Chapter 8

The extended water footprint of the Guadalquivir basin

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ABSTRACT: This chapter analyzes the Extended Water Footprint (EWF) of the Guadalquivir basin in south of Spain. An innovative aspect is that not only the use of blue water for direct human use (irrigation, urban and industrial supply) has been taken into account but also the use of green water for the mentioned uses and the natural ecosystems; the latter amounts to 291 mm/year. The results show that agriculture is the main consumer (192 mm/year), 34% being blue water and 66% green water. Economic productivity fluctuates between less than 0.40 €/m^3 for the most traditional crops (cereals, maize, cotton and rice) and values reaching 2 €/m^3 for olives and more than 4 €/m^3 for vegetables. But the highest economic productivity is tourism (more than 200 €/m^3) and industries such as thermo-solar energy (50 €/m^3). A better water management could be achieved thanks to a reallocation of water resources between the different uses. This reallocation may occur without social conflict with the farmers since the quantities of blue water required constitute 1–2% of the current total blue water use. However, this process is much more complex since a large number of economic, social, political and environmental factors need to be considered.

Keywords: water footprint, water productivity, hydrological cycle, groundwater, irrigation

1 INTRODUCTION

This chapter synthesizes the key issues of a monograph published by the Water Observatory of the Botín Foundation (Salmoral *et al.*, 2011), where details on methodology, data sources and references can be found. Guadalquivir basin, located in south of Spain (Figure 1), is a semiarid region (535 mm/year of rainfall), in which water repartition among economic sectors and the environment implies a relevant and controversial issue for water resources management. It has an area of 57,527 km^2, with a population of approximately 4.1 million, and the irrigated area reached 8,460 km^2 (846,000 ha) in the year 2008. The present study analyzes the Extended Water Footprint (EWF) of the Guadalquivir basin, considering both the traditional Water Footprint (WF) accounting in terms of water consumption, and the associated economic value. The study focuses on the quantitative components of the green (rainwater stored in

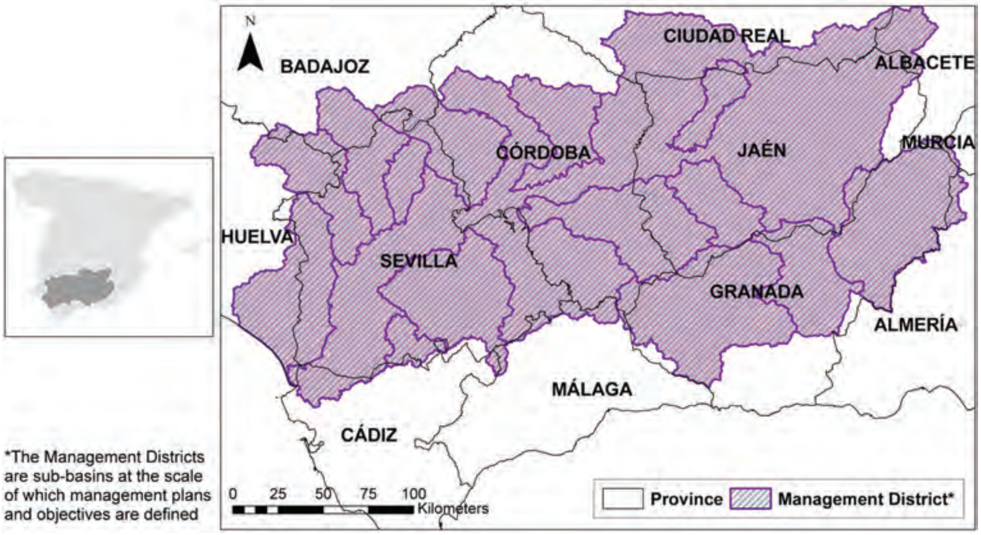

Figure 1 Localization of Guadalquivir basin and its different management districts. (Source: Own elaboration).

the soil) and blue (surface and groundwater) WF but does not estimate the grey colour component (freshwater required to assimilate load of pollutants).

