Science of the Total Environment 565 (2016) 181–190

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Water accounting for stressed river basins based on water resources management models

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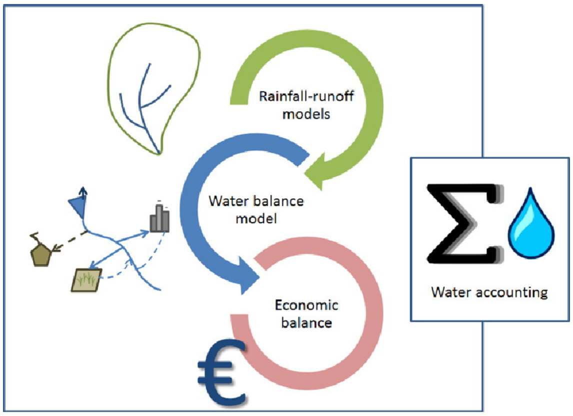
HIGHLIGHTS

- Water accounting allows comparing hydrological data at spatial and temporal scale.
- Jucar River Basin District represents an example of water stressed river basins.
- Simulation models solve the difficulties in monitoring the water cycle components.
- Knowing water services costs enables the sustainable use of water resources.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 December 2015
Received in revised form 8 April 2016
Accepted 22 April 2016
Available online xxxx

Editor: D. Barcelo

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

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 15,143 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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http://dx.doi.org/10.1016/j.scitotenv.2016.04.161

1. Introduction

The EU Water Framework Directive (WFD) (EP European Parliament, 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 (European Commission), 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; Pedro-Monzonís et al., 2016; Tilmant et al., 2015). 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., 2006).

Both WFD and Blueprint emphasize 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 organizing 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); and (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).

2. Materials and methods

The proposed methodology (see Fig. 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.

The PATRICAL model (Pérez-Martín et al., 2014) is a large-scale, conceptual, and monthly, spatially distributed (grid 1×1 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).

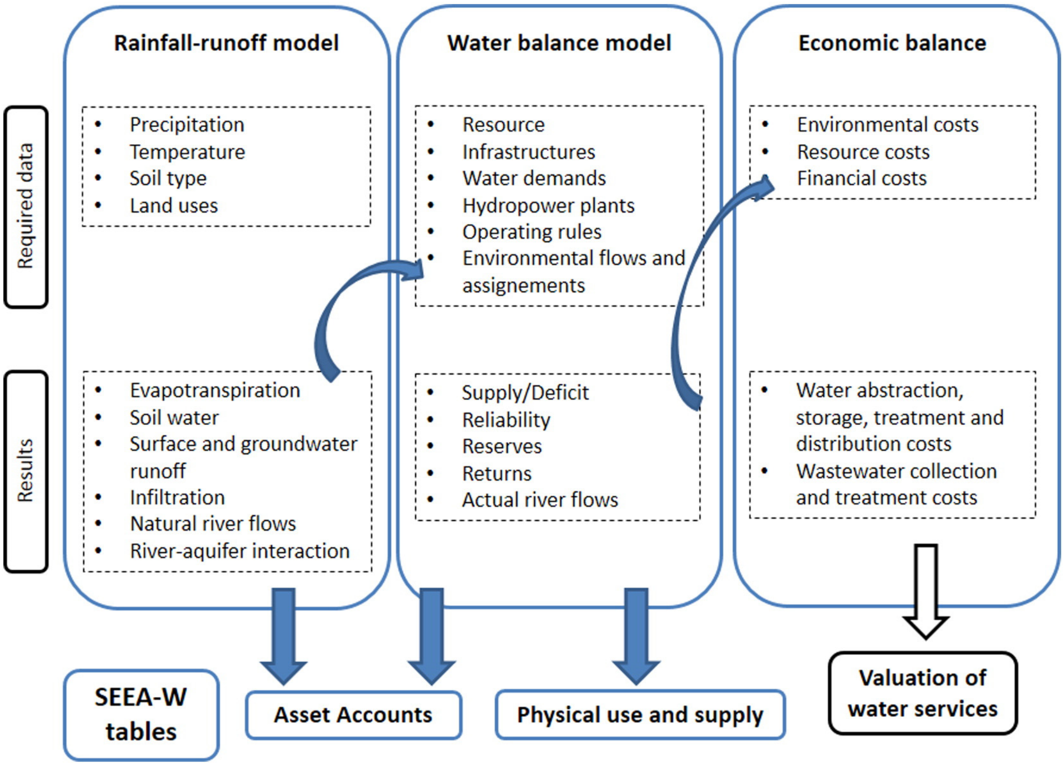

Fig. 1. Scheme of the approach to obtain SEEA-W tables by using different types of models related to water resources management.

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 & 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; and
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.

