PAPELES DE AGUA VIRTUAL

Número 5

INCORPORATING THE WATER FOOTPRINT AND ENVIRONMENTAL WATER REQUIREMENTS INTO POLICY: REFLECTIONS FROM THE DOÑANA REGION (SPAIN)

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Fundación Marcelino Botín

http://www.fundacionmbotin.org

Papeles de Agua Virtual. Observatorio del Agua
Edita: Fundación Marcelino Botín. Pedrueca, 1 (Santander)
www.fundacionmbotin.org

ISBN: 978-84-96655-23-2 (obra completa)
ISBN: 978-84-96655-76-8 (Número 5)
Depósito legal: M. 47.402-2010
Impreso en REALIGRAF, S.A. Madrid, noviembre de 2010

Table of contents

Abstract

This report is a preliminary attempt to test the feasibility of a 'more cash and care of nature per drop' policy based on a hydrologic and economic analysis of the water footprint and environmental water requirements in the Doñana region, which includes the Doñana National and Natural Parks and its surroundings. This region is located at the coastal end of the Guadalquivir valley and comprises the marshes and estuary of the Guadalquivir river in south-western Spain. It preserves one of the largest and most important remaining wetlands in Europe. This initial analysis shows that the environment is the main water user amounting to about 59% of total water use, followed by agriculture with around 40% and urban and industrial water supply 1%, for an average rainfall year. The green water use by forests represents about 44% of the total water use. Groundwater is also a key factor. It is well known since decades that the small but meaningful depletion of the water table due to groundwater abstraction for irrigation, for urban water supply and by eucalyptus plantations has an impact on the natural vegetation. As a first estimation, following a WWF report using the ELOHA approach, it as been accepted that the theoretical environmental flows in the Doñana region, needed to sustain the wetlands, amount to about 200 Mm^3/year including surface and groundwater bodies in average years. The current blue water available for human use (total surface and groundwater available minus environmental water requirements) is estimated to be about 240 Mm^3/year; lower than the blue water footprint for agriculture, which is about 280 Mm^3/year. Within agriculture however the largest amount of blue (surface and groundwater)

water is used to produce water-intensive low-economic value crops such as rice. It seems that a possible option to take 'care of nature' would be to buy the water rights of the farmers growing low-value crops and allocate this water for environmental uses. As a matter of fact the option of buying water rights has already begun not to protect nature but to sell those water rights to farmers growing cash crops instead of rice. The preliminary results seem to indicate that the application of an integrated approach using the water footprint and environmental water requirement analysis, could improve the practice of water resources planning and management, the preservation of ecosystems and the associated livelihoods. It seems to be a win-win solution that probably can be applied in other similar cases.

1. Introduction

Assessment of water availability, water use and water scarcity has been the subject of increasingly intensive research over the past years. However, the requirements of ecosystems for water have rarely been considered explicitly in such assessments. The present report analyses the environmental water requirements for the Doñana region within this framework.

This is a very important issue from a global perspective. Many authors state that the global annual precipitation over continents amounts to about 110,000 km^3 whereas the global water footprint (consumptive water use) is around 8,000 km^3 (Falkenmark and Rockström, 2004; Comprehensive Assessment of Water Management in Agriculture, 2007; Hoekstra and Chapagain, 2008; WWAP, 2009). Therefore the human direct use of water is less than 8%. However, more accurate figures are needed in relation to the water quantity that is accessible and reliable for human use considering the water requirements for the ecosystems, which is in principle a smaller quantity than the absolute raw water available in nature. Estimations of this type are rare and generally without enough factual evidence. The present study is a preliminary attempt to contribute to fill this gap in the water resources literature. Furthermore, it is the first time that the environmental water requirements are analysed together with the water footprint.

The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer (Hoekstra, 2003). The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business (Hoekstra et al., 2009). Water use is measured in terms of water volumes consumed (evaporated) and/or lost polluted per unit of time. A water footprint can be calculated for any well-defined group of consumers (e.g. an individual, family, village, city, province, state or nation) or producers (e.g. a public organization, private enterprise or economic sector). The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations. The total water footprint breaks down into three components: the blue, green and grey water footprint (Hoekstra et al., 2009). The blue water footprint is the volume of freshwater that evaporates from the global blue water resources (surface water and ground water) or is lost as a result of the production process. The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture). The grey water footprint refers to the volume of polluted water as a result of the production process. The grey water footprint method and data however are currently being refined.

The water footprint focuses on human water use. A significant innovation of this work is to emphasize the imperative challenge of considering the environmental water requirements as well. Environmental water requirements or environmental flow requirements refer to the water considered sufficient for protecting the structure and function of a surface or groundwater ecosystem and its dependent species. These requirements are defined by both the long-term availability of water and its variability, and are established through environmental, social, and economic assessment (King et al., 2000; IUCN 2003). Obtaining clear data on environmental water requirements would allow comparing the actual water footprint with the theoretical amount of water available for human use (total water available minus environmental water requirements). This may allow building a transparent, multidisciplinary framework for informing water allocation decisions. It is critically important that a certain volume of water is planned for the maintenance of ecosystem functions and the services they provide to humans. Planning water allocation taking into account the environmental water needs would be helpful to achieve the right balance between allocating water for direct human use (e.g. agriculture, power generation, domestic purposes and industry) and indirect human use (maintenance of ecosystem goods and services) (Acreman 1998). This is one way to approach a win-win situation balancing and harmonising human and environmental water requirements. This could also contribute to the implementation of the EU Water Framework Directive (2000/60/EC) (WFD), which sets the clear objective of achieving the 'good status', both ecological and chemical, of all water bodies in the EU (surface as well as groundwater) by 2015. This is particularly relevant since Spain is the first country that has included the water footprint analysis into governmental policy making in the context of the WFD (Official State Gazette, 2008).

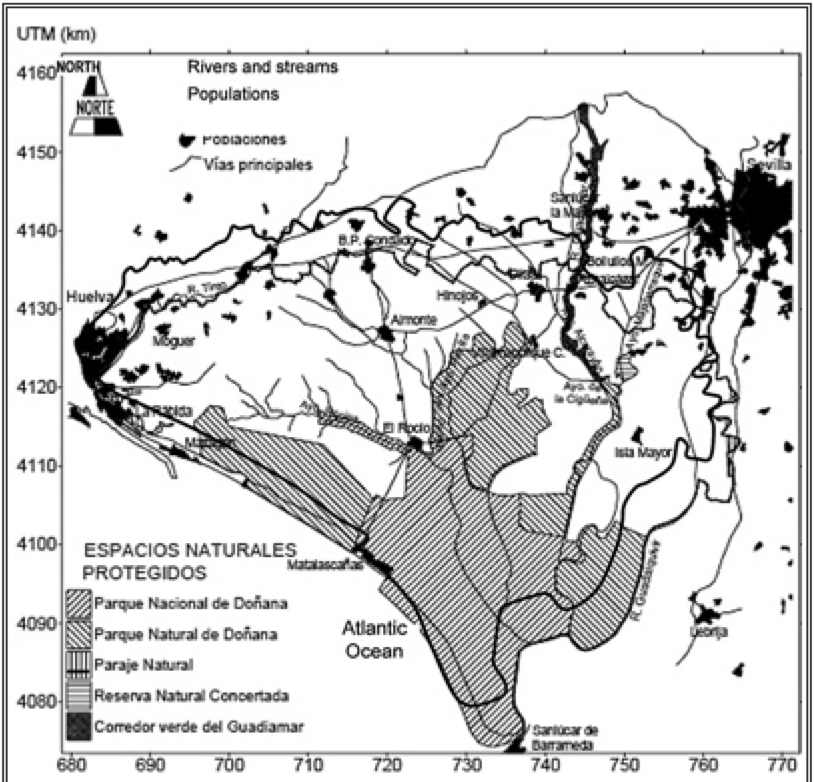
This report analyses the water footprint of the Doñana region and presents a first and preliminary attempt to quantify the environmental water requirements from the ecosystem perspective. The Doñana region is located at the coastal end of the Guadalquivir valley and comprises the delta and the estuary of the Guadalquivir river in south-western Spain. It preserves one of the largest and most important remaining wetlands in Europe. The final objective is to improve the practice of water resources planning and management, and the condition of ecosystems and associated livelihoods through the application of the water footprint analysis. This report also aims to illustrate the role of the environment as a legitimate 'water user' in water resources assessments. For this purpose the present study analyses the current environmental green and blue (surface and ground) water use and the theoretical environmental water requirements following the ELOHA approach. Due to the limited information on environmental water requirements, rough figures are provided. Second, the water footprint for agriculture, household and industry is provided from the production perspective. In the case of agriculture, notably the main water consumer (representing about 98% of the total human water consumption), a hydrologic and economic analysis is presented. Finally, the actual blue water consumption is compared with the theoretical blue water available for human use (total blue water available minus environmental flow requirements), analysing the challenges and opportunities for water resources management in the Doñana region. Steps for future research in this field are also suggested.

2. Study area

The Doñana region (2900 km^2), in south-western Spain, extends along the coastal plain of the Gulf of Cádiz from the right bank of the estuary of the Guadalquivir river to the estuary of the Tinto river (Custodio et al., 2009). It includes several territories with a different degree of environmental protection: Doñana National Park, Doñana Natural Park and its area of influence (Figure 1). The Doñana National Park (Parque Nacional de Doñana, traditionally referred as Coto de Doñana) is a UNESCO World Heritage and a Ramsar site, and a prised wildlife refuge. It covers an area of 542 km^2, while the peripheral protected buffer zone or Natural Park has 537 km^2 (Andalusian Regional Government, 2009). The Doñana region includes the following 14 municipalities: Almonte, Bonares, Bollulos par del Condado, Hinojos, Lucena del Puerto, Moguer, Palos, Rociana del Condado (Huelva province), Aznalcázar, Puebla del Río, Pilas, Villamanrique de la Condesa, Isla Mayor, previously named Villafranco del Guadalquivir (Sevilla province) and Sanlúcar de Barrameda (Cádiz province). Data from Sanlúcar, on the left bank of Guadalquivir river, were not considered for the study.

