Chapter 7

An overview of groundwater resources in Spain

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ABSTRACT: In Spain, as in most arid and semiarid countries, during the last half century the *silent revolution* of intensive groundwater use has provided important socio-economic benefits. Nonetheless, traditionally water management has focused on surface water and has paid little attention to groundwater. The European Water Framework Directive (WFD) planning process has resulted in significant advancements in the knowledge of groundwater resources and their use in Spain. However, data on groundwater resources are still partially incomplete and an official country-wide overview of groundwater resources (and their uses) is still not available. At present the estimated groundwater demand is about 7,000 million m^3/year, mainly for irrigation purposes. Intensive groundwater use has contributed to the degradation of this strategic resource, which is expected to be partially remediated by the WFD implementation. Previous studies in Andalusia found that in irrigated agriculture groundwater use was economically more productive than surface water. This was attributed to a series of factors, chiefly groundwater resilience to long dry spells, and it was suggested that this could apply also to other regions in Spain. The data presented in this chapter seem to question this former idea, since no clear correlation could be found between the source of water and its apparent water productivity in irrigated agriculture. This is an issue that merits further study, including combining local and country-wide data to refine the calculations.

Keywords: groundwater, economic uses, water quantity, water quality, Water Framework Directive, groundwater body

1 INTRODUCTION

Groundwater (GW) has often been called the *hidden* resource: by nature groundwater is *out of sight* and therefore often also *out of mind* for policy-makers, lay people, and, to a lesser extent, water practitioners. Nonetheless, this resource has allowed for a significant socio-economic development in many regions of the world, and plays a strategic role in many countries, especially in arid and semiarid regions. Spain, with a semi-arid climate in most of its territory, is no exception to these trends and the key role played by groundwater in several spheres of Spanish society (urban supply, economic uses or groundwater-dependent ecosystems) makes it crucial to have a good knowledge of this resource.

Studies of specific aquifers are of great value for collecting high-resolution data and understanding local dynamics. At the same time, country-wide studies of groundwater resources and their uses have the value of helping decision-makers, practitioners and scientists to grasp the magnitude of groundwater challenges at a country level and to frame local water problems into a *bigger picture*. Thus, country-wide analyses allow for a better understanding of inter-linkages, similarities and differences between challenges at different scales; and the identification of possible links between the evolution of groundwater use and other water-related phenomena such as changes in groundwater quality, the appearance of new water uses, or the creation of different forms of groundwater user associations. Moreover, the assessment of the monetary value of groundwater uses provides an overview of their economic relevance, informing decisions related to water rights reallocation or investments in new water infrastructure.

At present, no recent general overview of Spanish groundwater resources and uses is available. The Groundwater White Book (MIE & MOPTM, 1995), the Water White Book (MMA, 2000) and the book by Llamas *et al.* (2001) are the only comprehensive studies on this subject that have been undertaken in Spain during the past two decades. Dumont *et al.* (2011) and Molinero *et al.* (2011) made a first attempt to fill this gap with an overview of groundwater uses and status based on the RBDs planning documents available in year 2010. In terms of economic value, regional and local studies on the value of groundwater uses provide interesting insights into the subject (e.g. Hernández-Mora & Llamas, 2001; Aldaya & Llamas, 2008; Salmoral *et al.*, 2011), while the most recent works on the economic value of water uses at national level do not distinguish between ground and surface water (MMA, 2007; Garrido *et al.*, 2010).

This chapter aims at providing this missing overview at national level in Spain. A key source of information for the elaboration of the present analysis has been the official documentation produced by the River Basin Organisations (RBOs) as part of the new planning process required by the European Water Framework Directive (WFD, see Chapter 3). Due to delays in the WFD planning process, part of the data for some River Basin Districts (RBDs) (e.g. Tagus, Ebro) were still unavailable at the termination of this chapter.

This chapter starts with an overview of current estimates of groundwater resources, their quantitative and qualitative status, and continues with a snapshot of groundwater uses by the different sectors, with special emphasis on the economic value of irrigated agriculture. It concludes with considerations of the challenges ahead in improving the knowledge of this strategic resource.

2 GROUNDWATER RESOURCES

During the last decade, the regulatory system of the Spanish groundwater sector has experienced several changes, mainly due to the approval and transposition of the WFD (Directive 2000/60/EC, transposed into Spanish law in 2003) and the associated Directive for the protection of groundwater (Directive 2006/118/EC, transposed in 2008).

In terms of water planning, the WFD involves changing the basic groundwater management unit, from hydrogeological units (HUs) to groundwater bodies (GWBs). A groundwater body includes one or several aquifers (or portions of them) whose waters have common characteristics and are confronted with similar challenges – either qualitative or quantitative. During the WFD planning process, 730 GWBs have been identified and characterized across the country (Figure 1). The shift from hydrogeological units to GWBs has meant almost doubling the number of groundwater management units relative to the former 411 HUs. The HUs covered around a third of the area of Spain (over 175,000 km^2) while the GWBs now include almost two thirds of the whole territory (about 350,000 km^2). This change of management units has implied including in the planning process aquifers that locally play a key role in water supply (e.g. for some small urban areas) and that previously were not considered as HUs because of their limited water yield. Moreover, it has entailed an important effort in the definition and characterization of the new GWBs and increased management efforts in terms of monitoring and implementation of measures to ensure good status for a larger number of aquifers.

The WFD River Basin Management Plans (RBMPs) contain two main sections assessing groundwater resources: the inventory of natural water resources, which includes hydrological series of aquifer recharge and groundwater flow (and other variables); and the assessment of the available resources, which in turn is estimated using the concept of renewable resource.