The study presents some innovations in the methodology and results in comparison to previous WF studies:

– The EWF on groundwater is calculated at the basin scale.
– The hypothesis that crop irrigation requirements are fully met is not considered.
– The WF of dams (evaporation) is taken into account.
– The WF accounting of the different economic sectors and main land uses (including green water used by forests and pasture) has been balanced at basin scale and included within the hydrological cycle.

2 METHODOLOGY AND DATA

2.1 Water footprint of agriculture and livestock

The agricultural WF was estimated for the time period 1997–2008 and the blue and green components were distinguished. Green water was calculated as the minimum between effective rainfall and crop water requirements. In semi-arid regions like the Guadalquivir, farmers often have to cope with restrictions on water availability, thus for blue water accounting we considered that irrigation water requirements were not fully met. Blue water was calculated on the basis of the water allocated for each crop group within each *management district* and considering an additional irrigation restriction depending on the level of drought according to the Drought Plan of the Guadalquivir River Basin Authority (GRBA). Rainfed and irrigated crop areas were obtained from regional statistics at municipal level. In the case of groundwater, the total amount of abstractions for agriculture was obtained from the GRBA.

For livestock, the direct WF is the volume of water required for animal drinking and farm management. The indirect WF refers to virtual water embedded into animal feed coming partially from the agrarian production (already accounted in the agricultural WF), pastures within the basin and feed imports. The assessment of the livestock WF on the resources of the basin only considers the direct consumption.

2.2 Water footprint of the industry, domestic supply, energy, tourism and dams

Urban, tourism and industrial WFs were estimated based on data provided by the GRBA. To obtain the water consumption for domestic and industrial sectors, return flows of 72% and 44% (CHG, 2010) respectively were subtracted from each sector's total water abstractions. Specific data on groundwater abstractions are obtained from the same source. The volume of water evaporated from dams was calculated using the same method as Hardy & Garrido (2010), considering that all reservoirs are artificial lakes. Thus the evaporation is considered as a WF. This WF was not attributed to a specific use as the objectives of a dam are numerous.

2.3 Balance of green and blue water at basin scale

In order to make the WF assessment meaningful for water planning purposes, we have integrated the different WFs calculated within the mean annual water balance of the basin (Table 1). Data on mean annual precipitation, total run-off (surface plus groundwater run-off) and actual evapotranspiration was obtained from the GRBA and we used the values of the WFs calculated for an average climatic year (2003) on the following basis:

– Total run-off is the sum of the blue WF and the remaining water flow running along the streams and through groundwater bodies.
– Basin actual evapotranspiration represents the sum of the green WF consumed by crops and pastures and the water consumed by forest ecosystems. The water

Table 1 Components of the hydrologic cycle and the balance of green and blue water at the scale of the basin.

*Rainfall**	*Run-off***	*Evapotranspiration***
563 mm/year	107 mm/year	456 mm/year
100%	19%	81%
32,042 hm^3	6,087 hm^3	25,955 hm^3
	Blue WF + Blue water flows	Green water (agriculture, pasture, forests ecosystems)

Source: Salmoral *et al.* (2011).

[hm^3 = cubic hectometre = million m^3 = 10^6 m^3].
* For the reference year 2003.
** The repartition between run-off and evapotranspiration is given by CHG (2010).

Table 2 Economic indicators used to assess the economic water productivity.

Sector	*Valuation factor*
Agriculture	Water and land productivities: production value in real € (year 2000) per unit of water consumed or land cultivated.
Domestic supply	Tariff of tap water for urban users.
Industry	Average tariff of water supplied to the industry.
Tourism	Evaluation of the economic returns of tourism for the local economy.
Energy	Energy tariff (€/kWh) multiplied by the amount of production obtained depending on the type of plant (expressed in kWh/m^3).

demanded by forest ecosystems is a difficult variable to calculate. We estimated this volume by subtracting total run-off and green WF of crops and pastures from annual precipitation.