Doñana has a Mediterranean type climate with oceanic influences. The average annual rainfall is about 550-570

FIGURE 1. *Location of the Doñana National and Natural Parks within the Doñana region. Source: modified from Custodio et al. (2006)*



mm, with important interannual variations; rainy years approaching 1,000 mm and dry years descending to 300 mm (Muñoz-Reinoso, 2001). This rainfall mainly occurs between October and March (80% of total yearly amount), whereas the summer is very dry. The mean annual temperature varies between 16 and 17°C, with mean temperatures of 24.7 and 24.4°C in July and August, respectively. The winters are mild (10.9 and 10.0°C in December and January, respectively). Both the high mean temperature and the variation of rainfall determine the water availability for ecosystems, which fluctuates from a plentiful supply in winter to a persistent drought in summer.

The Doñana National Park is one of the largest European breeding areas for migrating birds. It shelters a vast and well preserved continental marsh (25.000 ha), which remains flooded during winter and spring months exhibiting a high biological productivity. Although it originated as a tidal marsh in the estuary of the Guadalquivir river, it is now separated from the river only receiving the flow of small tributaries. Doñana Parks present a great diversity of biotopes: marsh, swamps, with large temporary ponds, beaches, fixed and wandering dunes, with temporary and permanent ponds, pine and cork oak woodlands and a diverse shrubbery bearing Mediterranean scrub in dune ridges and heath in floodable depressions (García Novo and Marín Cabrera, 2006). The marshes host four threatened bird species, one of the biggest heronries in the Mediterranean, and host a figure of 5-600,000 wintering waterfowl. An estimated figure of 6 millions of migratory birds will pass by the Park on a yearly basis, either commuting from N to S Europe or else from Europe to Africa through Gibraltar Strait. 78% of European birds have been recorded in Doñana. The Park also preserves an almost complete mammal fauna with fallow deer and red deer, wild boar, European badger, Egyptian mongoose, and endangered species such as the Iberian Lynx and the Spanish Imperial Eagle. The flora includes some 900 vascular plants. A summary of Doñana species biodiversity including vertebrates, plants and plankton species (2200 species in all) has been compiled by García Novo and Marín Cabrera (2006).

In 1963, the World Wilde Fund for Nature (WWF), together with the Spanish government, purchased a section of 6,974 ha of Guadalquivir marshes and surrounding sandy areas building up the Reserva de la Estación Biológica de Doñana. A few years later, in 1969 a wider area including the Reserva was preserved as Doñana National Park (34,625 ha). On a later date (1979) the protected area was further enlarged to 77,260 ha including the National Park and surrounding areas with limited resource exploitation for environmental protection. The Natural Park of Doñana was created in 1982 incorporating the protection areas and after some later additions, the National Park extends for 54,720 ha and the Natural Park for 53.709 ha making a vast protected area of 1,084 km^2. On 1992 an International Commission of Experts presented a Sustainability Plan for the development of Doñana region (Castells et al., 1992). It was the earliest example of sustainability plans ever published and its implementation has secured the preservation of the National Park to the present day.

The most serious incident occurred in 1998 when the retention walls of a mine tailing deposit from a pyrite mine (in Aznalcollar, some 60 km N of the Park) collapsed (Grimalt et al., 1999). The discharge of about two million cubic meters of minerals and four million cubic meters of mineralised water flowed into the Guadiamar River, reaching the Natural Park and the Guadalquivir Estuary in the following days. The spill covered 4,286 ha of land surface, with 2,500 ha of cropland, contaminating soils with arsenopyrites and pyrolusite, releasing Ag, As, Bi, Cd, Co, Cu, Fe, Hg, Pb, S, Sb, Se, Tl and Zn. The accident had significant ecological and economic consequences, severely affecting organisms of Guadiamar river and destroying the agriculture of the valley. Considerable efforts by the Spanish Government succeeded in an early control of the spill, and the long-standing effort to remediate the contamination and restoring of the area (Manzano et al., 1999). Along with clean up and restoration, the Spanish Ministry of Environment formulated in 1998 the "Doñana 2005" project, which encompasses a series of strategic actions to restore the traditional hydraulic dynamics of Doñana Parks.

More than twenty years ago concern was expressed over the impact of mass tourism and intensive irrigated agriculture in the region outside but around the National Park (Llamas 1988, 1989; Suso and Llamas, 1993). This concern continues and has also been expressed by International institutions (UNEP, 2004; WWF, 2009b). There have been fears that these activities were causing the depletion of regional aquifers, leading to a fall in groundwater levels and a gradual reduction in the extent and duration of seasonal flooding in the marshes (Zunzunegui et al., 1998; Serrano and Zunzunegui, 2008).

3. Method

The present study estimates the water footprint within the Doñana region considering the green, blue and grey water components for the most representative crops and the blue water component for industrial products and urban water use for an average rainfall year (2001). Within the blue water component, the volumes of surface and groundwater consumption are differentiated. In most of the cases numbers are rounded in order to avoid a feeling of accuracy that would be unrealistic.

Water footprint of primary crops

The green, blue and grey water footprints of primary crops were calculated following the methodology described in Hoekstra and Chagapain (2008) and Hoekstra et al. (2009). The total crop water requirement, effective rainfall (fraction of rainfall that is stored in the soil and available for the growth of plants) and irrigation requirements per region have been estimated using the CROPWAT model (FAO, 1998; FAO, 2009a). The calculations have been done using climate data from the nearest and most representative meteorological station located in the major crop-producing regions (Sevilla-Tablada) and a specific cropping pattern for each crop according to the type of climate.

The green water footprint of the crop (m^3/ton) has been estimated as the ratio of the green water use (m^3/ha) to the crop yield (ton/ha), where total green water use is obtained by summing up green water evapotranspiration over the growing period. Green water evapotranspiration is calculated based on the CROPWAT model outputs, as the minimum of effective rainfall and crop water requirement with a time step of ten days.

The blue water footprint of the crop has been taken equal to the ratio of the volume of irrigation water consumed to the crop yield. The irrigation water consumed is based on the CROPWAT model output and estimated as the difference between the crop water requirement and effective rainfall on a ten-day basis. When the effective rainfall is greater than the crop water requirement the irrigation requirement is equal to zero. The total evapotranspiration of irrigation water is obtained by summing up the blue water evapotranspiration over the crop growing period.

Even with some limitations, the grey water footprint was used to estimate the nitrogen pollution from agriculture. The grey water footprint of a primary crop (m^3/ton) is calculated as the load of pollutants that enters the water system (kg/year) divided by the maximum acceptable concentration for the pollutant considered (kg/m^3) and the crop production (ton/year) (Hoekstra and Chapagain, 2008). In this study, nitrogen was chosen as an indicator of the impact of fertiliser use in the production systems. The total volume of water required per ton of N is calculated considering the volume of nitrogen leached (ton/ton) and the maximum allowable concentration in the surface or groundwater bodies. The quantity of nitrogen that reaches free flowing water bodies has been assumed to be 10 percent of the applied fertilization rate (in kg/ha/yr) (following Hoekstra and Chapagain, 2008). In line with the European Nitrates, Groundwater and Drinking Water Directives, the standard for nitrate is 50 milligrams per litre (measured as NO_3^-). This is very similar to the drinking water standard recommendation by the US Environmental Protection Agency (EPA, 2005), which is 10 mg N per litre, equivalent to about 45 mg NO_3^- per litre. The standard of 10 mg N per litre was used to estimate the volume of water necessary to dilute polluted leaching flows to permissible limits. This is a conservative approach, since the natural background concentration of N in the water used for dilution has been assumed negligible.

Finally, in this study we have included the concept of economic water productivity (€/m^3) to assess the production value, expressed in market price (€/ton) per cubic meter of water consumed when producing the commodity (m^3/ton).

Environmental water requirements

Concerning the environmental water requirements, the blue water requirement values (including surface and groundwater) were based on already existing calculations for the

Doñana region, including the National Park, Natural Park and its region of influence, by WWF (2009a). These estimations were based on the ELOHA approach (Ecological Limits of Hydrologic Alteration) (Poff et al., 2009), which many consider a scientifically robust and flexible framework for assessing and managing environmental flows, where knowledge is systematically organized within a context of decision making. This method, considering the flow-ecology relationships and covering a wide range of issues, can optimally support comprehensive regional flow management. However, it can only be applied where hydrology is understood. It reflects the published research to date and not all ecosystem responses. Furthermore, one has to be very careful when making predictions based on this method.

Similar to the water footprint of primary crops, the green water use by natural forests was estimated using the CROPWAT model (FAO, 2009a). The eucalyptus water consumption was taken from CSIC (2008).

4. Data sources

Data have been compiled from different sources.