The WFD and the IPH (*Instrucción de Planificación Hidrológica*, or technical instructions to guide the hydrological planning process; MARM, 2008) issued by the former Spanish Ministry for Environment, Rural and Marine Affairs (MARM)

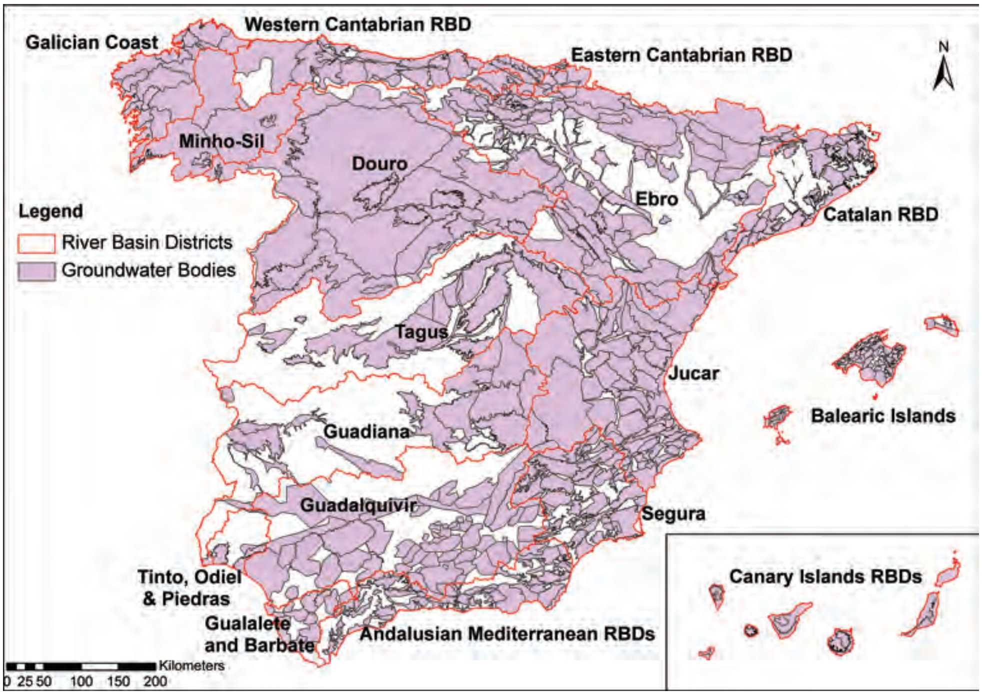

Figure 1 Groundwater bodies in Spain. (Source: Own elaboration from data of SIA (2012)).

provide guidelines to homogenize the approach of River Basin Organisations to the assessment of groundwater. Nonetheless, the application of IPH is compulsory only in inter-regional RBDs[1], and even in these ones, there has been a certain heterogeneous interpretation of some of the established guidelines (see also Dumont *et al.*, 2011). This should be taken into account when interpreting the overall and RBD-specific figures presented in the next pages.

Table 1 summarizes the estimates of recharge, renewable resources and available resources, as provided in the RBDs planning documents made available at the end of

Table 1 Number of groundwater bodies (GWB), renewable resource and available resource by River Basin District (RBD).

River Basin District	*# GWB*	*GWB area (km^2)*	*Recharge[a] (mm/year)*	*GW renewable resource[b] (hm^3/year)*	*Available GW resource (hm^3/year)*
Galician Coast	18	12,988	242	3,869	3,471
Minho-Sil	6	17,602	ND	3,774	3,193
Western Cantabrian RBD	20	13,875	301	4,217	3,328
Eastern Cantabrian RBD	14	3,472	386	1,273	1,090
Douro	64	75,885[c]	71	3,737	2,990
Ebro	105	54,125	ND	ND	ND
Catalan RBD	39	11,254	70	1,930	1,141
Tagus	24	21,866	ND	ND	ND
Guadiana	20	22,484	34	550	623
Jucar	90	40,135	61	3,355	2,327
Segura	63	18,500	36	700	535
Guadalquivir	60	35,609	ND	2,700	1,962
Tinto, Odiel & Piedras	4	1,018	56	66	46
Guadalete & Barbate	14	1,927	ND	166	52
Andalusian RBDs	67	10,395	80	833	676
Balearic Islands	90	4,737	ND	410	181
Canary Islands[d]	32	7,425	2–370	ND	360
Total	730	353,297	–	–	21,975[e]

Source: Own elaboration from RBDs planning documents publicly available in December 2011.

Notes
The autonomous cities of Ceuta and Melilla are not included. ND = No Data. In the case of Tagus, Ebro and some of the Canary RBDs, the lack of data is due to a delay in the planning process.
[hm^3 = cubic hectometre = million m^3 = 10^6 m^3].

a In the RBMPs there is some terminological confusion about groundwater recharge, rainfall infiltration and renewable resource: the same terms not always refer to the same concepts, and different terms sometimes refer to the same concept.
b In some cases these figures represent the *potential resource* or *natural GW resource*. The meaning of these values can be slightly different even when the term used in the RBMP is *renewable resource*.
c Surface area corresponding to the lower groundwater units.
d Figures for the Canary Islands summarize the results of their 7 RBDs (one for each island).
e Tagus and Ebro are not included in this figure.

1 Inter-regional RBDs are those shared by several regions (Autonomous Communities) and are managed by the central government through River Basin Organisations called *Confederaciones Hidrográficas*. RBDs located entirely in one region are managed by RBOs called *Agencias Autonómicas del Agua*.

2011 and shows that the overall available groundwater resources are calculated to be approximately 22,000 hm^3/year [hm^3 = cubic hectometre = million $m^3 = 10^6 m^3$]. This represents a significant share of the regulated Spanish water resources, as the storage capacity of surface water reservoirs for consumptive use is about 55,400 hm^3 and the average surface water reserve for consumptive use during the last ten years was approximately 33,400 hm^3 (MAGRAMA, 2012).

The estimation of the available groundwater resources is particularly sensitive and challenging because it defines the amount of water that is actually available for economic uses and determines the quantitative status of a groundwater body. According to the WFD definition, which was translated literally into the IPH, the available groundwater resource "means the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters … to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems" (WFD, art. 2).

According to this definition, all the inputs to a GWB are accounted as renewable resource (including irrigation return flows), which can lead to some resources being taken into account more than once if, for example, GW resources estimates for each GWB are added together to obtain a global figure for the whole RBD (see also Martínez Cortina *et al.*, 2011). Moreover, the quantification of water needs for the associated surface water bodies and terrestrial ecosystems is very challenging, since there are no widely accepted criteria to define them (see also Chapter 11).

