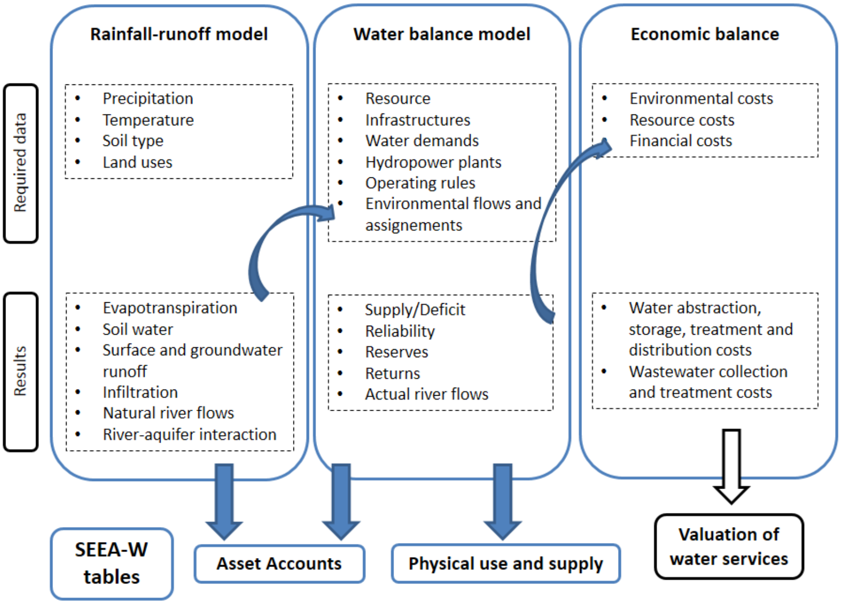

Figure 1. Scheme of the approach to obtain SEEA-W tables by using different types of models related to water resources management

The PATRICAL model (Pérez-Martín et al., 2014) is a large-scale, conceptual, and monthly, spatially distributed (grid 1 x 1 km^2) water balance model with water quality that includes: streamflows, river-aquifer interactions, interactions between aquifers, groundwater discharge to wetlands and to the sea and average groundwater levels in aquifers. Within the model the river basin is divided into two vertical layers: an upper zone (where the model is distributed) and a lower zone (where the model is semi-distributed). Inputs to the model are monthly precipitation and air temperature. The model has the following modules: 1) snow, 2) runoff generation and soil moisture accounting, 3) runoff separation into surface flow and infiltration, 4) groundwater, 5) routing, and 6) groundwater transfer. At the moment, this model is used for different assignments related to the implementation of the WFD in the Jucar RBD (Ferrer et al., 2012), in the assessment of climate change impact on water resources (Estrela et al., 2012) and also in the definition of nitrate concentration objectives in groundwater bodies in Spain (Pérez-Martín et al., 2012).

AQUATOOL (Andreu et al., 1996) is a user-friendly DSS widely employed by Spanish River Basin Authorities, as well as in other countries (Salla et al., 2014; Sulis and Sechi, 2013; Uche et al., 2013). This DSS consists of several modules allowing the analysis of different approaches in water resources systems. The SIMGES module (Andreu et al., 1996) can simulate the water resources system, on a monthly time scale, by a simple flow balance in a flow network in order to find a flow solution compatible with the defined constraints. It can consider the aquifers, the returns to surface and groundwater system, the evaporation and infiltration losses from reservoirs, the energy production, the consideration of environmental flows as well as different water use priorities, and the definition of operating rules to reproduce source-demand interactions that can help improving integrated river basin management.

To construct SEEA-W tables, we have developed an acquisition tool called AQUACCOUNTS, integrated into AQUATOOL DSS. This tool enables to link the main variables of the rainfall-runoff model such as precipitation, actual evapotranspiration, surface runoff, infiltration and river-aquifer interaction; with the results of the water balance model, such as water allocations, reserves, evaporation in reservoirs, among others, that can be managed by technicians. Both models (rainfall-runoff model and water balance model) enable the assembling of water asset accounts, matrix of flows between water resources and physical water supply and use tables. In the case of physical water supply and use tables, the economic activities are classified according to the International Standard Industrial Classification of All Economic Activities (ISIC) (UN, 2008), distinguishing the following groups:

a) ISIC divisions 1-3, which include agriculture, forestry and fishing;
b) ISIC divisions 5-33 and 41-43, which include mining and quarrying, manufacturing, and construction;
c) ISIC division 35: electricity, gas, steam and air-conditioning supply;
d) ISIC division 36: water collection, treatment and supply;
e) ISIC division 37: sewerage;
f) ISIC divisions 38, 39 and 45-99, which correspond to the service industries.

With regards to economic issues, the WFD demands the assessment of the cost recovery of water services (Assimacopoulos et al., 2005; EC, 2012), although it does not define the methodology to calculate it (Borrego-Marín et al., 2015).

Seeing that different approaches were used in the previous river basin management plans, a new standard procedure was reported for the second cycle of WFD implementation in 2015 (Borrego-Marín et al., 2015). The estimation of the water services cost is based on this revision of cost recovery. The components of the full water services cost are composed by environmental, resource and financial costs (WATECO, 2002). Water services are classified in: a) High-pressure services (abstraction, storage and supply through public services for all uses), b) Abstraction and groundwater supply (no self-service), c) Distribution of water for irrigation, d) Urban cycle (treatment and distribution of drinking water), e) Self-service, f) Reuse, g) Desalination, and h) Collection and wastewater treatment in public networks. The estimation of the financial cost is based on data from public administrations budgets for each water service. Environmental costs are conceived as a penalty for deteriorate the status of water bodies and they are based on the annual equivalent cost of the necessary measures to correct the damages associated with a water service. Lastly, we do not consider the resource costs, although ignoring the resource opportunity cost can produce important errors in investments and water allocations (Pulido-Velazquez et al., 2013). The approach used operates as a simulation-based hydroeconomic model. Thereby, we have a simulation model capable of representing the modus operandi of the system under the current operating rules and the economic assessment resulting from the water resource allocation. At this point, we would like to emphasize the use of hydroeconomic models to obtain water allocation costs, but the economic, social and environmental benefits remain a major challenge (Martínez-Paz et al., 2014), being out of our reach.

A5.3. CASE STUDY: THE JUCAR RIVER BASIN DISTRICT

A5.3.1. CHARACTERIZATION OF THE STUDY AREA

The Jucar RBD, with a surface of 43,000 km^2, is located in the eastern part of the Iberian Peninsula in Spain and is formed by the aggregation of watersheds that inflow into the Mediterranean Sea, between the Segura and Cenia river mouths, including also the latter. The set of basins is structured in nine water exploitation systems around the main rivers; among those, the Jucar is highlighted as it covers approximately 50% of the total area, which is therefore named Jucar RBD (see figure 2).