🕑 Agricultural data

Data related to area (crop area both rainfed and irrigated) were taken from Custodio et al. (2006). Data on average rainfed and irrigated crop yield (kg/ha) at provincial level (Sevilla) and crop market prices were taken from the Agroalimentary Statistics Yearbook of the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2009) for the average rainfall year 2001. As a first approximation an average rainfall year is analysed. In further studies, however, it would be interesting to account for temporal variability within and between years. Climate data for the water footprint calculations have been taken from the CLIMWAT database (FAO, 2009b), using climate data from Sevilla-Tablada meteorological station. Crop coefficients for the different crops were obtained from Chapagain and Hoekstra (2004) and FAO (FAO, 1998; 2009b). Data on the application of nitrogen fertilisers for Andalucía have been obtained from the Spanish Ministry for the Environment (MIMAM, 2007).

🕑 Hydrologic data

Data related to water origin (surface and groundwater) by agricultural region were taken from the 1999 Agrarian Census of the National Statistics Institute (INE, 1999). Data concerning urban water supply were obtained from Custodio et al. (2006).

🕑 Environmental data

Limited data are available on environmental water requirements. Data on environmental blue water requirements were taken from WWF (2009a). As previously mentioned, data on environmental green water use by forests were estimated using the CROPWAT model (FAO, 2009a). A constant crop coefficient of 1 —as recommended for rubber trees, tea and conifer trees (Allen et al., 1998)— was assumed representative for natural forests (Roost et al., 2008).

5. Land and water use in the Doñana region

As mentioned in the methodology chapter, the analysis has been carried out for the Doñana region (2900 km^2), which includes the Doñana National Park (542 km^2), the Natural Park (537 km^2), and its area of influence (see Figure 1).

5.1. Land uses in the Doñana Region

The Doñana region is characterised by an extreme polarization between natural, urban, and agricultural uses (García Novo and Marín Cabrera, 2006) (Table 1 and Figure 2). On the one hand, natural uses consist of marshes, river banks and forest of great ecological and environmental value and limited economic use (Andalusian Regional Government, 1999). On the other hand, urban and agricultural uses are intensive, highly productive farming (rice fields and strawberries in greenhouses), which coexist with more extensive and traditional farming (vineyards and olive groves) (Andalusian Regional Government, 1999).

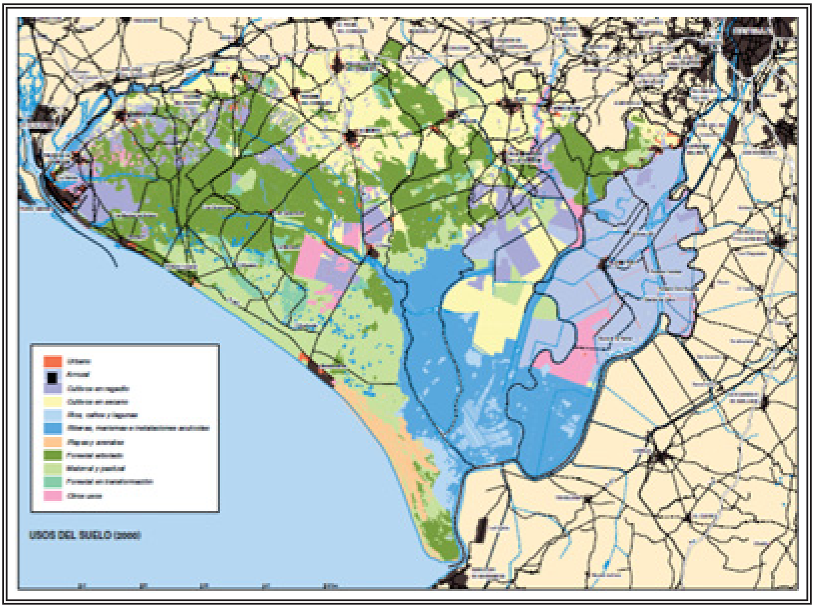
Urban uses are concentrated in the Sevilla-Huelva corridor, where all the main municipal towns are located. Apart from this corridor, just two coastal touristic resorts (Matalascañas and Mazagón) are present.

Concerning the agricultural land use, during the last 30 years, new crops have been introduced in the region, such as strawberries and raspberries. Even if they are not spatially

TABLE 1. *Land uses in the Doñana region. Source: Modified from Custodio et al. (2006)*

Area	**Km²**
Doñana region	2900
Aquifer Almonte-Marismas (AAM)	2400
Permeable area of AAM	1840
Wetland	1500
National Park	542
Natural Park	537
Cultivated area	877
Forested area	1210
Santa Olalla lake	0.48

FIGURE 2. *Land uses in the Doñana region. Source: modified from Andalusian Regional Government (2003)*



extensive, they are very significant, not only in economic but also in environmental terms since the agricultural intensification and the widespread use of plastic greenhouses brings along environmental consequences (Andalusian Regional Government, 2002).

Ecosystems

According to the vegetation composition and ecological processes, Doñana comprises the following ecosystems (García Novo, 1997; Custodio et al., 2009):

The beach. The littoral of the National Park extends for 25 km, from the Guadalquivir estuary in the East to

Matalascañas, a touristic resort in the West. A second leg about 30 km long, primarily belonging to the Natural Park, extends from Matalascañas to Mazagón resort in the Ría de Huelva. This long beach, one of the few unspoiled littoral landscapes of the Iberian Peninsula, describes a wide arch. The light coloured and fine sands of mixed eolian and estuarine origin indicate a long distance transport downcurrent in the littoral West-East stream that from South Portugal reaches de Guadalquivir estuary. The beach is rich in marine birds (seagulls, oystercatchers) and plovers.

Stabilized sands. Within the stabilized sands, it is the hydrological behaviour of the soil surface as a discharge or a recharge area of the aquifer that makes the main environmental difference. A modest topographic gradient of about 6 m in height difference, opposes dry "elevations" to wet "depressions" where soil water is available during the dry summer. Aquifer discharge of low conductivity waters (0.5-4 mS/cm) in depressions feeds shallow temporary ponds or deeper permanent ponds. The inherited dune morphology of dune crests or sand bars (naves) further differentiates elevations.

Woodlands. Woodlands represent the mature terrestrial ecosystem with the largest structural development and more intense environmental control. In the mobile dunes there are two types: planted or seminatural *Pinus pinea* woodlands with remnants of junipers, *Juniperus oxycedrus ssp. macrocarpa.* In the stabilized sands woodlands are represented by the modest sized *Juniperus phoenicea ssp. turbinata,* in the dry sand bars, cork-oaks *Quercus suber* and ash tree, *Fraxinus angustifolia* in the moister sands and poplars, *Populus alba* and tamarisks, in some foodable areas: arranged according to water conductivity from low (*Tamarix africana*) to medium (*T. canariensis*) and high (*T. gallica*) values. Eucalypts *Eucalyptus globulus* and *E. camaldulensis* were extensively planted in the early 60's and 70's of previous century for timber production. Most of the eucalyptus plantations have been largely eradicated, few of them surviving as abandoned plantations with a poor understory. The predominant woodland type is dominated by cork-oaks.

The Mediterranean scrublands. Forest degradation resulted in sandy soil impoverishment and the spread of shrubbery vegetation. Prescribed fire regimes for range management induced pyrophitic scrub vegetation that largely dominates Doñana vegetation. Sharp boundaries between scrub types rarely occur. Transitions or clines are the rule both in space (horizontal or vertical structures) and time (succession). Down slope, "monte blanco" (white scrub) ecosystem develops with the thorny *Ulex australis* and *Ulex argenteus ssp. subsericeus*, *Halimium halimifolium*, whose light colored leaves dominate vegetation shade. Monte blanco type occurs on the 1.5 to 3 m range above the piezometric surface, receiving some summer water supply. In the wetter areas, at the bottom of the slopes, the "monte negro" ecosystem (black scrub), a heath, dominates the scrubbery with a composition closely resembling that in the wetter slacks: *Calluna vulgaris*, *Erica umbellata*, *E. scoparia ssp. scoparia*, *Genista triacanthos ssp. triacanthos*, *Cistus psilosepalus*, *C. salvifolius* and their hybrids are widespread. Sites suffering temporary flooding let other species be present in the "hygrophytic monte negro" ecosystem with *Erica ciliaris*, *Molinia caerulea ssp. arundinacea*, *Imperata cylindrica*, *Ulex minor*, *Scirpus holoschoenus* and *Saccharum ravennae*, that can attain 4 m of height. Monte negro type grows to a short distance above the water table on the permanent discharge surfaces of the aquifer, benefiting from permanent soil water supply. Soil water logging occurs when water table surfaces, inducing the "hygrophytic scrub" at the bottom of the slopes or in upwelling surfaces at any height (Muñoz-Reinoso and García Novo, 2004).

The grasslands. In the stabilized sands some permanent grasslands are recognized. In the small patches among shrubs a seasonal therophytic vegetation develops. In the wide ecotone (locally known as Vera) making the transition from sands to the marsh a series of grassland types have been described. Water availability, flooding duration, water conductivity and grazing pressure control plant species composition.

Hygrophytic vegetation. In large depressions and around the ponds, fringes of hygrophytic vegetation develop, often forming linear forests closely resembling the river bank forests with ashes, *Fraxinus angustifolia ssp. angustifolia*, poplars, *Populus alba*, and willows, *Salix atrocinerea* and the dense hygrophytic scrubbery described above, that withstands temporary flooding. Closer to the water surface, grassland appears which is rich in sedges, rushes, buttercups and flooding resistant species.

The ponds. Locally known as “lagunas”, the ponds of the stabilized sands are variable ecosystems both in time and space. Shallow (20-40 cm deep) ponds are small (0.5-1 ha), usually presenting terrestrial vegetation which will be killed during heavy rainfall periods when ponds are filled. A strong successional cycle starts after pond desiccation. Deeper ponds with a stable aquifer discharge are lined along dune fronts in both active and stabilized dunes. These large pond attain 4 m of depth and 100 ha (Lagunas de Santa Olalla-Dulce) under high water conditions, showing no terrestrial vegetation invasions.