Undoubtedly the different characteristics of each RBD and GWB make it difficult to strictly apply the same criteria in all of them. Nonetheless, it seems that in the WFD planning process there are also some terminological and conceptual uncertainties that have led to a heterogeneous interpretation of some concepts, mainly in relation to renewable and available resources (Box 1).

Box 1 Some examples of criteria for the calculation of the available GW resources

– In Minho-Sil the renewable resource is considered to be equal to the rainfall infiltration estimated using a hydrological model. The available resources are at least 10% of the renewable resource, with additional requirements in protected river stretches.
– In Douro the RBMP estimates the *total natural resource*, which takes into account both lateral groundwater transfers and the so-called rejected recharge (when infiltration is larger than what the GWB can store). The available resource is 80% of the total natural resource, plus the return flows and the artificially recharged volumes.
– The Balearic Islands RBMP uses the term *potential GW resource* referring to all the system inputs (infiltrated rainfall). The available resources are those abstracted in 2006 (estimate based on water demands).
– In Guadalquivir the renewable resource corresponds to the aquifer recharge. The available resource is 80% of that figure, except in specific GWB where it is 50%.

(Source: based on RBDs planning documents publicly available in December 2011)

3 GROUNDWATER STATUS

The WFD has shifted the focus of groundwater management from only satisfying water demands to achieving good chemical and quantitative status[2] of groundwater bodies, as well as protecting the associated aquatic and terrestrial ecosystems. In Spain more emphasis has traditionally been set on quantitative problems than on the deterioration of groundwater quality, although in many cases this does not reflect the real challenges in the medium or long term (see Chapter 12). The WFD gives equal weight to these two aspects of groundwater protection and underscores that they are closely intertwined. Indeed the Directive requires European Union (EU) Member States to assess both the chemical and the quantitative status of groundwater bodies and establishes that the global status of a particular GWB is determined by the poorer of the two.

The WFD requires that all the GWBs be in (at least) good status by 2015, although it is possible to request time extensions to 2021 and 2027 or to set less stringent objectives (LSO) for those GWBs where good status cannot be met. According to the RBDs planning documents, 392 of the 730 groundwater bodies are currently in good status (54%); 583 groundwater bodies will meet the objective of good status by 2027 (about 80% of the GWBs), while less stringent objectives have been set in 26 GWBs (4%). In the remaining 121 GWBs (17%) there are insufficient data to predict the achievement of good status by 2027 (Figure 2).

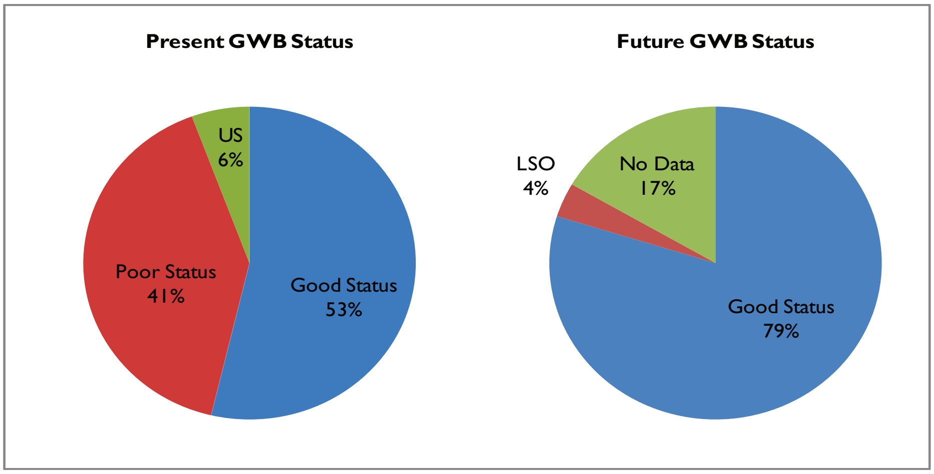

Figure 2 Overview of groundwater bodies status. US: Under Study; LSO: Less Stringent Objectives. Data by RBD can be found in Table A-1 in the Appendix to this chapter. (Source: Own elaboration, based on the RBDs planning documents publicly available in December 2011).

2 Good groundwater chemical status is achieved when the chemical composition of the water body: is not affected by salt intrusion; meets the established quality standards; does not prevent the associated surface waters from achieving the established environmental objectives; and does not cause significant damage to the associated terrestrial ecosystems.

Good groundwater quantitative status is achieved when: the available groundwater resource is not exceeded by the long-term annual average rate of abstraction, and the GWB is not affected by anthropogenic alterations that can cause water salinization or other intrusion or prevent the associated surface waters from achieving the established environmental objectives.

The RBDs with a higher number of GWBs in poor status are Guadiana (75% of the GBWs) and Segura (68%), while the Northern RBDs barely have any GWBs in poor status (see Table A-1 in the Appendix). It should be noted that the magnitude of the challenge ahead may also be seen by using parameters other than the number of GWBs in each status category. For example in Guadalquivir, 19 GWBs (32%) have a poor quantitative status and those GWBs provide about 75% of the groundwater abstracted in the RBD (Dumont *et al*., 2011). However, overall figures have to be interpreted with caution, as the actual situation in each RBD depends on the specific socio-economic context and the resulting anthropic pressure on groundwater resources.

Pollution, mainly by nitrates, is the main cause of non-compliance with the objectives of good status: out of 297 GWBs currently in poor status, 75% do not comply with the required quality standards. Similarly, qualitative problems are the main reason for establishing *less stringent objectives* for 2027 in 26 GWBs.

The WFD process has required investments in the improvement of the knowledge of groundwater resources, especially by increasing the density of the groundwater monitoring network. The diagnosis of groundwater status presented in Table A-1 of the Appendix is based on data from a monitoring network that are still under development and consolidation, thus in some GWBs the data may not fully reflect the real status of the water body.

4 GROUNDWATER USES

Compliance with the WFD requires adequate knowledge about the pressures on groundwater bodies in terms of quantity and quality. As in the case of groundwater resources assessment, a first difficulty in obtaining a global estimate of groundwater uses in Spain is the terminology applied in the RBMPs to refer to water use (use, demand, consumption, gross- or net-withdrawal). In some cases, some terms are utilised as synonyms although they actually refer to very different concepts. A second important obstacle is the generalized absence of direct water use measurements. As a consequence, methods to estimate groundwater abstraction vary across RBDs.