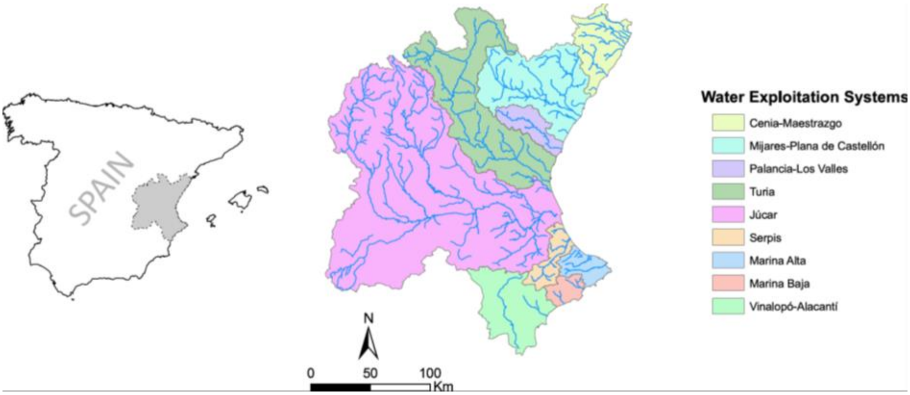

Figure 2. Location of the Jucar RBD in the Iberian Peninsula

The Jucar RBD is characterized by a typical Mediterranean climate, with warm summers and mild winters, and where the average annual temperatures range from 14 to 16,5°C. The high temporal and spatial variability represent the main feature of Jucar RBD's climate. The average annual rainfall of the district is about 500 mm, varying between 750 mm in the headwaters of the main rivers and 300 mm in the southern regions. Time or seasonal variability in the rainfall regime is relevant in the region, existing frequent torrential rainfall episodes (short time and high intensity episodes) commonly known as “cold drop” (“gota fría” in Spanish), which are convective storms taking place mainly in autumn. On the other hand, the district suffers from dry periods, alternating with relatively wet periods. This makes water scarcity during dry periods one of the worst problems in this region. Conjunctive use of surface-ground waters has been historically a very important option in the district. In recent years, this situation has triggered an increased use of non-conventional resources, such as wastewater reuse or desalination of sea water.

The Jucar RBD has a permanent population over 5 million inhabitants. Agricultural irrigation is the main water use in the Jucar RBD with a 78% of the total gross requirements (which includes net consumption, leakages and returns), urban and tourism necessities represent around 18% and industrial requirements use slightly less than 5% of the total consumptive uses. Otherwise, groundwater resources represent the 51% of the total water resource of the district in comparison with the 45% from surface water. Resources from reuse represent 3% of the total water resources. For more detailed information about the Jucar RBD, consult the web page of the Jucar RBA (www.chj.es).

A5.3.2. MODELLING THE JUCAR RBD BY USING AQUATOOL DSS

At this point, a water allocation model has been developed with SIMGES module in which all the required data related with water resources, infrastructures and water requirements are included. Given the high number of elements to include in the model, the layout of the model was designed by spreadsheet databases provided by the Jucar RBA. The simulation model includes: 28 artificial reservoirs, 18 lakes, 210 user groups, 20 hydropower stations and 116 groundwater bodies, identifying the detail and complexity of the system.

The elements represented in the water balance model are described below:

- Surface water bodies. They include all the rivers, reservoirs and lakes defined by the Centre for Public Works Studies and Experimentation (CEDEX) (CEDEX, 2005) to which was commissioned the development of the basic hydrographic network in the Iberian Peninsula for the Report to the European Commission on Articles 5 and 6 of the WFD (CHJ, 2005). The inclusion of surface water bodies in the model requires a huge amount of information related to maximum and minimum flows, priorities, aquifers in which flows infiltrate, among others. In the same way, reservoirs and lakes required data related to evaporation rate, information related to level-area-volume, and monthly maximum, target and minimum rules curves used for zoning the reservoirs in order to manage water according to the priorities, among others.
- Streamflows. Streamflow data series in natural regime included in the simulation model come from the results of PATRICAL rainfall-runoff model (Pérez-Martín et al., 2014). These results include the surface and groundwater flows, cover the period 1940/41-2011/12 and are expressed in hm^3/month units. It is noteworthy that the hydrological year in Spain begins in October during the beginning of the rainy season and finishes in September coinciding with the end of the irrigation calendar. Moreover in Spain water resources systems are characterized by a marked reduction in streamflows throughout the past 30 years (Pérez-Martín et al., 2013; Pedro-Monzonís et al., 2015a), being the reason why two periods are usually considered in Spanish water planning works that are 1940/41-2011/12 (long period) and 1980/81-2011/12 (short period). In this research, we simulate water resources

management models during the long period and we analyse the results obtained for the short period. Thus, we are approaching the current conditions and this allow us to obtain the initial volumes of reservoirs in an objective way.

- Groundwater bodies. We have included all groundwater bodies considered in water planning works in Jucar RBD as unicellular aquifer elements. It is required to highlight that a high number of them might be unnecessary because of their low exploitation degree. Instead of this, they have been included because one of the objectives is considering all the elements of the water balance, being or not relevant. The values of the aquifer discharge coefficient (α) have been obtained from PATRICAL model (Pérez-Martín et al., 2014). Groundwater bodies have been simulated by applying the principle of superposition (Reilly et al., 1984; Solera et al., 2010). This approach implies that any action has an effect on the piezometric levels and flows into the aquifer that can superimpose natural levels and flows.
- Water users. Three types of user groups were considered: 92 urban users, 95 agrarian and 23 industrial ones. Nominal water requirements contain a huge amount of information, such as the evolution of requirements during the year, the origin of the resource, returns and reliability criteria, among others. In relation to physical and use tables, traditionally in Spain the uses of water are divided into urban uses, agrarian uses, industrial uses for energy production, other industrial uses, aquaculture, recreational uses, boating and water transportation (BOE, 2008). This classification differs from the economic sectors described in ISIC (UN, 2008), consequently there are some sectors, such as division 36 and 37, which are difficult to include in our analysis. Other sectors such as service industries (divisions 38, 39 and 45-99) or households are both included in urban uses. In the case of Jucar RBD households represent 77% of urban requirements and service industries represent 23%.
- External transfers. Due to the water scarcity condition of Jucar RBD, the use of resources coming from other territories should be highlighted. Mancomunidad de los Canales del Taibilla (MCT) supplies water destined to urban uses. Their water supply is provided by the Tajo-Segura Aqueduct (ATS), the Taibilla River and desalination plants (March et al., 2014). Moreover, water resources from the ATS and Segura RBD

are used for agrarian requirements to the southern water exploitation system.

As far as water management is concerned, as many other stressed river basins, in Jucar RBD water users employ several sources of supplies. Urban supplies are generally guaranteed, however, agrarian supplies depend on the hydrological state of the system: normal, pre-alert, alert and emergency; defined by the Status Index from the National Drought Indicator System in Spain (Pedro-Monzonís et al., 2015b). The management of water resources made by SIMGES consists on, firstly, organizing water users according to their priority. In this way, urban users have higher priority than agrarian ones. In the case that a particular use can be supplied by more than one resource, supply priorities are used to rank the choices for obtaining water. Similarly, reservoirs are organized with priority numbers in order to release water firstly from reservoirs located downstream (inter-reservoir relationships). The model also considers operating rules, defined by monthly curves for a reservoir or a group of reservoirs which define a threshold to trigger an action, such as reducing or activating other sources of supplies (Lerma et al., 2014). During wet years, agrarian uses are supplied with conventional resources (surface or groundwater, as the case may be). In those years with less availability of surface streamflows (normal and pre-alert status), they use conventional resources and also non-conventional resources such as reused water. Under drought conditions (alert and emergency status) the use of non-conventional resources is widespread, such as emergency wells and desalination, and also external transfers are performed.