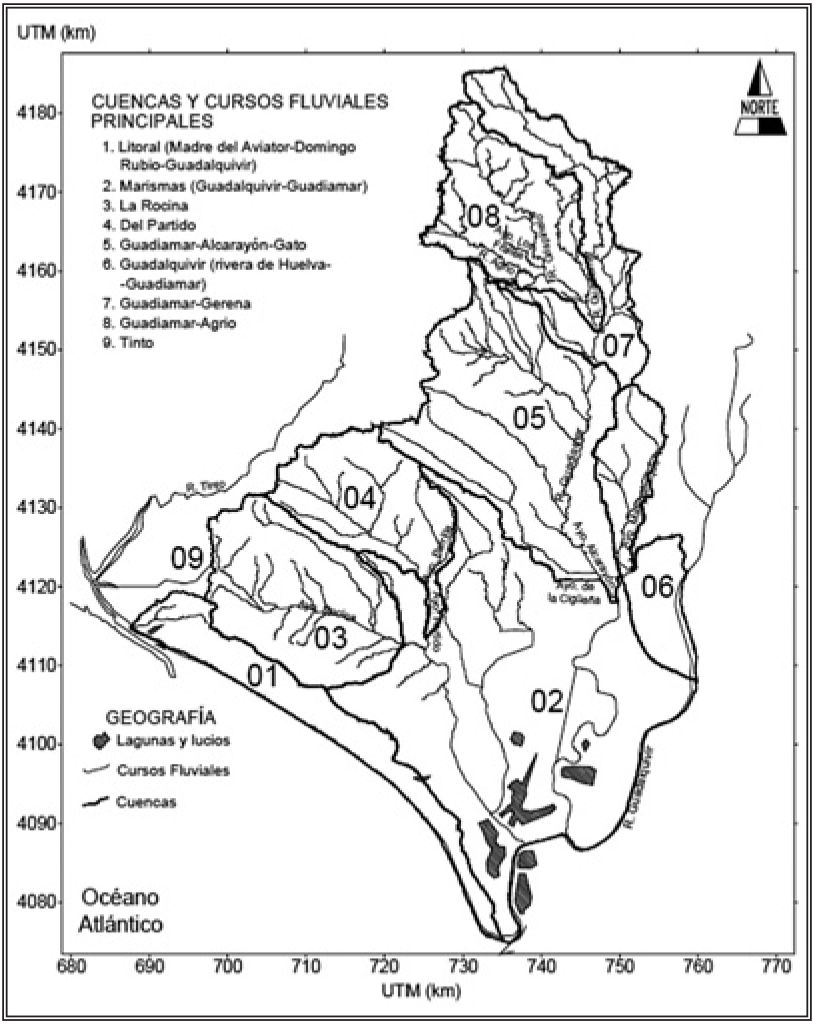
The marshes. Doñana marshes, extending for around 28,000 ha, constitute a vast seasonal freshwater wetland of international importance. They are Europe’s largest sanctuary for migrating birds. They were declared National park in 1969, Biosphere reserve in 1980, Important Wetland Site under the Ramsar Convention in 1982 and Natural World Heritage Site in 1984 (García Novo and Marín Cabrera, 2006). The variable winter rains flood Doñana marshes forming a wide shallow lake that dries up during spring and summer. Flooded areas are very variable in depth and turbidity, and they change depending on the amount and pattern of rainfall and time of the year.

5.2. Water in the Doñana region

Water availability is the controlling factor for the maintenance of both aquatic and terrestrial ecosystems, the composition of plant communities, their biomass, productivity and succession (Muñoz-Reinoso, 2001). Under natural conditions, most of the contributions of water were coming from precipitation, several rivers and streams (Guadalquivir, Guadiamar —now diverted— La Rocina, El Partido, las Cañadas, etc.) including regular entries through the Guadalquivir estuary and aquifer discharge (García Novo and Marín Cabrera, 2006) (Figure 3). The upstream and middlestream of the Guadiamar riverflow (there is a dam upstream and diversion at the end) and the Guadalquivir river (densely regulated watershed), however, are to some extent anthropically controlled by means of hydraulic engineering.

Groundwater is crucial for the maintenance of rivers and wetlands of Doñana. The aquifer system of Almonte-Marismas feeds upwelling surfaces at various points on the periphery of the marshes, allowing the formation of temporary ponds characteristics of these areas, as well as springs that drain into the marsh. Groundwater recharge occurs mainly by infiltration of rainfall through permeable saturated sands and to a lower extent by irrigation return flows, by infiltration of used water and by small contributions of the Guadiamar river (Custodio et al., 2006). The aquifer on the

Figure 3. *Rivers and their watersheds in the region of Doñana. Source: Custodio et al. (2006).*



other hand continuously discharges to the sea along the coast, to the main streams (La Rocina), to the Tinto river and its affluents and to the ecotones (contact areas between the sands and the marsh), which at the same time maintain phreatophitic vegetation, both natural (monte negro and the remaining gallery forests) and those planted trees capable to reach the aquifer level with deep roots (as eucalypts). Temporary and permanent ponds (Santa Olalla-Dulce system) are maintained by aquifer discharges the water level closely following aquifer fluctuations (Serrano and Zunzunegui, 2008). These natural discharges of groundwater and the small streams (or caños) and associated streams are an essential trait to explain the rich ecological diversity of Doñana region (García Novo et al., 1996; 2007; Custodio et al., 2006).

6. Environmental water use and requirements within the Doñana region

In this section, the current environmental green and blue water use is estimated, followed by the analysis of the theoretical environmental blue water requirements.

6.1. Environmental blue water use

The current environmental blue water use in the Doñana region amounts to about 154 Mm^3/year, 116 related to surface and 38 to groundwater (Andalusian Regional Government, 2002; 2003). Within the Doñana region, in spite of the complexity and interrelation of the hydrologic cycle, the following blue water units can be differentiated with certain degree of independence, based on their hydrodynamic behaviour (Andalusian Regional Government, 2002):

- The Tinto river basin is an independent hydrodynamic unit composed on the one hand by small streams draining into the Tinto River, and on the other hand by the

Domingo Rubio and Madre del Aviator streams, that drains into the ocean.

- The coastal strip of the Almonte-Marismas aquifer. To the south of the hydrogeological watershed defined by the Almonte-Marismas aquifer, rainfall infiltrates in large amounts into the aquifer, subsequently draining into the Atlantic Ocean. In total this flow adds up to about 38 Mm^3/year (Andalusian Regional Government, 2002).

- Strip edge of the natural marsh and streams of the central area of the Doñana Natural Park (La Rocina, El Partido, Cañada Mayor, Juncosilla and Portachuelo). In this area the underground flows of the aquifer towards La Vera and La Retuerta (approximately 30 Mm^3/year), together with the irregular surface water contributions (of the order of 86 Mm^3/year), feed the marshes, or to a lesser extent other wetlands and endoreic systems (Andalusian Regional Government, 2002).

- Guadiamar river and its affluent streams. The non-regulated flows of the Guadiamar river, along with the urban and industrial waste water discharges, are partially used for irrigation. The surpluses are dumped into the Guadalquivir river. Just in extraordinary avenues it overflows and incorporates its contributions to the National Park marshes through the Lucio del Cangrejo.

- Guadalquivir river no longer flows into the Park marshes but a large network of channels and ditches provided with floodgates let estuary waters from Brazo de la Torre and Guadalquivir river enter marshes and paddy fields for irrigation and aquaculture. About 400 Mm^3/year are pumped from the Guadalquivir river to irrigate the rice fields, most of which returns directly to the river or through the Brazo de la Torre. Just in extraordinary avenues some defence systems are overflowed and marshes are flooded from the estuary. This has occurred for the last time in 1973. The large precipitations during 2009/-10 winter made marshes flood from rainfall and small tributaries to unusually high water levels (1.5-2 m). Large water volumes were finally discharged to estuary.

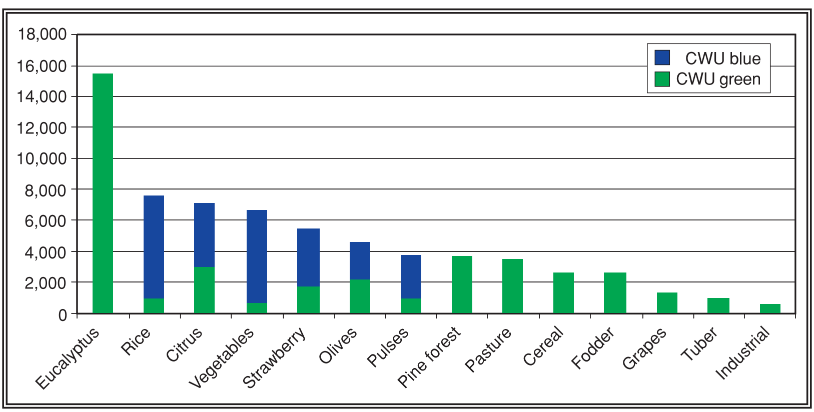
6.2. Environmental green water use

Another question that should also be incorporated into water allocation decisions and environmental water requirement analyses is the green water used by natural vegetation. Hitherto, the environmental flow studies (e.g. Smakhtin et al., 2004) have mainly focused on blue water use without considering the green water evapotranspiration from the natural vegetation.