In most of the RBDs, the planning documents estimate water demands, which are expressed in *Units of Demand* (a spatial polygon with a specific water demand) for the main water uses (urban supply, agriculture, industry). The demands of each *Unit* are obtained using a combination of direct (e.g. water meters, supply surveys), mixed (e.g. remote sensing) and indirect methods (e.g. statistical data on population or crop areas multiplied by an average water demand rate). Sometimes, official water rights registries are also used as a source of information to estimate water demands, although the RBMPs acknowledge that those registries often do not reflect the situation on the ground. For example, in some of the northern RBDs the sum of the granted water rights doubles or quadruples the estimates made through the *Units of Demand*[3], possibly due to the fact that some water demands have decreased or that water rights were granted overestimating the actual demands. In the Guadiana RBD, groundwater rights sum 923 hm^3/year (Rodríguez-Cabellos, pers. comm., January 2012), but the estimated abstraction is only 500 hm^3/year, due to the current legal restrictions on groundwater use.

3 In W. Cantabrian RBD: 769 *vs*. 474 hm^3/year for all uses and sources of water. In E. Cantabrian RBD: 407 *vs*. 112 hm^3/year.

A decade ago, groundwater demand was estimated to be about 5,500 hm^3/year (MMA, 2000). According to the most updated planning documents, the estimated overall groundwater demand is now about 7,000 hm^3/year. This represents about 22% of Spain's total water demand (31,500 hm^3/year).

Most groundwater demand (over 80%) occurs in 7 of the 25 existing RBDs (Figure 3). In absolute terms, the RBD with the highest groundwater withdrawals is Jucar (1,600 hm^3/year), followed by Douro and Guadalquivir with close to 1,000 hm^3/year, while estimated extractions are around 500 hm^3/year in Segura, Guadiana, the Catalan RBD and the

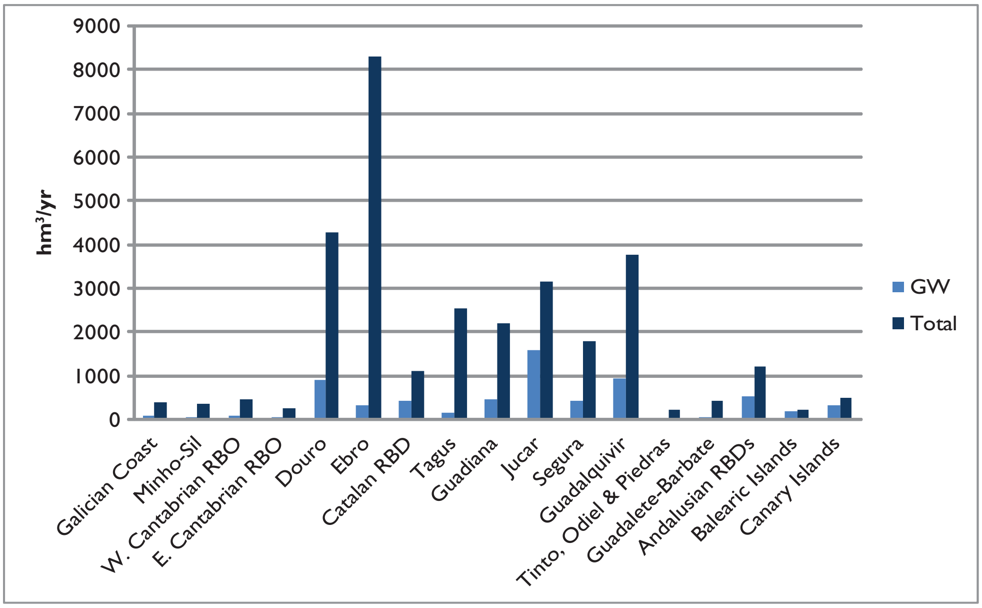

Figure 3 Share of groundwater demand over the total water demand by River Basin District (RBD). (Source: Own elaboration based on RBDs planning documents publicly available in December 2011).

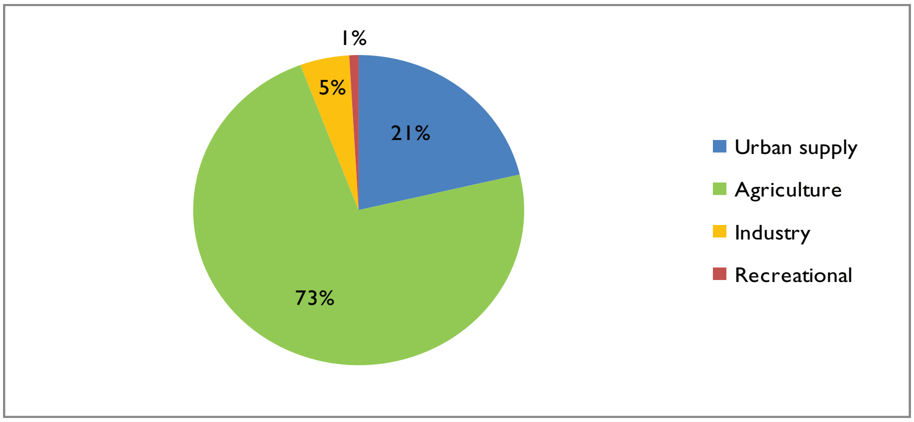

Figure 4 Estimated overall groundwater demand by sector. (Source: Own elaboration based on RBDs planning documents publicly available in December 2011).

Andalusian RBDs. The highest shares (over 40%) of groundwater withdrawals (relative to the RBD total) can be found in the Canary and Balearic Islands, Jucar and the Catalan and Andalusian RBDs (see Table A-2 in the Appendix).

Overall, the main groundwater use is agriculture (73%). At a country level, groundwater supplies only 21% of the domestic water demand (and industrial uses connected to the urban water supply network) (Figure 4). Nonetheless, groundwater plays a key role in the urban supply in some RBDs such as the Canary Islands, Balearic Islands, Jucar, Catalonia (where industrial use is especially important), and several RBDs in northern Spain.