According to the water service costs collected from Annex 9 of the Jucar River Basin Management Plan (BOE, 2016) the average cost of water depends on several factors such as the origin (surface water, groundwater, reused water or desalinated water) and the use (agrarian use, urban use or industrial use). In the case of water transfers the prices of the services are published (BOE, 2012; MCT, 2016). In the case of urban use the average cost of water by employing surface supply is estimated in 1.38 €/m^3, groundwater supply is estimated in 1.61 €/m^3, desalinated water is estimated in 7.27 €/m^3 and water transferred from other territories in 2.02 €/m^3. In the case of industrial water the average costs are 1.45 €/m^3, 0.18 €/m^3 and 7.44 €/m^3 by employing surface, groundwater or desalinated water respectively. This disparity of average costs in desalinated water is explained by the huge investment in desalination plants during the last decade, which are no longer in operation, while surface infrastructures remain fully amortized. The average cost of collection and treatment of used water is 0.61 €/m^3 for both urban and industrial uses. On the other hand, agrarian supplies are estimated in 0.14 €/m^3 for surface water, 0.29€/m^3 for groundwater supplies, 0.23€/m^3 for reused water and 0.24 €/m^3 for water transferred from other territories. These costs have been obtained for the period 2004-2013 and they are expressed at constant 2012 prices, coinciding with the last year of the simulation.

A5.4. RESULTS

As an example of the applicability of SEEA-W approach in the Jucar RBD, the following sections present the physical supply and use tables, the asset accounts and an estimation of water services costs for the average year. The reference period used for the determination of these tables is 1980/81-2011/12.

A5.4.1. PHYSICAL SUPPLY AND USE ACCOUNTS

The physical use and supply tables are presented below (see table 1 and 2). As we observe in table 1, the major use is allocated for agrarian requirements (7772 hm^3/year) and energy production (6590 hm^3/year) followed at some distance by households (376 hm^3/year) and service industries (114 hm^3/year). Attending to the origin of water resources, abstractions from surface water for energy production represent the highest figures followed by abstractions from soil water for agrarian uses (5474 hm^3/year), while the rest of abstractions have relatively low values in comparison. With these elevated figures, the 4 hm^3/year of water abstracted from the sea go unnoticed despite their significance. Leaving aside energy production and soil water abstractions, taking into account the origin of water resources groundwater represents 51% of total water resources followed by surface water. On the other hand, according to the use of water received from other economic units, reused water in conjunction with water transferred from other territories play an important role in the district, representing 115 hm^3/year and 81 hm^3/year respectively. Reused water is mainly used in agrarian and industrial supplies while approximately, 40 hm^3/year coming from the MCT are destined to households and service industries, and about other 41 hm^3/year from the ATS and Segura RBD are used for agrarian supplies.

In table 2, we observe that the origin of reused water comes from households and service industries. This table also includes the volume of water returned by the different uses to water resources (surface water and groundwater) and to other sources (sea water). As expected, the highest returns come from hydropower production, which are equal to its abstractions. At this point, it is required to highlight that wastewater can be discharged directly into the environment (in which case it is recorded as a return flow) or supplied to another industry for further use (reused water). Once returns are discharged into the environment (row 5.a from table 2) if they are abstracted downstream, they may be considered as indirect reused water, or in other words, as new abstractions from the environment. However, when these volumes are used directly for other uses, mainly agrarian ones, we refer to them as direct reuse.

		Industries (by ISIC category)									
A. Physical use table (hm^3)		1 - 3	5 - 33, 41 - 43	35	36	37	38, 39, 45 - 99	Total	Households	Rest of the world	Total
From the environment	**1. Total abstraction (= 1.a + 1.b = 1.i + 1.ii)**	7772	95	6590			114	**14571**	376		**14947**
	1.a Abstraction for own use	7772	95	6590			114	**14571**	376		**14947**
	1.b Abstraction for distribution										
	1.i From inland water resources	7772	95	6590			114	**14571**	376		**14947**
	1.i.1 Surface water	1236	0	6590			37	**7863**	122		**7986**
	1.i.2 Groundwater	1062	95				77	**1234**	254		**1488**
	1.i.3 Soil water	5474						**5474**			**5474**
	1.ii Collection of precipitation										
	1.iii Abstraction from the sea						1	**1**	3		**4**
Within the economy	**2. Use of water received from other economic units**	150	6				9	**165**	31	0	**196**
	of which:										
	2.a Reused water	109	6					**115**			**115**
	2.b Transfers from other territories	41					9	**50**	31		**81**
	3. Total use of water (= 1 + 2)	**7922**	**101**	**6590**	**0**	**0**	**124**	**14736**	**407**	**0**	**15143**

Table 1. Physical use table for the average year 1980/81-2011/12 (hm^3)

		Industries (by ISIC category)							Households	Rest of the world	Total
B. Physical supply table (hm^3)		1 - 3	5 - 33, 41 - 43	35	36	37	38, 39, 45 - 99	Total			
Within the economy	**4. Supply of water to other economic units**	0	0	0	0	0	27	**27**	88	81	**196**
	of which:										
	4.a Reused water						27	**27**	88		**115**
	4.b Transfers from other territories									81	**81**
Into the environment	**5. Total returns (= 5.a + 5.b)**	835	81	6590	0	0	91	**7598**	301	0	**7898**
	5.a To water resources	726	81	6590	0	0	57	**7454**	187		**7641**
	5.a.i Surface water	271	81	6590			57	**6999**	187		**7186**
	5.a.ii Groundwater	455	0				0	**455**	0		**455**
	5.a.iii Soil water										
	5.b To other sources	109					35	**144**	113		**257**
	6. Total supply of water (= 4 + 5)	**835**	**81**	**6590**	**0**	**0**	**118**	**7624**	**389**	**81**	**8094**
	7. Consumption (= 3 - 6)	**7087**	**20**	**0**	**0**	**0**	**5**	**7112**	**18**	**-81**	**7049**
	7.a Losses from evaporation										
	7.b Losses in distribution not because of leakages										

Table 2. Physical supply table for the average year 1980/81-2011/12 (hm^3)

Based on the results of physical use and supply tables (see table 1 and table 2) the ratio between irrigation water consumed (2248 – 835 = 1613 hm^3/year) and irrigation water used (7922 - 5474 = 2448 hm^3/year) for the whole district is about 65%. This value represents the average efficiency of irrigation requirements in Jucar RBD. Although at first sight, this value may seem too low, we should highlight that the efficiency in the traditional irrigation users in Turia water exploitation system is more or less about 30%, while in Vinalopó-Alacantí water exploitation system the efficiency is more or less about 90% due to sprinkler and dripper irrigation systems.