2.4 Economic water productivity

The economic assessment of the WF is based on a series of indicators adapted to the economic sector considered (see Table 2). For the purpose of this study, only blue water was evaluated in economic terms.

3 RESULTS

3.1 The Extended Water Footprint (EFW) of the Guadalquivir basin

3.1.1 The EWF of agriculture and its evolution over time

Between 1997 and 2008 the total WF (green and blue) of agriculture production ranged between 4,200 hm^3 (year 1999) and 7,400 hm^3 (year 2001) [hm^3 = cubic hectometre = million m^3 = 10^6 m^3]. These variations are mainly ascribed to the irregular pattern of precipitations within the basin, which have a high influence on the green WF (Figure 2). The slightly greater green water footprint in 1999 in comparison to 2005, despite rainfall having been much lower in the former, is because of olive tree expansion among these years. During the period, 69% of mean annual WF in the Guadalquivir basin was green and the remaining 31% was blue, including both surface and groundwater. Overall, olive orchards consumed the largest proportion of green and blue water (72% and 31% of the total WF, respectively).

The economic water productivity in the basin rose from 0.70 €/m^3 to 1.40 €/m^3 between 1997 and 2007, however water productivity differs considerably among crops (Figure 3). Between 1997 and 2007, 46% of the blue water consumption belongs to crops that generate less than 0.40 €/m^3, mainly cotton, rice and maize. Crops generating more than 1.50 €/m^3 only account for 10% of total blue WF (vineyards, open air vegetables, winter fodder and strawberry). In other words, the largest proportion of blue water resources is allocated to produce low water economic productivity crops

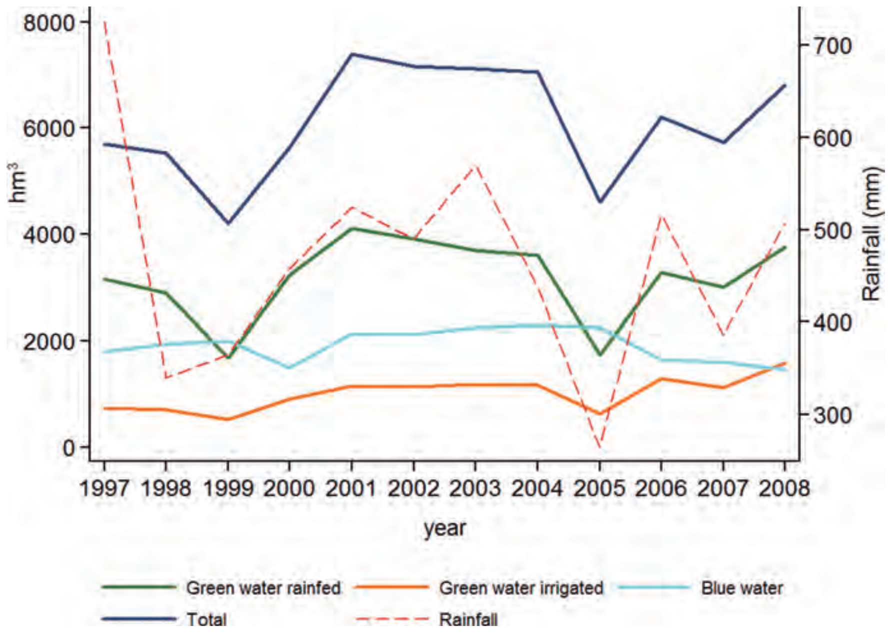

Figure 2 The water footprint of crop production. (Source: Salmoral *et al.* (2011)).