Box 2 Surface water, groundwater and conjunctive use

In this chapter water resources estimates are presented distinguishing between surface water and groundwater. However, the reality on the ground is far more complex, and water users often strategically combine all the resources that they have to find the best formula (in terms of availability, price, quality and timing) for their activity. Hence, conjunctive use of surface and groundwater is the rule in many regions of Spain. The Llobregat area, in Catalonia, is one of the best examples of successful conjunctive water use in Spain. As another example, in Campo de Cartagena aquifer (Segura basin), irrigated agriculture is supplied by a mix of surface water transferred from the Tagus basin (through the Tagus-Segura Transfer, TTS in Spanish) and groundwater. During droughts, the transferred volumes are restricted and farmers complement surface water by pumping groundwater. Thus, during dry periods, groundwater represents 70% of the supply for irrigation, while during wet periods it is only 30% (see Figure 5).

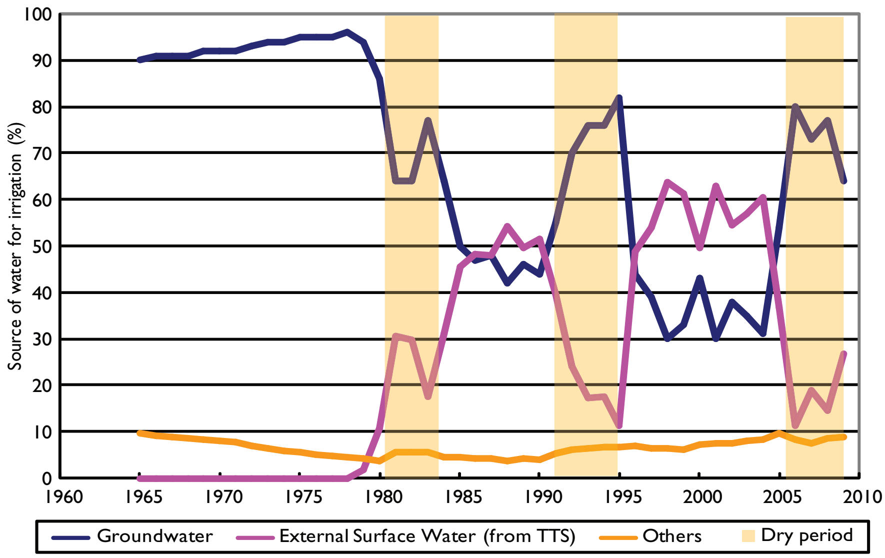

Figure 5 Surface and groundwater use in the Campo de Cartagena area. (Source: Cabezas (2011))

5 THE ECONOMIC VALUE OF GROUNDWATER USE IN AGRICULTURE

The planning documents elaborated by the RBOs provide figures about the overall value of water use by different economic sectors, including irrigated agriculture. However, these data are rarely broken down by source of water (surface, groundwater, desalinated, reused, conjunctive use), thus making it difficult to understand the contribution of different water sources to the economy of the RBD and therefore identify some of the trends driving their use. This section makes a first attempt to fill this gap for irrigated agriculture.

5.1 Methodological approach

As the data available in the RBDs planning documents consider agriculture as a whole and do not associate GW extraction or consumption to a specific crop, it has been necessary to build an ad hoc 5-step methodology based on the extended water footprint approach of Garrido *et al*. (2010).

The origin of the irrigation water (groundwater, surface, conjunctive use[4]) was obtained for different water management units (Agricultural Demand Units; Water Exploitation Systems; Regional Irrigation Inventory) provided by the RBOs, while the yearly irrigated crop surface was available at the municipal level from the Ministry for Environment, Agriculture and Rural Affairs. The attribution of crop areas to a specific water origin was obtained by crossing the municipal boundaries and the water management units, using geographical information system tools (Figure 6, Step 1).

To estimate water consumption by crop and year, the blue and green water consumption[5] was calculated applying the methodology of Garrido *et al*. (2010) and extracted only the blue component, which corresponds to the annual irrigation water consumption per crop. In a second stage, the crop net irrigation requirements defined by each RBO were used as upper limits for the blue water consumption (Step 2). This approach helps adjusting the estimated consumption to practices on the field, which include deficit irrigation.

The area of crops irrigated by each water source was multiplied by the crop water consumption rates to obtain crop consumption by water source (crop blue water footprint, WF, Step 3). The apparent land productivity (€/ha) was estimated from the crop yields (t/ha) [t = tonne = 10^3 kg] and crop market prices (€/kg) obtained from MARM (2010). The ratio between the apparent land productivity and the crop water consumption yield the apparent water productivity (€/m^3) by water source.

This study shed light on several shortcomings of the data available to calculate the economic value of irrigated agriculture by water source. First, at the conclusion of this study there were no up-to-date country-wide data about the sources of water for irrigation by crop type and at high-resolution geographical level. The last

4 Desalinated and reused waters were not considered due to their small significance in absolute terms of irrigation volumes and also due to the lack of systematic data on these two sources. Conjunctive use of surface and groundwater was calculated only in the Jucar RBD, where official data were available.

5 Blue water is the consumed irrigation water, while green water is the water that the plant obtains from the soil water content due to precipitation.