A5.4.2. ASSET ACCOUNTS

Water asset accounts reflect a water balance in a territory, measuring the stocks at the beginning and at the end of a time period and recording the changes (increases or decreases) in the environment during that time. As we observe in table 3, the opening stocks in artificial reservoirs, which refer to the volume of water stored in September 1980, are 1510 hm^3 (far away from their total capacity estimated in 3336 hm^3). The opening stock in groundwater reaches the value of 92308 hm^3. This latter aggregates the results of the hydrological model and the water resources management model according to the principle of superposition (Reilly et al., 1984; Solera et al., 2010). Asset accounts are linked with water supply and use tables. As we observe, the returns that appear in asset accounts, which are 7898 hm^3/year, correspond to the total returns to water resources in the physical supply table (see row 5 from table 2). Turning to the returns, the highest values correspond with the returns of hydropower plants (6590 hm^3/year out of 7898 hm^3/year). On the other hand, about 455 hm^3/year of returns recharge the aquifers and the rest flow to rivers mainly. Precipitation is directly assigned to soil water (20798 hm^3/year). As indicated above, the abstraction that appears in table 3, which is 14947 hm^3/year, corresponds to the abstraction from water resources by the economy in the physical use table (see row 1.i from table 1). As we observe in table 1, rivers and soil water supply hydropower production and rainfed agriculture respectively. The largest amount of outflows are produced by rivers; comparing table 1 and table 3, we observe that 257 hm^3/year out of 1624 hm^3/year of outflows to the sea correspond with returns to sea water. The closing stocks are approaching to the opening ones, closing the balance in the environment for the average year. In general terms, the highest values in the district correspond with precipitation and evapotranspiration, being one order of magnitude bigger than abstractions, returns or outflows to the sea and, even more, considering that water used by hydropower plants is abstracted and returned many times. As a result, detecting possible errors in variables controlled by human actions becomes a very difficult task due to the fact that they remain masked by much bigger values. Similarly, table 4 represents the flows between water resources in the environment. This latter assists in identifying the contribution of reservoirs in the water resource management in the district, the contribution of groundwater to rivers, as well as the contribution of precipitation to river flows and groundwater recharge, among others.

	EA.131. Surface water				EA. 132 Groundwater	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks	**1510**	**25**		**0**	**92308**	**1405**	**95248**
Increases in stocks							
2. Returns	1	54	7389		455		**7898**
3. Precipitation						20798	**20798**
4. Inflows	4349	303	7283	0	3277	0	**15211**
4.a. From upstream territories							
4.b. From other resources in the territory	4349	303	7283		3277	0	**15211**
Decreases in stocks							
5. Abstraction	49	1	7936		1488	5474	**14947**
6. Evapotranspiration/actual evapotranspiration	80	66				11415	**11562**
7. Outflows	3768	236	6784	0	2815	3909	**17491**
7.a. To downstream territories							
7.b. To the sea		146	1624		509		**2279**
7.c. To other resources in the territory	3768	89	5139		2309	3909	**15211**
8. Other changes in volume							
9. Closing stocks	**1524**	**27**		**0**	**92290**	**1405**	**95246**

Table 3. Water asset accounts for the average year 1980/81-2011/12 (hm³)

	EA.131. Surface water				EA. 132 Groundwater	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA.1311 Artificial reservoirs	4349	303	3581		187		**3768**
EA. 1312 Lakes			89				**89**
EA. 1313 Rivers					487		**5139**
EA. 1314 Snow, ice and glaciers							**0**
EA. 132 Groundwater			2306				**2306**
EA. 133 Soil water			1306		2603		**3909**
Inflows from other resources in the territory	**4349**	**303**	**7283**	**0**	**3277**	**0**	**15211**

Table 4. Matrix of flows between water resources for the average year 1980/81-2011/12 (hm^3)

A5.4.3. VALUATION OF WATER SERVICES

Table 5 is inspired in hybrid accounts of SEEA-W approach and aims to describe the water services in physical and monetary terms in Jucar RBD for the average year. As stated above, the reference period used for the determination of these figures is 1980/81-2011/12. As we observe, the total water services costs in Jucar RBD amounts to 1634 million € per year at constant 2012 prices. Half of these annual costs corresponds to household uses, the rest is associated to agriculture and industry services. In relation to the supplies of water requirements, we distinguish between abstractions from surface water, groundwater, desalinated water, reused water and the use of water received from other territories. This availability of sources of supply is a crucial feature of water-stressed river basins, where water is scarce and the generation of additional resources is required to guarantee the water supplies. This fact translates into large investments and it is responsible of the increase of the total water services costs. In this sense, considering the desalination costs it is worth noting that desalinated water is only destined to supply urban uses.

	Industries (by ISIC category)							Households	Rest of the world	Total
	1 - 3	5 - 33, 41 - 43	35	36	37	38, 39, 45 - 99	Total			
1. Abstraction, storage, treatment and distribution (Million €)	522	29				202	**753**	661		**1414**
1.a Surface water	177					51	**228**	169		**397**
1.b Groundwater	311	28				124	**463**	408		**871**
1.c Desalinated water						7	**7**	22		**29**
1.d Reused water	25	1					**26**			**26**
1.e Transfers from other territories	10					19	**29**	62		**91**
2. Wastewater collection and treatment (Million €)		50				40	**89**	131		**220**
3. Total water services (Million €)	**522**	**79**				**241**	**842**	**791**		**1634**
4. Abstraction, storage, treatment and distribution (hm^3)	2448	101	6590			125	**9264**	410		**9673**
4.a Surface water	1236		6590			37	**7863**	122		**7986**
4.b Groundwater	1062	95				77	**1234**	254		**1488**
4.c Desalinated water						1	**1**	3		**4**
4.d Reused water	109	6					**115**			**115**
4.e Transfers from other territories	41					9	**50**	31		**81**
5. Wastewater collection and treatment (hm^3)		81				65	**145**	213		**358**
6. Total water services (hm^3)	**2448**	**182**	**6590**			**189**	**9409**	**622**		**10031**

Table 5. Valuation of water services for the average year 1980/81-2011/12 (Million € at constant 2012 prices)

A5.4.4. INDICATORS DERIVED FROM WATER ACCOUNTING

From the results above, some indicators have been acquired referred to the period 1980/81-2011/12. Asset accounts table enable us to obtain the External Renewable Water Resources (ERWR) (UNDS, 2012) consisting of groundwater transfers and river runoff proceeding from other countries, in the case study this concept reaches the value of 0 hm^3/year, as observed in row 4.a from table 3. On the other hand, as indicated in row EA. 133 Soil water from matrix of flows (table 4), the Internal Renewable Water Resources (IRWR) (UNDS, 2012) represents the amount of resources generated in the river basin from precipitation, which is 3909 hm^3/year in the Jucar RBD. The Total Natural Renewable Water Resources (TNRWR) indicator (UNDS, 2012) is obtained as the sum of IRWR and ERWR and it corresponds to the maximum theoretical amount of water available for a country on an average year in a long reference period. This indicator is the same as IRWR. To assess the abstractions and the degree of water stress suffered by the Jucar RBD, the Water Exploitation Index (WEI) (EEA, 2005) is described as the mean annual total abstraction of freshwater divided by the mean annual total renewable freshwater resource. For the period considered the WEI in the case study is 242%, showing a high degree of water stress in the river basin. This high figure is due to the consideration of hydropower abstractions in the calculation of the index. Leaving aside the abstractions made by hydropower stations the WEI is 74%, much lower than the obtained previously. In the same way, Water Consumption Index (WCI) (UNDS, 2012) represents the ratio between water consumption and TNRWR. As this indicator takes into consideration the amount of water returned into the environment, the value obtained for the WCI in the case study is 40%, relaxing the degree of pressure in the district. Similarly, according to the results of the average year 1980/81-2011/12 the ratio of desalinated water amounts to 0.02%, in the case of reused water this ratio is 0.8% and 0.5% of total water used derives from water transferred from other territories. Despite the apparently minor significance of these volumes, they represent almost 9% of total water services costs as noted in table 5.