Due to the limited data availability, the current environmental green water use was estimated only for woodlands, which are mainly located in the western part of the region. This rough estimation is probably underestimating the environmental green water use in the region since neither grasslands, marsh vegetation nor the scrubland have been considered. Comparing the water consumed by the different crops and natural forests in terms of m^3/ha, results that the pine forests use less water than all the irrigated crops in the region (3650 m^3/ha versus 3700-7600 respectively), whilst using more water than rainfed crops (550-2600 m^3/ha) (Figure 4). However, these figures vary depending on the context; for instance, pine trees in the western Doñana region (area of El Abalario) are stunted probably with low evapotranspiration, whereas in Hinojos trees are huge possibly having a high evapotranspiration. In total, in the Doñana region, the environmental green water used by forests adds up to about 442 Mm^3/year. This calculation is based on pine forest (*Pinus pinea*) water requirements since these are currently the main forest species in the region. The non-agricultural evapotranspiration or environmental green water used by forests contributes significantly to the use of water resources, amounting to about 44% of total water use. These relevant figures, even if generally included in the water balance studies, have not been accounted in the traditional national water accounting systems. In the case of environmental flow studies (Smakhtin et al., 2004), they have mainly focused on blue water use without considering the green water evapotranspiration from natural vegetation. Further research is needed on this topic.

Figure 4 shows the high water consumption by eucalyptus trees. The introduction of eucalyptus tress in most of the western water table area (e.g. Moguer, El Abalario, La Mediana, La Rocina) some 50 years ago also impacted local phreatic wetlands. The increase of evapotranspirated volumes led to a water table drawdown large enough to reduce

FIGURE 4. *Green and blue water consumption (CWU) of agricultural crops and natural forests in the Doñana region for an average rainfall year (m3/ha). Source: Own elaboration.*



or eliminate local phreatic discharges to many ponds between El Abalario height, La Rocina stream (Manzano et al., 2005). This seems to have been the case of the formerly permanent pond-complexes of Ribetehilos and La Mediana. Nowadays, however, most eucalypt trees have been removed.

6.3. Environmental blue water requirements

The environmental blue water requirements were taken from a detailed estimation by WWF (2009a) using the ELOHA approach (Ecological Limits of Hydrologic Alteration). This approach is considered by many a scientifically robust and flexible framework for assessing and managing environmental flows, where knowledge is systematically organized within a context of decision making. According to this study the theoretical environmental surface and groundwater requirements of the Doñana region, in order to recover the wetlands in the National Park, amount to about 200 Mm^3/year in average years.

In the mentioned study the relationship between hydrology and ecology was considered to link the dynamics of ecosystems, habitats and species. Vegetation is a good performance indicator for its intrinsic importance and the role played on the various animal groups. For this reason the vegetation response to hydrological changes in Doñana through modelling and analysis of thematic mapping was analysed. For the period 1990-2004 some of the species that need more water have reduced their surface area more than 60%, in some cases reaching 80% reduction. This knowledge should be incorporated in the environmental flow proposals as explained below.

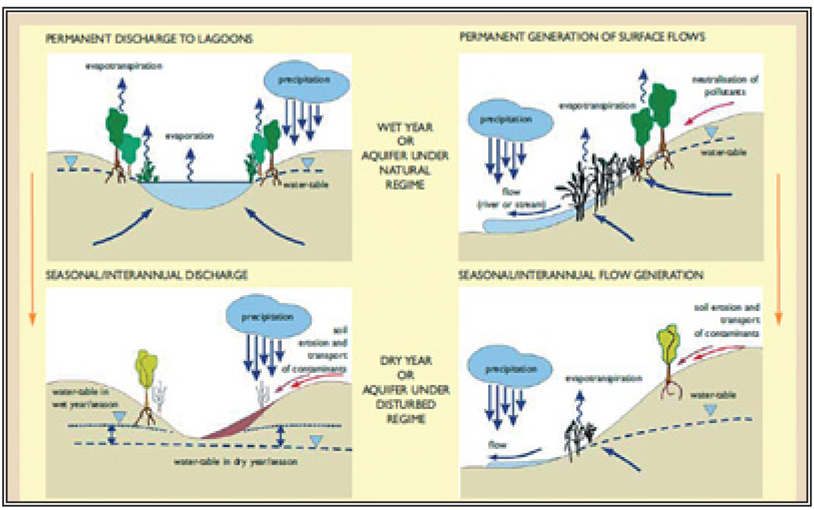
Environmental blue groundwater requirements

As previously mentioned, the Doñana area overlies a large sedimentary aquifer that is of outstanding environmental and human importance, as groundwater plays an essential role both in the generation and maintenance of a wide variety of ecologically important natural habitats, and in the subsistence and development of a human population that depends almost entirely on this groundwater for their domestic water supply and for crop irrigation. This aquifer is officially known as the Almonte-Marismas Hydrogeological Unit, and in practice simply as the Doñana Aquifer (García Novo and Marín Cabrera, 2006).

It is well known since decades that in various ecosystems in the Doñana area there is a clear relation between the depth of the groundwater table and the type of vegetation (Allier et al., 1974; Custodio, 2005) (Figure 5). For instance, as explained in a previous paragraph, the depressions of fixed dunes with winter flooding and where summer water table is shallower than 2 m exhibit "Monte Negro" vegetation with heather *Erica scoparia, E. ciliaris* and heath, *Calluna vulgaris* and remnants of former cork oak *Quercus suber* woodlands with strawberry trees *Arbutus unedo*. When water table in summer remains below 2 m of soil surface but not surfacing in winter, "Monte Blanco" vegetation prevails where *Halimium halimifolium* dominates). Should water table remain below 2 m and therefore inaccessible to plant roots all year around, a Mediterranean vegetation resembling garrigue or maquis types, rich in rockroses and aromatic plants grow in an open cover. When water table intersects the land surface forming small ponds in winter, permanent meadows often dominate the scenery (Custodio et al., 2009). These four types of vegetation have decisive influence in the animal community. In a parallel way, aquatic ecosystems are controlled at every level by water depth, transparency, chemical composition, turbulence and others. Obviously, the depletion of the water table because of groundwater abstraction for irrigation, for urban water supply and eucalyptus plantations (in the

1950's) had an impact (Figure 5). Such facts show how groundwater is a key factor to the development of the native vegetation and also prove that the degraded ecosystem can be restored and protected through water management. The groundwater discharge in "natural" conditions (without significant human intervention) ranges between 25-32 Mm^3/year to the Vera and 10-15 Mm^3/year to the Northern ecotone (Custodio et al., 2006). Groundwater allocation processes have traditionally not considered environmental values, although this is being included in some Australian states. The long-term viability of groundwater dependent ecosystems requires that they be identified, their water requirements understood and this understanding be built into groundwater allocation processes. This knowledge should also be incorporated in the ecological flow proposals which must find the ultimate conformity and consistency among the legal set.

FIGURE 5. *Most frequent types of wetlands depending on groundwater in Doñana. Source: Manzano et al. (2002; 2005).*



7. Water footprint within the Doñana region

7.1. Agricultural water footprint

The Doñana region crop area is about 87,683 ha according to Custodio et al. (2006). Table 2 shows the area dedicated to each type of crop in the year 2001. When looking at rainfed agriculture, cereals, industrial crops, fodder and grapes are the main crops in the Doñana region. Concerning irrigated agriculture, rice, olives, vegetables and strawberries are the major crops in the region. In the case of olive trees complementary irrigation is used. The rice in Doñana amounts to about 33% of total cropped area, completely grown in the province of Sevilla. Rice cultivation is located in the north and east of the Guadalquivir marshes, replacing the natural vegetation. The hydrologic regime of the marshes is almost completely artificial, with the inflows and tidal flats substituted by dikes, channels and gates. The water for the rice is in a way pumped from the Guadalquivir river.

Apart from the environmental water use, agriculture is the second main water user in the region, being the main

Table 2. *Crop area in the Doñana region (ha). Source: Custodio et al. (2006)*

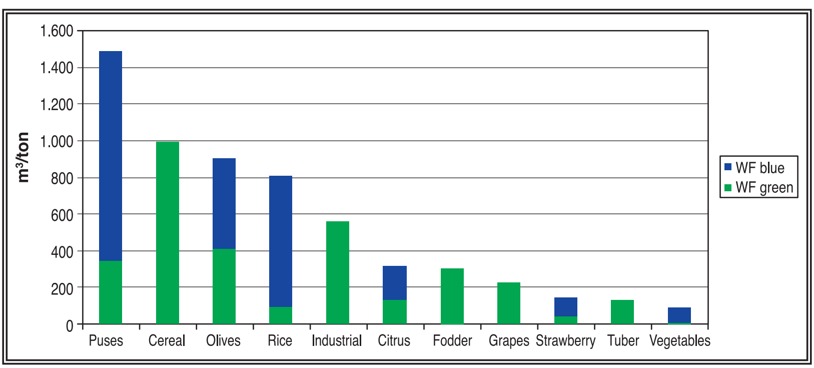
Crop type	Area (ha)	Irrigation
Rice	28922	Yes
Olives	14755	Yes
Cereal	11477	No
Industrial	9034	No
Fodder	6181	No
Vegetables	5463	Yes
Grapes	5343	No
Strawberry	5081	Yes
Tubers	1031	No
Pulses	396	Yes

source of employment and income in the area as well. This sector thus plays a highly important role in its conservation.

Figure 6 shows the water footprint figures in terms of m^3/ton for the different crops. The traditional rainfed vineyard and tubers (e.g. potatoes) are two of the most water efficient crops: apart from having a low water footprint are entirely based on green water resources. Vegetables and strawberries, grown under plastic also present a low water footprint, though they are almost entirely based on blue water. On the other hand pulses, cereals, olives and rice show higher water footprints, being the rice almost based on blue water resources.