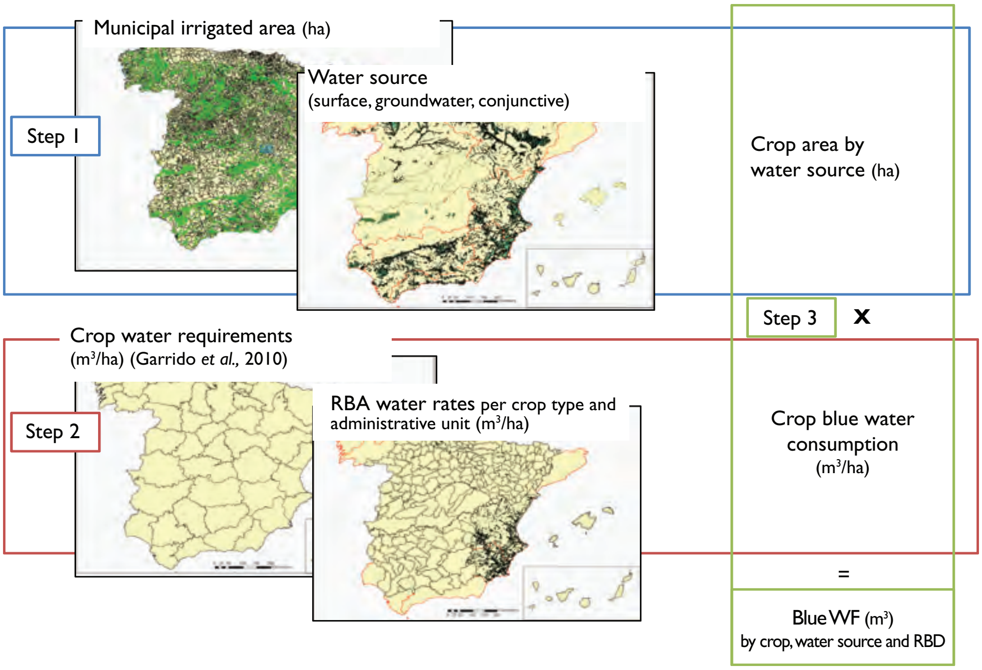

Figure 6 Steps 1 to 3 of the methodology followed for obtaining the crop blue water consumption by crop, origin of water and RBD. WF: Water Footprint. (Source: Own elaboration).

agricultural census recording this information dates back to 1999, and the 2009 census released in July 2011 did not include data on origin of water. Second, there are no country-wide fully reliable data on the area of irrigated crops on a yearly basis and at certain levels of detail – municipal or similar. There are several data sources but often figures either differ significantly depending on the provider or are not available for a long period of time or at high spatial resolution.

5.2 Main findings

Using the available official data, it was estimated that the consumption of groundwater for irrigation is approximately 3,200 hm³/year over an area of 1 Mha [Mha = million hectares = 10^6 ha], which represents about one third of the total irrigated surface (3.3 Mha) and one fourth of the total water consumption (approx. 12,000 hm³/year) (Table 2).

In the RBD planning documents groundwater demand for irrigation is estimated to be about 5,000 hm³/year. This figure refers to gross demand, i.e. including losses and return flows, which range from 10% to 40% of the applied water depending on the crop and irrigation technique. Taking into account this important difference in the considered variable (demand *vs*. consumption), the overall figures obtained in the analysis are fairly consistent with those used in the RBD documents. Nonetheless, discrepancies between the RBMPs data and figures in Table 2 can be detected at the scale of some RBDs. This is due to the fact

Table 2 Irrigation consumption and its economic value at RBD level (average 2005–2008).

RBD	*GW irrigated area (ha)*	*Total irrigated area (ha)*	*GW consumption (hm³/year)*	*Total consumption (hm³/year)*	*Value of the GW production (M€)*	*Total value of irrigated production (M€)*
Douro	136,073	402,035	544	1,582	302	941
Ebro	28,022	652,338	107	2,385	111	2,681
Northern RBDs	3,770	20,759	14	80	41	224
Tagus	13,772	190,590	60	834	42	599
Catalan RBD	29,102	60,061	105	211	124	257
Guadiana	143,636	326,784	377	1,191	512	1,604
Jucar	160,546	490,849	535	1,655	408	2,257
Segura	70,123	202,024	271	803	584	1,450
Guadalquivir	239,481	753,776	665	2,285	921	2,407
Andalusian RBDs	84,834	211,099	308	755	1,283	2,461
Balearic Islands	12,536	12,536	69	69	61	61
Canary Islands	22,889	23,408	166	169	338	354
Total	944,784	3,346,259	3,221	12,018	4,728	15,300

Source: Own elaboration.

Note: Due to data and resources constraints, estimates for the Northern RBDs (Western Cantabrian RBD, Eastern Cantabrian RBD, Minho-Sil, Galician Coast) and Tagus, were calculated with a simplified version of the methodology. In Jucar, the values obtained for conjunctive use were attributed to surface and groundwater on an equal share (Estrela, pers. comm., January 2012). The 2008 regional irrigation inventory for Guadalquivir and the Andalusian RBDs is considered to be more reliable than the MARM agrarian statistical data, especially in relation to olive production (see Chapter 8). Therefore figures for olive production were adjusted taking into account data from that inventory.

that RBAs often combine data from different sources for estimating irrigated crops consumption while the present study used only the official agrarian statistical data[6]. Table 2, however, provides a comparison between RBDs using the same set of data and gives an order of magnitude of groundwater irrigation consumption and its economic value.

A 1999 study undertaken for Andalusia showed that the apparent productivity of groundwater (GWAP) in irrigated agriculture was significantly higher than that of surface water (SWAP) (Hernández-Mora & Llamas, 2001). This trend was confirmed by Corominas (pers. comm.), who found that in 2008 the apparent productivity of the Andalusian groundwater irrigation on average was more than twice that of surface water (1 €/m³ *vs*. 2.60 €/m³). According to Hernández-Mora & Llamas (2001) reasons for this could be found in the greater control and supply guarantee that groundwater provides mainly during droughts, and the greater dynamism that characterize farmers who seek their own sources of water and bear the full direct costs of drilling, pumping and distribution. Llamas (2003) suggested that this could apply also to other regions

6 Figures for Guadalquivir and the Andalusian RBDs in the 2008 regional irrigation inventory are higher than those obtained with the nation-wide data: Guadalquivir: GW irrigated land: 321,233 ha; GW production value: 1,009 M€.

Andalusian RBDs: GW irrigated land: 101,902 ha; GW production value: 1,770 M€ (Corominas, pers. comm., January 2012).

of Spain and remarked that similar trends can be observed also in other countries like India. The data produced in this study allow analysing further the relationship between crops water apparent productivity (WAP) and the source of water used.

Table 2 shows the economic value of agricultural production using groundwater, which is about 4,700 M€/year or 30% of the total value of Spain's irrigated crop production. When considering all crops and all RBDs it can be observed that the overall GWAP is on average between 30% and 50% (depending on the year) higher than the SWAP. Nonetheless, this trend is not evident when looking at specific RBDs and crops (Figure 7).