3. Case study: the Jucar River Basin District

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 Fig. 2).

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).

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 (Pedro-Monzonís et al., 2015a; Pérez-Martín et al., 2013), 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

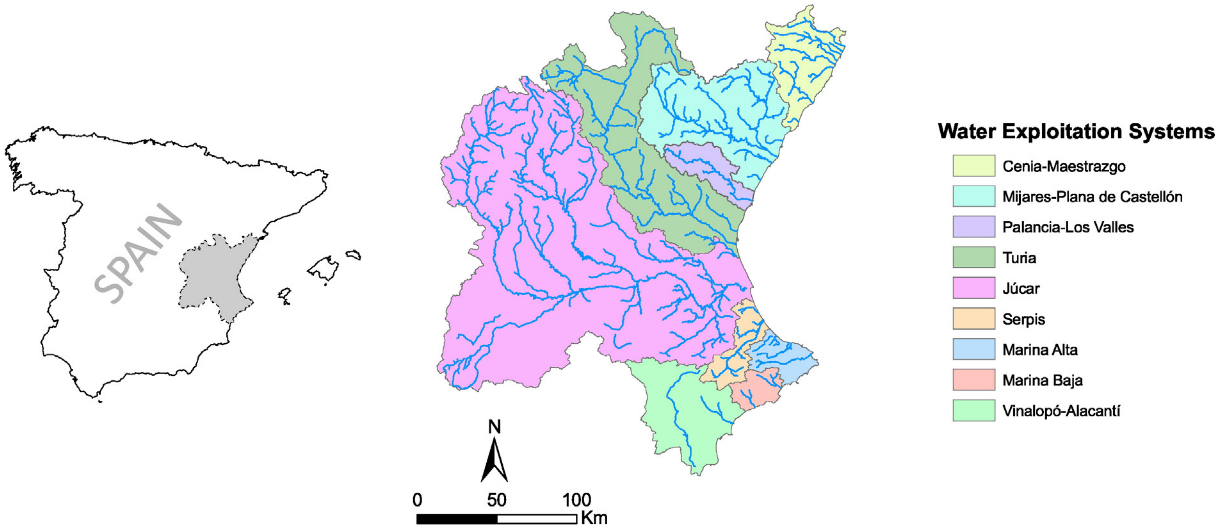

Fig. 2. Location of the Jucar RBD in the Iberian Peninsula.

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, prealert, 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.

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.

4.1. Physical supply and use accounts

The physical use and supply tables are presented below (see Tables 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.

Based on the results of physical use and supply tables (see Tables 1 and 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

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

A. Physical use table (hm^3)		Industries (by ISIC category)							Households	Rest of the world	Total
		1–3	5–33, 41–43	35	36	37	38, 39, 45–99	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 of which:	150	6				9	165	31	0	196
	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

water exploitation system the efficiency is more or less about 90% due to sprinkler and dripper irrigation systems.

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 92,308 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 (20,798 hm^3/year). As indicated above, the abstraction that appears in Table 3, which is 14,947 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 Tables 1 and 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.

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,

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

B. Physical supply table (hm^3)		Industries (by ISIC category)							Households	Rest of the world	Total
		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 of which:	0	0	0	0	0	27	27	88	81	196
	4.a Reused water							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 3
Water asset accounts for the average year 1980/81–2011/12 (hm^3).

	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**
Increase 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							**0**
7.b. To the sea		146	1624		509		**2279**
7.c. To other resources in the territory	3768	89	5139		2306	3909	**15211**
8. Other changes in volume							
9. Closing stocks	**1524**	**27**		**0**	**92290**	**1405**	**95246**

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.

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.

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 cannot 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.

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

	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			3581		187		**3768**
EA. 1312 Lakes			89				**89**
EA. 1313 Rivers	4349	303			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 5
Valuation of water services for the average year 1980/81–2011/12 (million € at constant 2012 prices).

	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

Several authors (Molden & Sakthivadivel, 1999; Momblanch et al., 2014; Pedro-Monzonís et al., 2016; Tilmant et al., 2015) 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 h 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 & 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”.

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 15,143 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.

Acknowledgements

The authors thank the anonymous reviewers for their valuable comments, suggestions and positive feedback. All remaining errors, however, are solely the responsibility of the authors. We would also like to express our gratitude to the Jucar River Basin Authority – Confederación Hidrográfica del Júcar (Spanish Ministry of Agriculture, Food and Environment) for providing data to develop this study. The authors wish to thank the Spanish Ministry of Economy and Competitiveness for its financial support through the NUTEGES project (CGL2012-34978). We also value the support provided by the European Community's Seventh Framework Program in financing the projects ENHANCE (FP7-ENV-2012, 308438) and IMPREX (H2020-WATER-2014-2015, 641811).

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