A5.5. DISCUSSION

The SEEA-W approach represents a powerful tool for describing the water cycle, proving to be capable of improving transparency in water management decisions. Among its benefits, they allow users to detect deficiencies in controlling water in conjunction with a preventive use of water and the application of water rights. PATRICAL has allowed the collection of the water cycle parameters, which can not be obtained by monitoring, such as evapotranspiration, soil water, the distinction between surface and groundwater runoff or the returns to surface and groundwater bodies. Alone or, in combination with other tools, AQUATOOL DSS has demonstrated to be a reliable tool for building asset accounts and physical supply and use tables under SEEA-W approach, as it has been shown in this and other recent works (Pedro-Monzonís et al., 2016). And the acquisition tool AQUACCOUNTS has enabled to link the main variables of the rainfall-runoff model, with the results of the water allocation model and the economic data, enabling us to obtain the above water accounts in specific months or periods.

Several authors (Molden and Sakthivadivel, 1999; Momblanch et al., 2014; Tilmant et al., 2015; Pero-Monzonís et al., 2016) pointed out that the first handicap of water accounting is the spatial and temporal aggregation. Regarding the spatial consideration, this research has considered the whole territory of Jucar RBD, but it could be possible to apply this approach at each of the nine water exploitation systems that conforms the Jucar RBD. Regarding the temporal consideration, water balances and, hence, water accounts can be built at monthly scale, annual scale or for an average year. As noted by Tilmant et al. (2015), even though the SEEA-W is increasingly implemented, there is no agreement in which is the best approach to build its tables. In accordance with the main objective of the water accounting which is to compare hydrological information at spatial and at temporal scale, it is required to have standard procedures for calculating the water accounts.

In this paper physical use and supply tables and asset accounts have been obtained according to SEEA-W approach. According to the assignation system based on water rights in Spain, water is managed by river basin authorities in order to distribute surface and groundwater resources. In this sense, rainfed agriculture has traditionally played a secondary role in Jucar RBD. The difficulty of monitoring soil water abstractions is the reason why management models do not consider soil water as a source of water resources being hydrological models the providers of this information. It is necessary to emphasize that evapotranspiration represents a huge amount of water, distorting abstractions from surface and groundwater which are more interesting or decisive to the water users as noted by Momblanch et al. (2014). It is worth remarking that small errors in the evapotranspiration values may be in the same order of magnitude as the rest of water abstractions in the Jucar RBD. Note that in other regions in Spain rainfed agriculture plays an essential role and this point requires further in-depth analysis (Borrego-Marín et al., 2015). As far as hydropower abstractions are concerned, the values presented in the tables are obtained as a result of the water allocation model, which may overestimate the energy production as it considers that hydropower plants are operating 24 hours a day. These high figures of hydropower abstractions distorts the main uses in the district, and, even more, considering that in stressed river basins, the volume of water abstracted for hydropower generation depends on the water resources management and, in the case of Jucar RBD, water resources are mainly managed for urban and agrarian uses. Finally, there is a lack of information about losses in distribution networks which makes difficult to consider them.

In relation to asset accounts, it is worth noting that there are variables such as reservoir volumes, abstractions or outflows to the sea, which can be controlled by technicians, that might be covered up by other variables such precipitation or evapotranspiration (Pedro-Monzonís et al., 2016). In this sense, Momblanch et al. (2014) highlighted that small errors (5%) in these large terms may reach the same order of importance as water requirements.

In relation to the valuation of water resources, as noted by Borrego-Marín et al. (2015) “the implementation of SEEA-W remains scarce, and full exploitation of the economic tables of the framework is negligible”. Probably, the main reason is that water resources valuation can be quite complex due to the fact that data are often not available or too expensive to collect (UNDS, 2012). Up to now, economic information is presented in either administrative or regional scale, which does fit neither river basin nor water exploitation systems scale. As a result, the absence of direct sources of economic data for filling these tables involves downscaling statistics in many cases (Borrego-Marín et al., 2015), having serious obstacles when we analyse past series (EC, 2015). Here we present a straightforward approach based on average costs for all water services, which have been estimated according to cost recovery analysis. Our valuation of water services is inspired in SEEA-W hybrid accounts taking into account the restrictions of data availability. In this sense, the objectives of hybrid and economic accounts are to describe the supply and use of water related products in monetary terms and on identifying (a) the costs associated with their production; (b) the income generated by their production; (c) the investment in water related infrastructure and the maintenance costs; and (d) the fees paid by the users for water related services, as well as the subsidies received (UNDS, 2012). To do this, SEEA-W tables require information on output and supply of industries at basic prices, intermediate consumption and use, cost fixed capital formation, taxes and subsidies on products, and trade and transport margins among others. This amount of data is not always easy to find. In accordance with the approach proposed in this paper based on average costs instead of other cost-benefit analysis tools, considering these figures may be interesting from users point of view, due to the fact that they do not represent the users' costs as governments usually bear part of the expenses (Borrego-Marín et al., 2015). Besides, using average cost neglects the fact that optimal management decisions are based on marginal costs rather than average costs (Griffin, 2006). Lastly, in the case of energy production, it is not possible to know its average costs as energy sectors are not subject to a cost recovery analysis (EC, 2012).

On the other hand, several indicators have been obtained in order to maximise the profits of water accounting. In this sense, IRWR and ERWR are mainly based on the amount of water generated in a territory, paying attention to groundwater transfers and river runoff proceeding from upstream territories. Also, as noted by Pedro-Monzonís et al. (2016) these indicators (IRWR and ERWR) seem more appropriate for transboundary river basins, where water management affects the availability of water resources in the nearby region. At this point, we miss an indicator that reflects the need of using external water transfers from other territories. A first approach to the stress suffered for the system is presented through WEI and WCI, but they present some inconveniences related with seasonality (EEA, 2013) as they are defined at annual scale and they are not able to identify scarcity episodes at monthly level. In the case of WEI, the inclusion of hydropower abstractions for its calculation should be discussed. Moreover, according to Spanish law (BOE, 2008), water supplies are considered satisfied if their monthly/annual deficits do not exceed a certain threshold and this information is not presented in SEEA-W tables, questioning their validity for resource allocation and reservation purposes.