Figure 8 shows the linear fit between average apparent water productivity of crops (average of SWAP and GWAP) and the percentage of groundwater used to

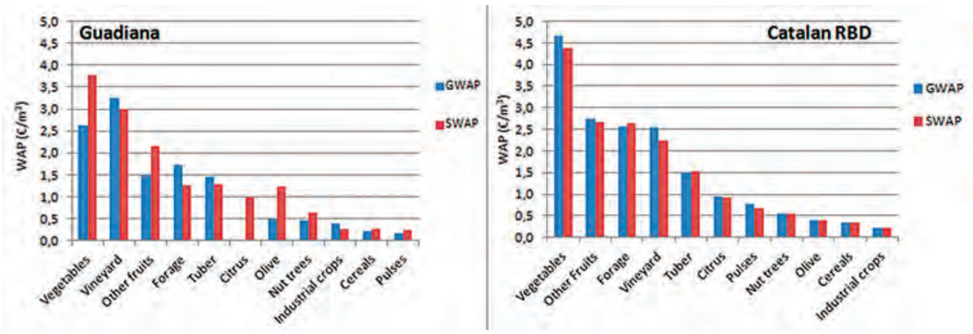

Figure 7 Surface and groundwater apparent productivity (SWAP, GWAP) in Guadiana and the Catalan RBD. (Source: Own elaboration).

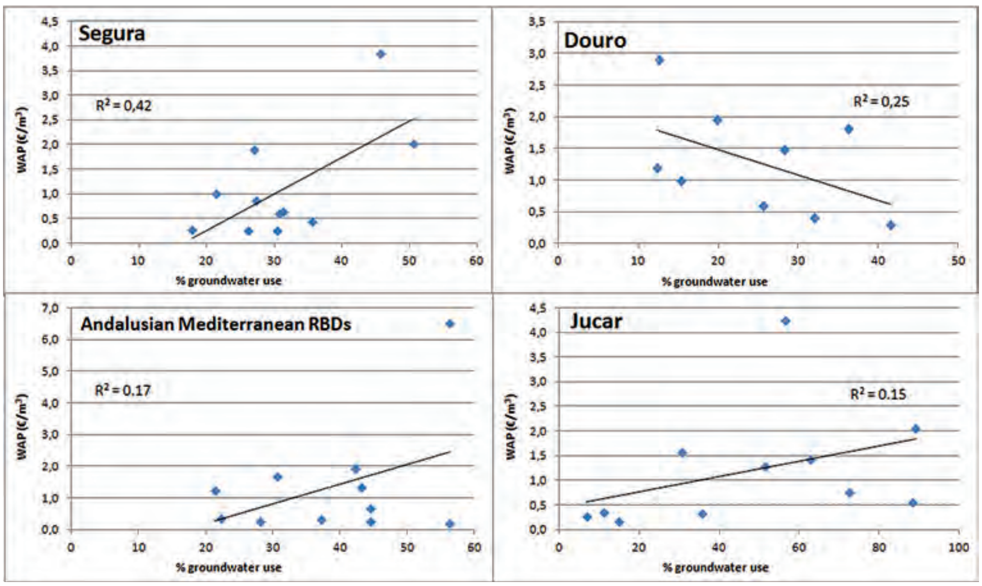

Figure 8 Linear fit between average apparent water productivity (WAP) and percentage of groundwater use by crop in selected RBDs. Each diamond represents a crop type. (Source: Own elaboration).

irrigate crops in several RBDs. It can be observed that the correlation of those two variables is rather poor, and in some cases (e.g. Douro) the RBD average water apparent productivity is higher for crops irrigated with surface water.

These preliminary results are in line with the study of the Guadiana basin by Aldaya & Llamas (2008), where no major differences were found in the WAP with surface and groundwater, and suggest that the trends detected in Andalusia should be extrapolated to other regions with caution. Indeed, these findings seem to indicate that the reliability of groundwater and entrepreneur attitude attributed to groundwater users are only two among several factors that determine WAP of crops. Other factors like the availability and reliability of surface water supply, climatic and soil conditions, advanced irrigation systems or technical know-how could be equally important, thus reducing the comparative advantage of groundwater relative to surface water. Some of these factors are outlined hereafter.

First, at present farmers willing to shift to irrigation or increase their access to water often can only tap into groundwater because no additional surface resources are available in most of the RBDs (most of the economically and environmentally viable reservoirs have already been built in the 20th century). This means that farmers may opt to access groundwater even if their irrigated crops provide tight benefit margins and have a limited WAP. Second, in some basins multiannual reservoirs ensure a high reliability of surface water also in case of droughts, thus providing similar supply guarantee as groundwater. Third, the modernization of irrigation systems has contributed to the optimization of use (see Chapter 19), thus increasing the control and guarantee of surface water to a degree similar to groundwater self-supply. Fourth, improvements in irrigated agriculture as a whole (irrigation advisory services, better access to irrigation and production technology, etc.) contribute to a progressive shift of surface irrigation toward more productive crops. This shift has also been favoured by changes in the EU Common Agriculture Policy incentives and by the increase of international trade in crops. Finally, farmers increasingly use a combination of surface and groundwater (and to a lesser degree other sources like reused or desalinized water, if available) to ensure water supply. This diversification of source on one side makes the boundaries between surface and groundwater uses more difficult to draw, and on the other side, increases the water guarantee of irrigation, independently of its predominant water source.

6 CONCLUSIONS

The WFD planning process has produced important advancements in the knowledge of groundwater resources and their use in Spain. Nonetheless, pitfalls in the available data and the methodological heterogeneity across the country necessitate interpreting the resulting snapshot with caution. Moreover, while it is now possible to access data by RBD, an official up-to-date overview of groundwater resources and their uses at national level is still not publicly available.

As part of the WFD planning process, 730 GWBs covering an area of over 353,000 km^2 have been defined. The order of magnitude of the available groundwater resources in Spain is about 22,000 hm^3/year (Tagus and Ebro are not included). Currently, 54% of the GWBs are in good status and the WFD implementation process is expected to increase this percentage to 80% by 2027, while for 17% of the GWBs there are no sufficient data to model their status by 2027. Reasons for poor status are both quantitative water problems and pollution, especially due to excess nitrates and salinization.