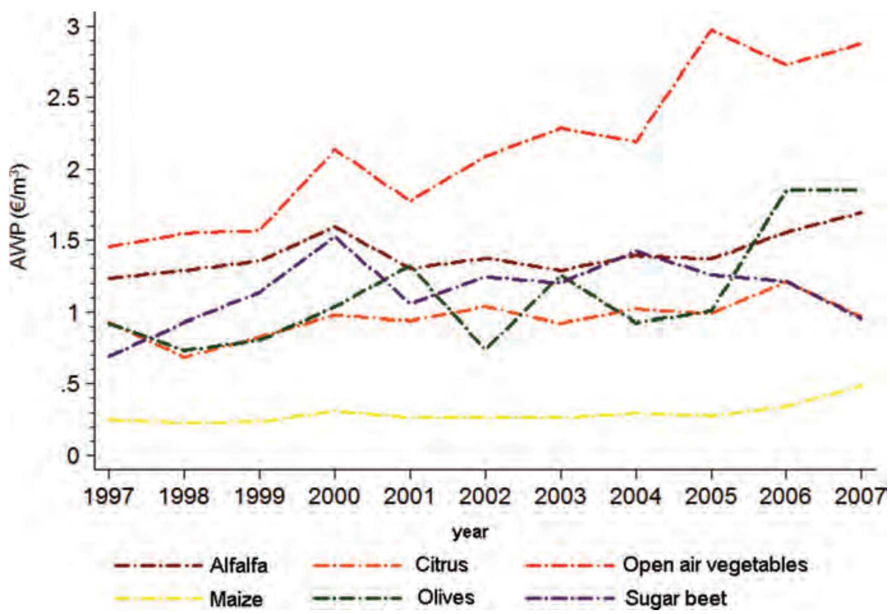

Figure 3 Blue water productivity (€/m³) between 1997–2007. (Source: Salmoral *et al.* (2011)).

Only crops which comprise more than 5% irrigated production over the time period are represented.

(see Chapter 6). For the whole basin, the land productivity associated to irrigated production is twice (1997) to four (2005) times greater than the one generated by rain-fed agriculture.

3.1.2 The EWF of groundwater in agriculture

According to the GRBA, annual groundwater abstractions in the basin reach 900 hm^3. Considering an average global irrigation efficiency of 85%, the WF of groundwater in the Guadalquivir basin is around 770 hm^3. However, if we calculate the WF using the regional statistic datasets of irrigated areas and we assume there is sufficient groundwater to fully meet irrigation crop requirements, we obtain a WF close to 1,060 hm^3 (see Table 3). Differences encountered among both WFs values are due to the fact that farmers may be irrigating below the full crop irrigation requirements.

Olive groves hold the largest share of the WF (65% when considering that irrigation requirements are not fully met), mainly because the irrigated surface of this crop has experienced the largest increase over the last years, with a WF of 120 hm^3 in 2002 and 490 hm^3 in 2008 (see Chapter 10). Vegetables and fruits account for 21% of the WF and industrial crops and cereals about 14%. As groundwater is mostly used to irrigate crops of higher value, the mean economic productivity is higher for groundwater (1.15 €/m^3) than for surface water (1.02 €/m^3). However, this is a small difference, probably not significant given the uncertainties in the numbers at the basin scale (see Chapter 7).

3.1.3 Synthesis of the EWF of the Guadalquivir

Table 4 summarizes the EWF of the different socioeconomic sectors within the basin. The reference year for agriculture is 2003 (normal climatic year without irrigation water restrictions), and 2007 for the remaining socioeconomic sectors. Overall, agriculture represents the largest WF proportion (93% of the total, 80% considering only blue water). Evaporation from reservoirs is also important since it comprises 11% of the blue WF. Sectors such as tourism and golf have a much lower share of the blue component (<1%) in spite of their greater water productivity.

Table 3 Extended water footprint and share of groundwater irrigated surfaces, year 2008.