Within the agricultural sector, rice seems to be the major water user in the Doñana region (Figure 7). The total water used (partly evaporated, partly returned to the catchment) to grow rice is about 13,000 m^3/ha (CHG, 2009), however, the total water consumed (evaporated or incorporated into the product, not returned to the catchment) is about half

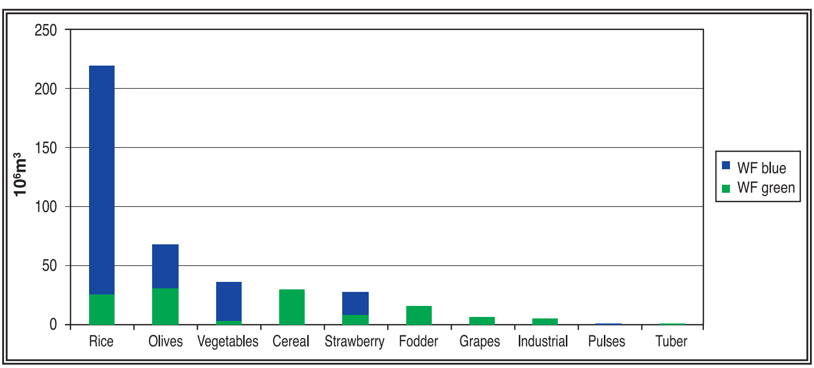
FIGURE 6. *Green and blue water footprint (WF) of agricultural crops in the Doñana region for an average rainfall year (m^3/ton). Source: Own elaboration (see table in Appendix I).*



this figure (7,600 m^3/ha) according to our estimations (Figure 4). Rice is grown on a very well defined monoculture basis, cross-linked by channels, drainages and tracks. Out of the transformed marsh, rice has also expanded, mainly in an illegal way, entering the public domain in the channeling of Guadiamar and Guadalquivir beaches, in the surroundings of the National Park (Andalusian Regional Government, 2002). Rice is the oldest and most stable crop in the transformed marsh. The paddy fields in the lower Guadalquivir produce about 44% of the national rice production, with about 80% of it located in the former marshes.

Strawberry cultivation has had large environmental consequences such as the lost of forested areas some erosion increase, habitat fragmentation, groundwater depletion, plastic residues from greenhouses and agrochemical pollution (Andalusian Regional Government, 2002; WWF, 2009b). Apart from these environmental problems, strawberry cultivation has a vital economical significance for the region. It is the crop with the highest water apparent productivity

FIGURE 7. *Total green and blue water consumption (WF) of agricultural crops in the Doñana region for an average rainfall year (10^6 m^3). Source: Own elaboration (see table in Appendix I).*



adding up to about 6 €/m^3 (Figure 8). The sector generates 55.000 jobs for a total of 4.5 million day´s stints. Most of the workers though are immigrants from Eastern Europe and Northern Africa, with a salary of about 36 €/day. This sector receives 24 million euros per year in form of direct public subsidies (average of 3,636 €/ha/year), which represents 10-12% of the income. Water only accounts for 3.42% of the total costs (WWF, 2009b).

It seems widely known that illegal or alegal water use affects the area neighbouring the Doñana National Park, especially in the rice-growing area of Los Hatos, north of the marsh, and at the west of the National Park, where the strawberry fields are concentrated (WWF, 2006). In the Los Hatos area, 12 Mm^3/year of groundwater are abstracted alegally, mainly to irrigate rice, which causes important depletion in the Doñana aquifer.

All in all, the total blue agricultural water footprint amounts to 282 Mm^3/year (71% surface and 29% groundwater) (Table 4) versus the 200 Mm^3/year of blue water needed by the environment and 443 Mm^3/year total blue water available in the region. Along these lines, the Chanza-Doñana project plans to transfer 5 Mm^3 from the Chanza-Piedra-Andévalo system to the Doñana region in order to replace groundwater use in the Doñana region. This volume of water however does not seem enough to satisfy the agricultural demand. Perhaps an option, part of the solution, would be to limit the number of (a)legal water abstractions from the Almonte-Marismas aquifer.

Grey water footprint

Agriculture also implies a threat of eventual damage to the ecosystems from the use of fertilizers and other chemicals

(Custodio and Palancar, 1995). To analyse this type of pollution the grey water footprint of nitrogen fertilizer was estimated within the Doñana region. The grey water footprint shows the volume of water required to assimilate the fertilisers that reached the water system based on the average N fertiliser application rate, an assumed leaching percentage of 10% and a nitrogen water quality standard of 10 mg/l (around 50 mg/l of NO_3) (Table 3).

Contrary to what one might expect, the grey water footprint, in terms of m^3/ton, is noticeably higher for cereals and industrial crops than for vegetables (see Table 3 and Figure 8). For wheat, fertiliser application rates are on average about 40% lower than for vegetables, but cereal yields per hectare are on average more than ninety times less than vegetable yields (see Appendix I). It is widely known, however, that vegetable production is a very intensive form of

TABLE 3. *Nitrogen fertilizer application and the grey water footprint (volume of water required to assimilate the fertilizers leached to the water bodies) (m^3/ton) in the Doñana region.*

	Average N fertilizer application rate**	Area*	Total N fertilizer applied	Nitrogen leached to the water bodies	EPA (2005) standard g/m^3	Volume of dilution water required	Production*	Grey water footprint
	kg/ha	ha	ton/year	ton/year	mg/l	10^6 m^3/year	Ton	m^3/ton
Cereal	91	11477	1044	104	10	10	29748	351
Fodder	28	6181	173	17	10	2	52539	33
Industrial	30	9034	271	27	10	3	8853	306
Olives	85	14755	1254	125	10	13	74778	168
Potatoes	51	1031	53	5	10	1	7661	69
Pulses	15	396	6	1	10	0	990	60
Vegetables	150	5463	819	82	10	8	391675	21

* Custodio et al. (2006).
** MIMAM (2007).

agriculture in terms of water use and chemical inputs. This becomes clear when one considers the nitrogen load per hectare: the average fertiliser application rate in terms of kg/ha is higher for vegetables than for cereals (150 versus 91 kg N/ha/year, respectively). One can thus see that the

FIGURE 8. *Grey water footprint related to nitrogen fertilizer of agricultural crops (WF_{grey}) in the Doñana region (m^3/ton). Source: Own elaboration.*

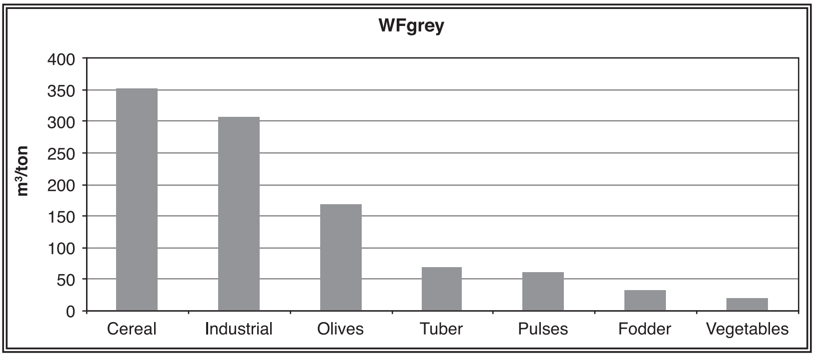
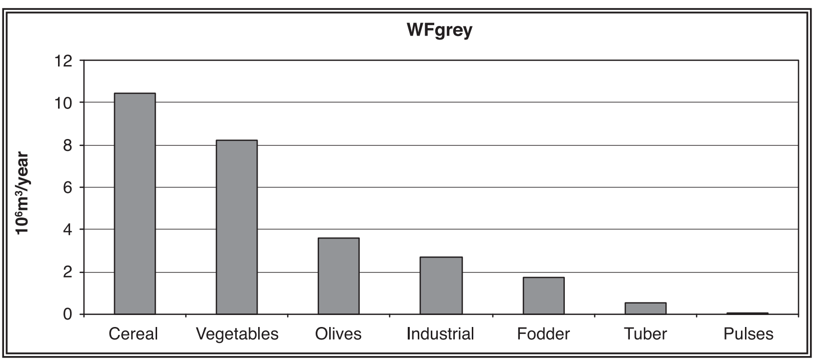


FIGURE 9. *Total grey water footprint related to nitrogen fertilizer of agricultural crops (WF_{grey}) in the Doñana region ($10^6 m^3$/year). Source: Own elaboration.*



grey water footprint of vegetables compared to cereals is low when expressed per ton but high when expressed per hectare, which is in line with previous studies (Aldaya and Hoekstra, 2009; Chapagain and Orr, 2009). The same can be observed for the blue water footprint: relatively low for vegetables when expressed per ton, but relatively high when expressed per hectare. The total grey water footprint related to nitrogen amounts to 27 Mm^3, which is about 6% of the total available blue water in the region (443 Mm^3). This means that 6% of the assimilative capacity of the blue water is being used by nitrogen fertilizers.

7.2. Industrial and urban water footprint

Industrial and urban water use refers to total withdrawals of blue water. In the case of Doñana, and according to Custodio et al. (2006), all the water abstracted for industrial and urban water supply comes entirely from local groundwater resources and amounts to about 6.7 Mm^3/year. The main towns within the Doñana region are Matalascañas, El Rocío, Villamanrique de la Condesa and Hinojos. In its boundaries one can find Moguer (and Mazagón), Palos, Lucena, Rociana, Pilas, Bollullos par del Condado, and Aznalcázar.