Another weakness of the SEEA-W tables is the fact they do not reflect environmental requirements. This is a crucial issue in water stressed river basins due to the fact that environmental benefits are extensively shared (Garrick et al., 2009) but the consideration of environmental flows may harmfully affect the current water uses in the river basin (Pellicer-Martínez and Martínez-Paz, 2016).

It is worth noting that Spanish Guideline of Water Planning (BOE, 2008) prioritises the environmental use of water front agrarian or industrial uses. During drought episodes, non-priority water uses are affected by a reduction in water availability and, moreover they are also affected by protection of the environment (Bennett, 2008). These circumstances have economic impacts that are not considered in hybrid and economical accounts. As noted in previous works (Pedro-Monzonís et al., 2016), improving water accounting methodologies in order to include environmental needs represents a clear requirement.

Water planning and management in water stressed river basins can be based on two possibilities: increasing water supply sources or focusing on demand management. Water supply in Spain during the last century has been based on enhancing water infrastructures (March et al., 2014). As noted by Ferrer (2012), in the Mediterranean region, the reuse of treated wastewater together with desalination represents a crucial element for the IWRM. Also the Intergovernmental Panel on Climate Change (IPCC) describes desalination as a conceivable choice, jointly with wastewater reuse, to amend the effects of climate change, specifically in arid and semi-arid regions (Bates et al., 2008). Nonetheless, desalination implies a high cost (related with energy consumption and CO_2 emissions) which is not affordable for farmers so only urban and tourism uses are willing to pay. Improving the knowledge on water services costs may help decision-makers and stakeholders with the adoption of new strategies compatible with economic developments and the sustainable use of water resources.

Despite all the benefits of the SEEA-W, water accounts provide a static representation of the region analysed (Momblanch et al., 2014). In our case, this image can vary temporally (from 1940 to 2012) and spatially (within each of the water exploitation systems in Jucar RBD). There are some valuable aspects that water accounts are not capable of offering in comparison with traditional analysis provided by water resource management models such as deficits on water requirements or the identification of the limit on total water abstractions. From the point of view of water planning and management, water accounts do not solve all the current inconveniences concerning water uses, in this sense, as noted by EC (2012) “water accounts alone are not enough as the information they provide is only the basis for action”.

A5.6. CONCLUSIONS

The main goal of this study, along with improving knowledge of all the components of the Jucar RBD itself, was the development of the required methodological tools for applying the SEEA-W and the acquisition of potential indicators derived from water accounting to be used during the planning and management stages of water resources. Therefore, this paper pretends to assist to the purposes of the "Blueprint to safeguard Europe's water resources".

In the case study analysed, the results indicate that for the average year 1980/81-2011/12, the total use of water in the district amounts to 15143 hm^3/year, being the TNRWR 3909 hm^3/year. The ratios of desalinated, reused water and water transferred from other territories amount to 0.02%, 0.8% and 0.5% respectively. On the other hand, the water service costs in Jucar RBD amounts to 1634 million € per year at constant 2012 prices, corresponding 9% of these costs to non-conventional resources, as described above.

This research has demonstrated the utility of hydrological and water resources management models for building asset accounts and physical supply and use tables under SEEA-W approach. The combined use of SIMGES and PATRICAL enable us to emulate the water cycle and water balances altered by human actions, taking into account water abstractions, returns, outflows to the sea or water transfers among others. The economic cost of water services has also been incorporated in a straightforward line, in conjunction with several indicators to reflect the water stress suffered in the territory. In any case, our methodology does not resolve all existing issues and there is still a long way to go in order to facilitate the evolutions and improvements that SEEA-W approach requires.

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ANNEX 6. WATER ACCOUNTING IN THE PO RIVER BASIN APPLIED TO CLIMATE CHANGE SCENARIOS[6]

Abstract

The influence of humans on the earth's temperature and climate is a fact recognised by scientific community and it is mainly caused by deforestation and burning fossil fuels. Mediterranean area is turning drier, becoming more vulnerable to wildfires and drought. In the coming years, it is expected that the increasing water demand in combination with water scarcity due to climate change would intensify the current water stress. The Po is the longest river in Italy, with a length of 652 km and it is also the largest river with an average discharge of 1540 m3/s. The Po Valley covers the economically most important area of Italy, and a population of more than 16 million which produces 40% of the national Gross Domestic Product. As other Mediterranean areas, this river basin is subject to high flow variation, frequent floods and periods of low flows that may be amplified in the coming years. The main objective of this study is to apply a modelling chain for the development of water accounting analysis in the Po River Basin, including the impact of climate change on the region. To do this, the climate change impacts have been obtained under the Intergovernmental Panel on Climate Change scenario RPC4.5. The hydrological/hydraulic components are simulated through a physically based distributed model (TOPKAPI) and a water balance model at basin scale (RIBASIM). The accounting approach has been the SEEAW. The results show that, in future scenarios, the

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application of measures will be required to mitigate climate change maintaining water allocations.

Keywords

Climate change, water accounting, System of Environmental-Economic Accounting for Water (SEEAW), Po River Basin

A6.1. INTRODUCTION

The influence of humans on the earth's temperature and climate is a fact recognised by scientific community, and it is mainly caused by deforestation and burning fossil fuels. All regions around the world are affected by climate change. According to European Commission [1] heat waves, forest fires and drought events are becoming frequent phenomena in Southern and Central Europe, while Mediterranean area is turning drier, becoming more vulnerable to wildfires and drought. The most important fact is that these impacts may be intensified in the coming years. In fact, several authors have reviewed climate change and land use impacts on water resources in European and Mediterranean areas manifesting that the increasing water demand in combination with water scarcity due to climate change would intensify the current water stress [2, 3].

To overcome this situation, adaptation actions are preventing the damage climate change can cause, saving lives and money later. Some examples of adaptation measures are adapting building codes to future climate conditions and extreme events, building flood defences, developing drought tolerant crops or the more efficiently use of scarce water resources [1]. Regarding the last, in this sense, the Blueprint to safeguard Europe's water resources [4] recognizes water accounting as a useful tool to supply basic information with the aim of providing support to decision-makers in water resource management [5, 6].

To assess the impacts of climate change on water resources management, the Po River Basin (PRB) in North Italy, has been selected as a case study, because of its importance, dimensions, availability of data, and the increased severity of drought and flood episodes in recent years. Other studies have been used as a basis for the development of this research. Vezzoli et al. [7] studied the climate change impacts on the whole PRB under RPC4.5 scenario to 2040 applying the bias correction to the outputs of impact model and not to climate data, showing a reduction on discharges.

Afterwards, Vezzoli et al. [3] simulations are extended to 2100 under RPC4.5 and RPC8.5 scenarios to evaluate water availability in the PRB.

This work is presented as follows: Section 2 summarises the methodology of the approach; Section 3 describes briefly the climate and hydrology of the PRB; in Section 4 the asset accounts for the considered scenarios are presented; Section 5 presents the discussion; and finally in Section 6 the main conclusions are drawn.