	Industrial crops	*Cereals*	*Olive*	*Vegetables*	*Fruits*	*Total*
Irrigated surface with groundwater (ha)	10,754	21,529	245,571	17,839	25,540	321,233
Water footprint* (hm^3)	60.8	42.6	794.8	102.4	60.7	1,061.3
Water footprint** (hm^3)	60.8	42.6	491.1	102.4	60.7	757.7
Water productivity*** (€/m^3)	0.47	0.49	1.17	1.22	2.06	
% of area irrigated with groundwater	11.5	19.8	53.3	31.9	21.3	38.3

Source: Salmoral *et al.* (2011).

* Crop water requirements are fully met; irrigation water for olive groves is 3,200 m^3/ha.
** Crop water requirements are not fully met; irrigation water for olive groves is 2,000 m^3/ha.
*** Assuming that requirements are not fully met.

Table 4 Synthesis of the extended water footprint for the Guadalquivir basin. Based on Salmoral *et al.* (2011).

	Water Footprint					*Economic indicator*	*Comments*
			hm³	*%ᵃ*	*%ᵇ*		
Agriculture	Green	Rainfed	3,690	48.8		[2]LP_{rain}	Winter cereals: 540 €/ha; Sunflower: 630 €/ha; Olive groves: 1,610 €/ha
		Irrigated	1,190	15.7			
		Total	Min.: 2,200 (in 1999) Max.: 5,345 (in 2008)				
	Blue (surface and groundwater)		2,240	29.6	80	[3]WP	Cotton: 0.20 €/m³; Rice: 0.40 €/m³; Citrics: 1 €/m³; Olive groves: 1.90 €/m³; Vineyard: 2.50 €/m³; Vegetables: 2.90 €/m³; Strawberry: 11 €/m³
			Min.: 1,470 (in 2008) Max.: 2,290 (in 2004)			[4]LP_{irr}	Maize: 2,320 €/ha; Olive groves: 2,840 €/ha; Vegetables: 12,650 €/ha
						[5]Δ€/m³	Sunflower: 0.20 €/m³; Olive groves: 0.80 €/m³; Vegetables: 2.10 €/m³
	Blue (groundwater)[1]		*750*	*9.9*	*26.8*		
	Total		7,120	93.2			
Livestock	Blue		19	0.3	0.7		Only direct consumption (drinking and exploitation management)
Urban supply	Blue (surface)		83	1.1	3	1.23 €/m³ (tariff)	Without including industry
	Blue (groundwater)		13	0.2	0.5		
Industry	Blue (surface)		35	0.5	1.2	1.40 €/m³ (tariff)	A portion is own supply, the rest from urban supply
	Blue (groundwater)[1]		9	0.1	0.3		
Tourism without golf	Blue		*4*	*0.1*	*0.1*	–	Included in urban supply
Golf	Blue		6	0.1	0.2	331.3 €/m³	Total economy generated
Dams	Blue		315	4.2	11.2		
Electricity generation	Blue		31	0.4	1.1		
	Thermo-solar plants		*3.6*	*0.0*	*0.1*	47 €/m³	Prediction 2015: 11.3 hm³
	Other (thermic)		*27*	*0.4*	*1*	140 €/m³	
Total			7,631	100			
Total without green water			2,751		100		

Figures in italics are included within their respective broader figure.
[1] Year 2008; [2] LP_{rain}: Land productivity in rainfed systems; [3] WP: Water productivity; [4] LP_{irr}: Land productivity in irrigated systems; [5] Δ€/m³: Increase of water productivity of irrigated systems in relation to the rainfed one; [a] %: Including green water in the total WF; [b] %: Without including green water in the total WF.