According to the RBDs planning documents, annual groundwater demand is about 7,000 hm^3 (or 22% of the total), which suggests an increase relative to previous 2000 official figures (5,500 hm^3/year). Unsurprisingly, the main water user is the agricultural sector (73% of groundwater demand), although groundwater plays a strategic role in urban water supply in several RBDs. Groundwater consumption is estimated to be about 3,200 hm^3/year for irrigated agriculture, 300 hm^3/year for urban supply and industry connected to the urban water network[7], and 60 hm^3/year for self-supplied industry.

In terms of groundwater productivity for irrigated agriculture, no clear difference between the apparent productivity of surface and groundwater in irrigated agriculture could be found in most of the RBDs. This differs from the results of previous regional studies and possible reasons have been suggested in this chapter. Surely this is an issue that merits further study, also combining local and country-wide data to refine the calculations, both on water consumption and economic productivity.

As a final consideration, it is important to highlight the uncertainty of all the estimates presented in this chapter, which is mainly due to the limited quality data on groundwater demand and consumption. In particular, there is an urgent need for more and better data on actual water consumption and the economic value of irrigated agriculture, differentiated by water source.

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7 Assuming a return flow of 80% of the supplied water.

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APPENDIX

Table A-1 Groundwater status in Spain.

River Basin Districts (RBD)	*# of GWB*	*Present good status (# of GWB)*	*Present poor status (# of GWB)*			*Environmental objectives*	
			Quantitative	*Chemical*	*Global*	*Projected good status*	*LSO (# of GWB)*
Galician Coast	18	18	0	0	0	–	0
Minho-Sil	6	5	0	1	1	GS in 2021: 6	0
Western Cantabrian RBD	20	20	0	0	0	–	0
Eastern Cantabrian RBD	14	13	0	1	1	GS in 2015: 14	0
Douro	64	48	5	14	16	GS in 2021: 47; GS in 2027: 50	14
Ebro	105	82	1	23	23	GS in 2027: 103	2
Catalan RBD	39	14	6	23	25	GS in 2015: 18; GS in 2027: 39	0
Tagus	24	9	2	14	15	ND	ND
Guadiana	20	5	11	13	15	GS in 2027: 20	0
Jucar	90	48	34	22	42	GS in 2015: 53; GS in 2021: 67; GS in 2027: 67–90	0 (ND:23)
Segura[a]	63	13	43	16	43 (US:7)	ND	ND
Guadalquivir	60	32	19	16	28	GS in 2015: 35; GS in 2021: 48; GS in 2027: 60	0
Tinto, Odiel & Piedras	4	2	0 (US: 1)	2	2	GS in 2015: 4	0
Guadalete & Barbate	14	5	3 (US: 8)	7 (US: 2)	7 (US:2)	GS in 2021: 7; GS in 2027: 10 (US: 2)	2 (US:2)
Andalusian RBDs	67	27	32	35	40	GS in 2015: 41; GS in 2021: 52; GS in 2027: 62	5
Balearic Islands	90	46	18	36	44	GS in 2015: 64; GS in 2021: 75; GS in 2027: 87	3
Canary Islands[b]	32	US	US	US	US	ND	ND
TOTAL	**730**	**392**	**174**	**223**	**297**	**GS in 2027: 583** **ND: 121**	**26**

Source: Own elaboration, based on data from RBDs planning documents publicly available in December 2011. Data for the autonomous cities of Ceuta and Melilla are not included.

Notes
GWB: groundwater bodies; LSO: less stringent objectives; GS: good status; US: under study; ND: no data.
a Data available in the report about Important Water Management Issues have been interpreted as follows: no risk = good status; proven risk = poor status.
b Figures for the Canary Islands summarize the data available for their 7 RBDs (one for each island).

Table A-2 Estimated groundwater extraction (mostly based on water demand estimates) and estimated total water demand by use. Figures in hm^3/year.

River Basin Districts (RBD)	*Urban supply*[a]		*Agriculture*[b]		*Industry*[c]		*Recreational uses*[d]		*TOTAL*[e]	
	GW	*Total*	*GW*	*Total*	*GW*	*Total*	*GW*	*Total*	*GW*	*Total*
Galician Coast	49	274	38	84	1	45	ND	1	88	404
Minho-Sil	34	81–114	30	206–306	6	15	3	4	73	369–439
Western Cantabrian RBD	91	239	6	70	15	162	ND	3	112	474
Eastern Cantabrian RBD	24–79	48–157	1	2–4	5	61–245	ND	1	77	112–407
Douro	68	332	800	3,900	50	60	6	8	746–924	4,300
Ebro	48	358–494	237–252	7,681	47	208	8	9	338	8,190
Catalan Basins	198	632	197	388	59	110	ND	8	454	1,138
Tagus	30	787	100–145	1,713	11–30	24–62	ND	ND	141–150	2,636
Guadiana	46	151–200	438	1,995	4	19–44	SD	ND	488–509	2,212–2,239
Jucar	323	548	1.178	2,474	100	124	9	10	1,610	3,156
Segura	ND	217–237	412–478	1,432–1,662	ND	23–30	ND	14	485	1,700–1,960
Guadalquivir	104	436	833	3,329	11	36	ND	ND	948	3,802
Tinto, Odiel & Piedras	4	56	31	151	0	46	2	2	31–37	253
Guadalete & Barbate	20	122	39	320	ND	ND	4	6	63	448
Andalusian RBDs	140	336	377	838	3	23	19	28	539	1,225
Balearic Islands	142	174	49	68	3	3	0	8	194	253
Canary Islands[f]	123	219	209	247	8	17	12	25	352	508
TOTAL (approx.)	**1,500**	**5,200**	**5,000**	**25,000**	**300**	**1,100**	**65**	**130**	**7,000**	**31,500**

Source: Own elaboration based on data from RBDs planning documents publicly available in December 2011. It does not include the autonomous cities of Ceuta and Melilla.

Notes

a These figures also include water use by the industry supplied through the urban distribution network.
b This includes irrigation and animal breeding.
c Industry not connected to the urban distribution network.
d Mainly golf courses.
e Often summing up figures for sectorial uses does not yield exactly the overall figures provided by the RBO (last column).
f Figures for the Canary Islands summarize the results of their 7 RBDs (one for each island).