Groundwater is mainly abstracted to supply the towns and the large touristic resorts of El Rocío, Matalascañas and Mazagón, which also affect wetlands (Manzano et al., 2005). Matalascañas tourist resort is located on the coastline within the municipality of Almonte, and has a set of wells for urban water supply along its northern fringe, just bordering the National Park. Daily cycle of water abstraction in wells is followed by water level fluctuations in ponds within the National Park with a few hours delay (Serrano and Zunzunegui, 2008). Matalascañas has less than 2,000 permanent inhabitants, but the population increases to more than 100,000 in summer and many weekends, showing a strong seasonal occupation (Muñoz-Reinoso, 2001). The urban water supply to Matalascañas is about 2.5-3 Mm^3/yr (Castell et al., 1992), mainly for human use and garden watering (DGOT, 1992). There is also a religious festival at El Rocio Shrine, which brings large crowds of about one million people every spring and large groups on holidays for all year long.

8. Water footprint and environmental water requirements within the Doñana region

Water is the strategic basis for the maintenance and development of Doñana from the ecological perspective: Doñana contains wetlands, marshes, ponds and terrestrial vegetation, which is largely dependent on surface water flows and on the water table depth. From the economic perspective, there is again a strong dependence for domestic supply, intensive agriculture and tourism. A first approximation of the water footprint and environmental water requirements is presented below.

Currently the main green and blue water user in the Doñana region is the environment, using about 59% of total water consumption in an average rainfall year (Table 4). Agriculture is the second main water user amounting to about 40% of total water consumption. Finally, urban water supply and industry use around 1% of the total water used. However, the latter two use exclusively blue water resources, which generally have a higher opportunity cost than green water use (Hoekstra and Chapagain, 2008). Green water can be productively used only for crop production (not in the sands) and natural biomass production (support of ecosystem functioning), while blue water can be used not only for irrigating crops and the ecosystems but also for various other types of domestic, agricultural and industrial water use. On the other hand, all the figures provided refer to consumptive water uses except some urban and industrial water withdrawal (non-consumptive use of water). In the case of the coastal touristic resorts of Matalascañas and Mazagón, their water use is consumptive since they discharge into the sea; they could however avoid this through water reuse. In fact Matalascañas golf course is irrigated with treated urban sewage. If consumptive uses were presented for the whole urban and industrial water uses, these numbers would be somewhat lower but the picture would not change noticeably.

TABLE 4. *Water footprint (WF) (consumptive water use) and environmental water requirements within the Doñana region for an average rainfall year (10^6 m^3/year).*

Water Footprint within the Doñana region						
	green	blue			grey[5]	Total[6]
		surface	ground	total		
Agricultural WF[1]	127	199	83	282	27	409
Urban and industrial WF[2]			7	7		7
Current environmental water use[3]	442	116	38	154		596
Current total water use	569	315	128	443		1012
Environmental water requirements[4]				200		200

[1] Water footprint related to agricultural production. Source: Own estimation. Surface and groundwater distinction for Marismas and Condado Litoral regions according to INE (1999).

[2] Water footprint related to urban and industrial water supply. Source: Custodio et al. (2006)

[3] Current environmental water use: Blue water use is based on data from the Andalusian Regional Government (2002) and green water use refers to own estimations for forests.

[4] Here environmental water requirements refer to the estimated freshwater needs to maintain ecosystems. Source: blue water requirements for a dry (80 Mm^3) and average year (200 Mm^3) from WWF (2009a). All of them are consumptive water uses except for the case of urban water supply and industrial water footprint. In the case of the coastal urbanizations of Matalascañas and Mazagón however their water use is consumptive since they discharge into the sea.

[5] Grey water footprint referring to nitrate pollution.

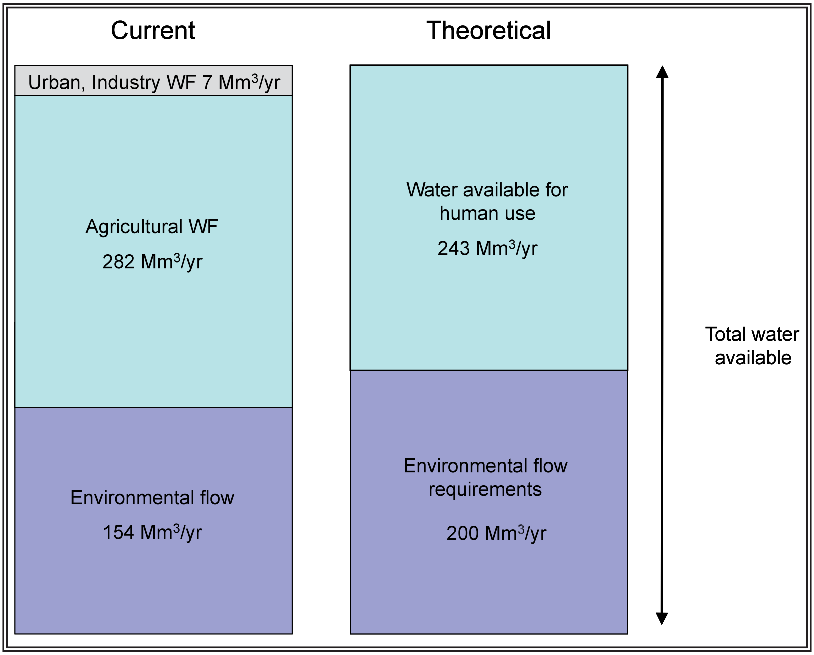
[6] Consumptive water use, without including grey water.

Agriculture and tourism, the two main economical activities, compete for water with environmental preservation (Manzano et al., 2005). Part of this area is under the two highest protection figures for natural spaces existing in Spain the Doñana National Park and Doñana Natural Park both merged in a wider figure as the Parks of Doñana under the administration of the Regional Government of Andalusia (Custodio et al., 2009). Within the National Park boundaries, human activity is greatly restricted, while across the Natural Park some traditional activities like pinecone collection, logging, beekeeping, fish farming and old-style charcoal preparation are allowed (UNEP, 2005). Cattle breeding (cows, horses and sheep) are maintained.

Over the years pristine Doñana wetlands have been profoundly modified from the hydrodynamic point of view because of a series of activities, mainly the drainage of the wetlands into agricultural land (mainly rice), but also by channelling the Guadiamar river. According to a report by WWF (2009a) currently Doñana receives less than 20% of the water contributions in natural regime. In line with the same report the environmental flows from the rivers needed to recover the wetlands in the National Park amount to about 200 Mm^3/year in average years and 80 Mm^3/year in dry years. The mentioned report follows the ELOHA approach for its estimation (Ecological Limits of Hydrologic Alteration) (WWF, 2009a). In our analysis we have focused on an average rainfall year (Figure 10). We have adopted in a preliminary way these estimations but this is obviously a simplification and first approximation since environmental flows not only refer to quantity but also to quality and timing of water flows along the year required to sustain healthy freshwater ecosystems and the benefits they provide to human communities.

Currently, the total water available in the Doñana region is roughly about 443 Mm^3/year (Figure 10). However, according

FIGURE 10. *Current water consumptive uses (own estimation based on Custodio et al. (2006), theoretical environmental requirements (according to WWF, 2009a) and current environmental flows (according to the Andalusian Regional Government, 2002). All figures are provided for an average rainfall year.*



to the environmental water requirements theoretically the water needed in an average rainfall year for the environment is around 200 Mm^3/year (WWF, 2009a). This suggests that at present the environmental water requirements are slightly constrained in average rainfall years due to irrigation.

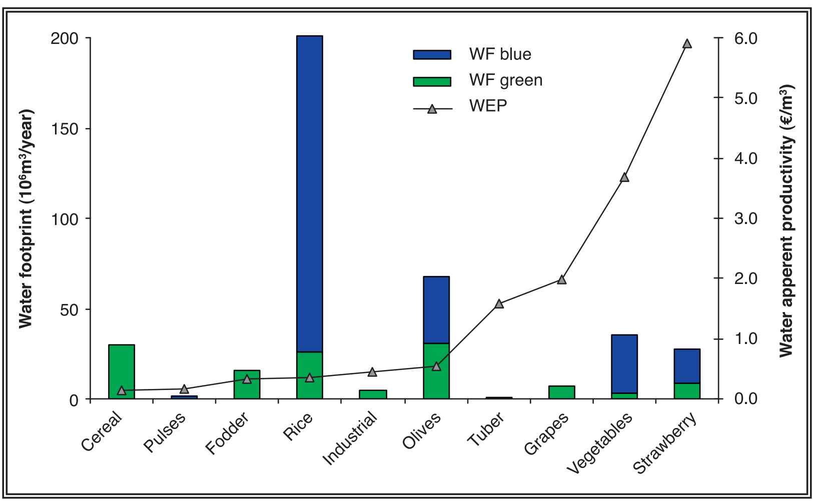
9. ECONOMIC ANALYSIS

The water apparent productivity analysis can be very useful in order to identify possible water uses not justified in economic efficiency terms and achieve an efficient allocation of water resources. This has been carried out for the main water using sectors, namely, agriculture and the environment.

Within the agricultural sector, in line with figure 11, there are crops that are very profitable such as strawberries or vegetables. There are other crops that, even if less lucrative (e.g. grapes), are rainfed crops or little irrigated and use mainly the soil water (green water). Besides having a lower opportunity cost, the use of green water for the production of crops has generally less negative environmental externalities than the use of blue water (irrigation with water abstracted from ground or surface water systems) (Aldaya et al., 2009).