A6.2. METHODOLOGY

The target of implementing climate and hydrological simulations is to assess the impacts of climate change and also the capability of PRB to adapt to new conditions. The methodology proposed consists on the application of four consecutive stages: 1) a module for the climate; 2) a fully distributed physically-based rainfall-runoff model (TOPKAPI); 3) a water resources management model (RIBASIM) for simulating the behaviour of river basins during varying hydrologic conditions, and 4) the building of the required databases to connect the two latest models to organize the information to obtain the asset accounts under SEEAW methodology.

The climate change impacts on the period 2001-2100 have been simulated under the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCP) 4.5 [8]. The hydrological model is composed by TOPKAPI (TOPographic Kinematic Approximation and Integration) model [9], a fully-distributed physically-based rainfall-runoff model that can provide high resolution information on the hydrological state of a catchment. Once obtained the runoff, this is the input to RIBASIM (River Basin Simulation Model) [10], a water balance model to simulate the behaviour of river basins during varying hydrologic conditions (see Figure 1). More detailed information about the application of these models in the case study are described in Vezzoli et al. [7] and Vezzoli et al. [3].

The accounting approach applied in this research has been the System of Environmental-Economic accounting for Water (SEEAW) [11]. As other accounting approaches, SEEAW was developed with the objective of standardizing concepts and methods in water accounting for organizing economic and hydrological information permitting a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources. SEEAW comprises five categories of accounts, this research is focused on obtaining asset accounts.

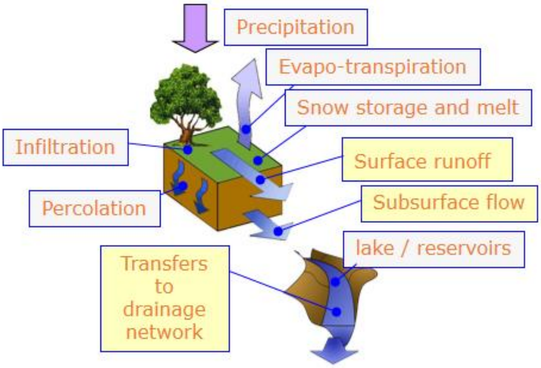

Figure 1. Scheme of the water resources assessment in Po River Basin

A6.3. DESCRIPTION OF THE CASE STUDY: THE PO RIVER BASIN

The Po is the longest river in Italy, with a length of 652 km from its source in Cottian Alps (at Pian del Re) to its mouth in the Adriatic Sea, in the north of Ravenna (see figure 2). It is also the largest river with an average discharge of 1540 m^3/s. The river basin area extends on about 71.000 km^2 in Italy, and about 3000 km^2 in Switzerland and France.

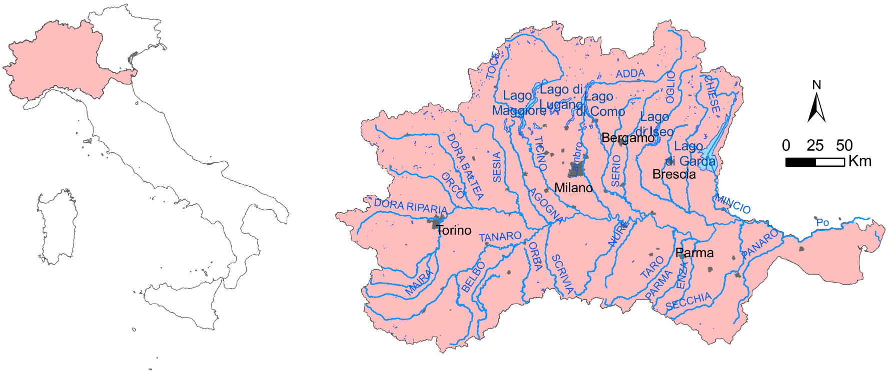

Figure 2. Location of the Po River Basin

Discharges are characterized by two maxima, in spring and autumn, and two minima, in winter and summer. On the one hand, the regime of Alpine tributaries responds to temperature pattern; late spring and summer discharges are the results of snow and glacier melting processes with a maximum in summer and a minimum in winter. On the other hand, the regime of Apennines tributaries are driven by precipitation, showing two maxima and two minima. In the Alpine area, there are 4 natural big lakes and 174 reservoirs, of which 143 are artificial reservoirs for hydropower production; furthermore, the basin comprises over 600 km^2 of glacier areas.

Climate conditions in the Po area are changing in a sensitive way: from 1960 to present an increase of the annual mean temperature of about 2°C has been observed, with a relevant increase of the linear trend which leads to forecasting an increase of the annual mean temperature close to 3-4 °C at the end of the century. The decrease of precipitation is not so evident, nevertheless, an increase in the intensity of the single rainfall events, but an overall decrease in the total number of the rainfall events can be observed, resulting in a decrease of the annual mean precipitation of about 20% observed during the last thirty years. The decrease is more evident during spring and summer seasons (when a maximum decrease of about 50% can be noticed) whereas the inter-annual variability increases. Furthermore, due to the strong negative correlation between the decreasing snow coverage and the increasing air temperature, a constant retreatment of the alpine glaciers is expected.

The PRB covers the economically most important area of Italy, and a population of more than 16 million which produces 40% of the national Gross Domestic Product (GDP). Water uses within the PRB come from the electricity sector, from inland navigation and for an irrigation based agriculture. The river is subject to high flow variation, frequent floods and periods of low flows. Total water abstraction account to more than 20.5 billion m^3 per year, most part of which (16.5 billion m^3) is used in agriculture/irrigation, 2.5 billion m^3 for drinking water and 1.5 billion m^3 for industrial uses. Abstractions account for 14.5 billion m^3 for surface waters and for 6 billion m^3 for groundwater.

In this research, we concentrate on Pontelagoscuro station, which is representative of the water cycle on the whole PRB.

A6.4. RESULTS

Water accounts enable us to compare hydrological information at temporal scale. As an example of the applicability of the model chain, the following sections show the asset accounts in the current scenario, taking as a reference the hydrological year 2010/11; and in the RCP 4.5 scenario to consider the effects of climate change, taking as a reference the time horizon 2040/41. The simulation of the current scenario has been driven by climate observations and it is used as a reference. For the scenario RCP 4.5, the simulations of precipitation and temperature until 2100 were provided by the Euro-Mediterranean Centre on Climate Change (CMCC). These simulations were obtained from the regional model COSMO-CLM model-driven global CMCC-CM [12]. RCP 4.5 scenario considers a stabilization of the entire radioactive forcing by 2100 through the adaptation of technologies and strategies to reduce greenhouse gas emissions [3]. This scenario assumes an increase in CO2 emissions until 2040 and a later decrease to less than the present, approximately 4.2 PgC / Yr.