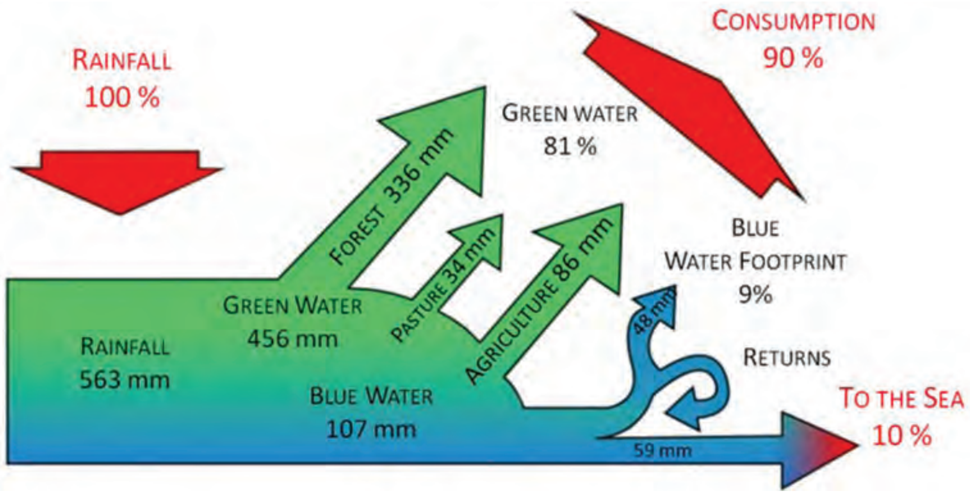

Figure 4 The WF within the hydrologic cycle (inspired by Falkenmark, 2009). (Source: Salmoral *et al.* (2011)).

The high water productivity of sectors like industry, energy generation and tourism advocates for prioritizing their use in comparison to agriculture. For instance, thermo-solar plant development should be encouraged as their use of water shows a high productivity (47 €/m^3) and represents a little share of the total WF. But this prioritization should not result in a rise of the overall basin WF and should be accompanied by an assessment of potential social and environmental impacts. It should also be kept in mind that the presented values are an average and reallocation of water or the prioritization of particular uses should be based on local estimations of the marginal value for water.

3.2 The WF and its integration within the hydrological cycle

Figure 4 summarizes the water balance of the Guadalquivir basin. More than 80% of precipitation turns into green water and only 20% is available downstream in rivers and aquifers as blue water. The majority of the green water is consumed by forests (74%), while the direct human appropriation of green water (WF of agriculture and pastures) amounts to 26%. Regarding blue water, 50% of the total run-off is consumed annually (blue WF) and the other half discharges into the ocean, after contributing to sustaining the ecological functioning of aquatic ecosystems on its way to the river mouth.

4 CONCLUSIONS

An innovative aspect of this study is that not only blue water for direct human use (irrigation, urban and industrial supply) has been taken into account but also green water for human use and nature. In a normal year, forests consume 20,000 hm^3 (340 mm), which represents two third of the annual precipitation. Water consumption related to direct human appropriation (WF of the different economic sectors) represents 24% of the precipitation, being the largest part linked to crop production, with 144 mm (15% of precipitation). Thus, green water management through land use planning is a key point to attaining ecosystem conservation and agriculture development (see Chapter 11). The impact of the blue WF on aquatic systems can also be questioned as more than half of the blue water is consumed, with a tendency for increasing groundwater consumption in the head of the basin mainly because of olive groves in Jaén province (see Chapter 10).

Over the period 1997–2008, 46% of the blue water resources were assigned to low value crops (≤0.40 €/m^3). The study suggests that a better water management could be reached thanks to water reallocation in activities of greater economic value such as thermo-solar energy. Although additional social and environmental indicators need to be incorporated in the analysis, this reallocation may occur without social conflict with the farmers since the quantities of blue water required for these high-value uses constitute 1–2% of the current total blue water use. However, this process is much more complex since a large number of factors need to be considered (food market, water priorities, water rights, rational water use, social issues and environmental constraints). In the meanwhile, the Government should promote a win-win solution, facilitating for farmers the change towards more productive and less harmful crops. This is the way that the new motto *more cash and care of nature per drop* could be achieved.

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