Rice is by far the most blue water consuming crop (Figure 11). The water used for rice cultivation is imported into

FIGURE 11. *Total green and blue water use of agricultural crops (WF_{green}, WF_{blue}) and water apparent productivity (WEP) in the Doñana region for an average rainfall year. Source: Own elaboration (see table in Appendix II).*



the region; it is pumped from the Guadalquivir river to irrigate the rice fields, most of which returns to the river. Rice in Sevilla, Spain's leading producer, is located on the right bank of the Guadalquivir river, in particular in the municipalities of Isla Mayor, Puebla del Río, Coria del Río and Villamanrique de la Condesa. The crop area in this region is about 28,000 hectares, amounting to about 310,000 tons harvested, which represents around 40% of the Spanish production. In recent years an effort has been made to reconcile the rice farming with biodiversity conservation, enhancing water use efficiency, upgrading production techniques and adopting integrated farming practices. More recently, during 2008-2009, the pilot project "Organic rice cultivation in the surroundings of the Guadalquivir protected coastal wetlands" was launched, which aims to promote the organic rice farming that fosters harmonious coexistence with the natural values of this area.

However, the apparent productivity of rice is about 0.3 €/m^3, one of the lowest in the region (Figure 11). That is probably one of the reasons why, during the 2007-2008 drought, the Central Board of Users of the Lower Almanzora, Almeria, began negotiations with irrigating farmers from the Lower Guadalquivir to arrange water rights transfers (also called Negratín-Almanzora transfer). They even bought 1600 ha of land devoted to rice cultivation in order to use these water rights in Almería (Corominas, 2008). An integration of rice fields and natural wetlands patches seems to be desirable from the ecosystem viewpoint.

Finally, even if still difficult and controversial, a first and rough attempt to value Doñana's ecosystem goods and services has been made. In line with Costanza et al. (1997), the economic value of the ecosystem services provided by a wetland is about 14,785 $/ha/year, that is, 10,665 €/ha/year. According to those authors these goods and services include water regulation, water supply, waste treatment, habitat/refugia, food production, raw materials, recreation and cultural services. Considering that the Doñana region has a wetland area of 1,500 km^2 and uses around 154 Mm^3/year (Andalusian Regional Government, 2002), the wetland economic productivity would be very roughly 10 €/m^3, which is notably higher than crop productivities, which amount to 0.1-6 €/m^3. There is another specific study on the economic valuation of recreational use in the Doñana region (Gómez-Limón et al., 2003), which amounts to 120 M euro/year. Although a simplification, these figures seems to point that investments in conservation in the Doñana region can provide benefits both to communities and their environment. An absolute preservation of the regional environment however would not be beneficial for the society. In the case of the Doñana region wetlands for instance, an agri-environment integration of rice fields and wildlife combining a mosaic composed of preserved wetland, aquaculture surfaces and paddy field patches is desirable from the ecological and social perspectives alike.

Unfortunately, data scarcity prevented enlarging the scope of the present paper to cover some other topics such as the water footprint of floodable areas, such as natural marshes, scrubbery, grasslands, and other ecosystem types. The ecosystem services of the Parks in terms of wildlife preservation both for visitors and for other natural areas which exchange individuals with Doñana. The ecosystem services of rice fields preserving waterfowl species which are scarce or almost absent from the Park. The role of channels and ditches which are used for cultivation or aquaculture in maintaining populations of aquatic organisms and from the opposite viewpoint, the role of channels and water ways in the introduction of damaging organisms to the Parks, the cultures or the human population. The evaluation of blue water flow which is maintained in Guadalquivir river during summer drought to keep water salinity below a threshold favourable to irrigation, is again a specific footprint to be incorporated in future analysis

10. Conclusions

Having achieved 'more crops and jobs per drop', the present analysis of the water footprint and environmental water requirements in the Doñana region suggests that achieving 'more cash and care of nature per drop' simultaneously could be feasible in this region if policy makers take action.

In the Doñana region, the environment is the main water user amounting to about 59% (600 Mm^3/year) of total water use, followed by agriculture with about 40% (410 Mm^3/year) and urban water supply and industry 1% (10 Mm^3/year).

The total blue water available in the region amounts to 443 Mm^3 for an average rainfall year. If the environmental water requirements were met, 200 Mm^3/year according to WWF (2009a) including marshes, streams and aquifer, the total water available for human use in the region would be 240 Mm^3/year. However, the current agricultural blue water consumption alone adds up to 280 Mm^3/year. The environmental blue water requirements thus seem to be mildly constrained in the Doñana region because of irrigation. The largest amount of irrigated water is for producing a low value crop (rice) (0.3 €/m^3).

According to these preliminary figures, and in spite of the positive measures for the protection of Doñana taken by the Spanish authorities (including hydrological restoration, the enlargement of the protected area and the substantial reduction of the irrigated area), there is still a certain risk of change in the ecological character of Doñana National Park because of surface and groundwater extraction mainly for agriculture.

The groundwater plays a significant hydrological and ecological role in the natural functioning of Doñana. It also supports a very diverse flora and fauna and is one of the most important National Parks in the European Union. The groundwater regime is threatened by abstraction of water for irrigation and the fertilizer leaching from agriculture. In this context, it is relevant to clarify the ownership and legality of wells and water withdrawals through them, as well as to establish ways of measurement. Additionally there is a need to further reduce fertilizer use and other agrochemicals shifting to organic agriculture for instance. Even if in the short term the effects will go unnoticed (the water-table changes in Doñana progress at a slow pace), in the long term the reduction of pollution and water consumption is crucial to ensure the conservation of Doñana.

Finally, the green water used by forests contributes significantly to the use of water resources (440 Mm^3/year, which is about 44% of total water use). This analysis is a first approximation since data on the environmental water uses are limited. If the evapotranspiration by scrublands had been taken into account, these figures would have probably been higher. Further research is needed on this topic.

In conclusion, it seems clear that integrated water allocation, planning and management is needed in the Doñana region, considering the environmental water requirements together with the blue (surface and ground), green and grey water footprints, to achieve a more compatible agricultural production with the protection of ecosystems and this is possible without impairing the livelihoods of the farmers because the main water consumer is a low economic value and water intensive crop —the rice. In other words, this analysis seems to indicate that in this case a policy of 'more cash and care of nature per drop' is feasible. Moreover, it may be a win-win solution where farmers and conservationist may be glad.

Acknowledgements

We wish to thank all the people and institutions that have made this research possible. First we would like to thank Agustín Argüelles and Alberto Norzagaray from the Guadalquivir River Basin Authority and Joan Corominas from the Andalusian Regional Government. We would also like to thank Professor Arjen Hoekstra for his useful advices. Finally, we can not forget the Marcelino Botín Foundatin who sponsored this research.

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Appendix I

Evapotranspiration (ET), crop water use (CWU), yield (Y), production (Prod) and water footprint (WF) for primary crops in the Doñana region.

	ETg mm	ETb mm	ET mm	CWUg m3/ha	CWUb m3/ha	CWU m3/ha	Y* ton/ha
Cereal	258	0	258	2579	0	2579	3
Fodder	258	0	258	2579	0	2579	9
Grapes	128	0	128	1282	0	1282	6
Industrial	55	0	55	548	0	548	1
Olives	209	430	638	2086	2500	4586	5
Pulses	87	285	372	868	2852	3720	3
Rice	89	668	758	893	6682	7575	9
Strawberry	166	375	541	1662	3745	5407	39
Tuber	97	0	97	966	0	966	7
Vegetables	62	591	653	618	5909	6527	72
Total							
Pine forest	365	0	365	3652	0	3652	
Pasture	343	0	343	3427	0	3427	

* *Source:* MAPA (2009)

** *Source:* Custodio et al. (2006)

ETg = green water evapotranspiration; ET_b = blue water evapotranspiration; ET = total evapotranspiration; CWU_g = green crop water use; CWU_b = blue crop water use; CWU = total crop water use; Y = yield; WF_g = green water footprint; WF_b = blue water footprint; WF = total water footprint; Prod = production.

WFg m3/ton	WFb m3/ton	WF m3/ton	Prod* ton/yr	WFg 106m3/yr	WFb 106m3/yr	WF 106m3/yr
995	0	995	29748	30	0	30
303	0	303	52539	16	0	16
229	0	229	29921	7	0	7
559	0	559	8853	5	0	5
412	493	905	74778	31	37	68
347	1141	1488	990	0	1	1
95	713	808	271144	26	193	219
43	97	140	195619	8	19	27
130	0	130	7661	1	0	1
9	82	91	391675	3	32	36
				127	283	410

Appendix II

Water footprint hydrologic and economic analysis.

	WF_{green} $10^6 m^3/yr$	WF_{blue} $10^6 m^3/yr$	WF_{grey} $10^6 m^3/yr$	BWAP €/m^3	WAP €/m^3
Cereal	30	0	10	0	0.1
Fodder	16	0	2	0	0.3
Grapes	7	0	—	0	2.0
Industrial	5	0	3	0	0.5
Olives	31	37	4	1.0	0.5
Pulses	0	1	0	0.2	0.2
Rice	26	193	—	0.4	0.3
Strawberry	8	19	—	8.5	5.9
Tuber	1	0	1	0	1.6
Vegetables	3	32	8	4.1	3.7
Total	127	283	27		
Wetland*					10

Source: Own elaboration

**Source:* Own elaboration based on Costanza et al. (1997)

WF_{green} = green water footprint; WF_{blue} = blue water footprint; WF_{grey} = grey water footprint; BWAP = blue water apparent productivity; WAP = total (green and blue) water apparent productivity; — = no data available.