A6.4.1. CURRENT SCENARIO

As we observe in table 1, at the beginning of the year the volume of reserves are over 95 km^3, while closing stocks include over 93 km^3. The values of snow and groundwater volumes at opening and closing stocks are explained by the principle of superposition [13]. In other words, we must pay attention to the changes in volumes and not in the volumes themselves. During 2010/11 precipitation represents more than 80 km^3, mainly in the form of rain. The volume abstracted for water uses comes from the intakes located in the river. It is also relevant that the amount of evapotranspiration from soil is twice than the water abstracted for water uses. On the other hand, the outflows to the sea exceeds 50 km^3. Other changes in volume are considered to close the balance, being explained the uncertainties such as variation in the river levels or aquifers and representing an error of 5% in the whole river basin. According to table 2, the main exchanges of flows between water resources are those between soil water and rivers.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks		**1.21**		**75.25**	**0.47**	**18.68**	**95.53**
Increases in stocks							
2. Returns			0.88		4.92		**5.79**
3. Precipitation				4.80		77.56	**82.37**
4. Inflows							
4.a. From upstream territories							
4.b. From other resources in the territory			66.73		19.40	5.59	**91.71**
Decreases in stocks							
5. Abstraction			14.69				**14.69**
6. Evapotranspiration/actual evapotranspiration						28.60	**28.60**
7. Outflows							
7.a. To downstream territories			0.34				**0.34**
7.b. To the sea			52.19				**52.19**
7.c. To other resources in the territory			14.55	5.59	14.25	57.32	**91.71**
8. Other changes in volume			14.18		-10.11	0.89	**4.96**
9. Closing stocks		**1.21**		**74.46**	**0.42**	**16.74**	**92.83**

Table 1. Water asset accounts in the Po River Basin in 2010/11 (km^3/year)

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA.1311 Artificial reservoirs							
EA. 1312 Lakes							
EA. 1313 Rivers					14.55		**14.55**
EA. 1314 Snow, ice and glaciers						5.59	**5.59**
EA. 132 Groundwater			14.25				**14.25**
EA. 133 Soil water			52.48		4.84		**57.32**
Inflows from other resources in the territory			66.73		19.40	5.59	**91.71**

Table 2. Matrix of flows between water resources in the Po River Basin in 2010/11 (km^3/year)

A6.4.2. SCENARIO RCP 4.5

Table 3 shows as at the beginning of the time horizon 2040/41 the volume of reserves are over 72 km^3, and closing stocks are over 67 km^3. The main differences are in the volume of snow reserves, which have been considerably reduced due to the increase of temperatures. During this year, precipitation represents more than 57 km^3, mainly in the form of rain. It is also noteworthy that the amount of evapotranspiration from soil is three times the water abstracted for water uses (twice for the current scenario). Moreover, outflows to the sea have been reduced to around 33 km^3. As we observe in the matrix of flows for the current scenario, table 4 shows that the main exchanges of flows between water resources are those between soil water to rivers.

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Total
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
1. Opening stocks		**1.21**		**53.63**	**0.38**	**17.04**	**72.27**
Increases in stocks							
2. Returns			0.28		3.07		**3.34**
3. Precipitation				3.34		54.29	**57.62**
4. Inflows							
4.a. From upstream territories							
4.b. From other resources in the territory			42.91		12.11	4.49	**59.50**
Decreases in stocks							
5. Abstraction			8.31				**8.31**
6. Evapotranspiration/actual evapotranspiration						22.16	**22.16**
7. Outflows							
7.a. To downstream territories			0.28				**0.28**
7.b. To the sea			32.91				**32.91**
7.c. To other resources in the territory			9.61	4.49	9.74	35.66	**59.50**
8. Other changes in volume			7.93		-5.50	-4.61	**-2.18**
9. Closing stocks		**1.21**		**52.48**	**0.32**	**13.39**	**67.40**

Table 3. Water asset accounts in the Po River Basin in time horizon 2040/41 (km^3/year)

	EA.131. Surface water				EA. 132 Ground water	EA. 133 Soil water	Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers			
EA.1311 Artificial reservoirs							
EA. 1312 Lakes							
EA. 1313 Rivers					9.61		**9.61**
EA. 1314 Snow, ice and glaciers						4.49	**4.49**
EA. 132 Groundwater			9.74				**9.74**
EA. 133 Soil water			33.17		2.49		**35.66**
Inflows from other resources in the territory			42.91		12.11	4.49	**59.50**

Table 4. Matrix of flows between water resources in the Po River Basin in time horizon 2040/41 (km^3/year)

A6.5. DISCUSSION

Despite all the uncertainties introduced by the assumptions associated in each step of the simulation chain [7], TOPKAPI and RIBASIM have been found to be a robust and powerful tool for the application of water accounting in the case study. As noted by Momblanch et al. [5], water balances cannot be more precise than the available records and observations in the basin.

As we know, future is uncertain and we use IPCC climatological scenarios in order to help water end users to prepare for the future. These scenarios are coherent and consistent descriptions about how climate on the Earth can change in the future. Figure 3 is presented below in order to show how the evolution of water resources in the future could be. The indicator named Total Actual Renewable Water Resources (TARWR) represents the maximum theoretical amount of water actually available at a given moment. A priori, figure 3a shows that the TARWR in RCP 4.5 scenario during the time horizons 2020/21, 2040/41 and 2099/00 is in the same order of magnitude than for the current scenario (2010/11). But, as it is observed high flows in spring due to snow melting processes become more frequent in RCP 4.5 scenario also with the intensification of low flows in summer. In the same way, figure 3b shows a reduction in the volume of snow stored in the river basin. It is noteworthy to highlight that as the total volume is unknown, we consider an initial volume of 100 km^3 of snow and this amount reduces over the time horizons.

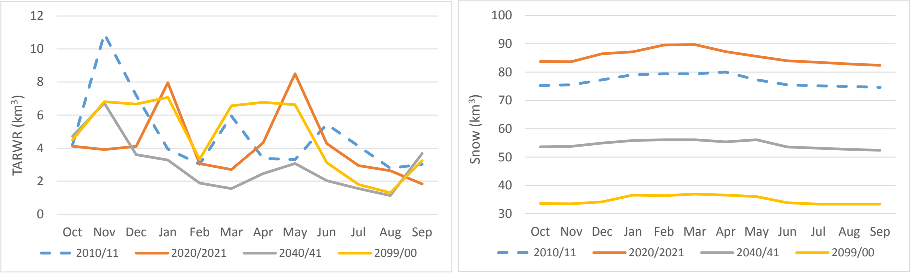

Figure 3. (a) Total Actual Renewable Water Resources (TARWR) and (b) volume of snow reserves for RPC4.5 scenario in selected time horizons

The consequences of polar ice sheets and glaciers melting may cause an increase in river levels, resulting in flooding and erosion along the river banks and causing damage to properties and infrastructures.

A6.6. CONCLUSIONS

The main objective of this study has been, on the one hand, the improvement of knowledge of the system itself and, on the other hand, the development of the methodological tools for the development of water accounting analysis in the Po River Basin, analysing the impact of climate change on the region.

The main conclusion obtained from this research is the fact that TOPKAPI and RIBASIM are reliable tools that provide information enough for asset accounts under the SEEAW methodology, allowing the collection of those parameters of water cycle that can not be obtained by monitoring.

This work has represented a first approximation of the development of water accounting, since new improvements in the chain model will allow us to consider the changes in the volumes and the amount of evaporation in reservoirs and lakes, the supply to groundwater demands, among others. Future works are aimed at including the economic issues in order to use this modelling chain as a predictive instrument for the implementation of measures required to improve the use of water resources according to the indications of the Blueprint.

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