Canal de Isabel II

BOOKLETS

RESEARCH + DEVELOPMENT & INNOVATION

5

Virtual Water and Hydrological Footprint in the Comunidad de Madrid

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PRESENTATION

Canal de Isabel II's Research, Development & Innovation Booklets form part of the company's Knowledge Management Strategy and of the development involved in the Investigation, Development and Innovation Plan.

These Booklets represent an element for diffusion of projects and initiatives that are developed and sponsored by Canal de Isabel II for innovation in those areas related with water service in the urban environment.

A series of different problems that have been undertaken in each project are put forward in the Booklets, along with the results that have been obtained. The intention behind their diffusion by means of these publications is to share the experiences and knowledge that have been acquired with the entire water services sector, with the scientific community and with all those working on research and innovation. What is intended with the publication of these Booklets is to contribute to the improvement and efficiency in water management and, consequently, in the quality of service provided to citizens.

Additionally to its publication in printed format, the booklets will also be available on Canal de Isabel II's web site, into the Publications section.

TECHNICAL INVENTORY

Title of the Project	Virtual Water and Hydrological Footprint in the Comunidad de Madrid
Line of Research	Assurance availability/demand balance
Units of Canal de Isabel II involved	Deputy Direction of Research, Development & Innovation
External Partnership	Collaboration agreement between Canal de Isabel II and the Madrid's University Polytechnic, ETS Agronomic Engineering.
Object and Justification of the Project	The new paradigms of planning, integrated resources management and interchanges between different uses and qualities of water urge to do a conceptual and in depth analysis different from the conventional one. The Virtual Water and Hydrological footprint approaches facilitate this analysis and the determination of the most efficient and sustainable options for the water msnsgement. Virtual water includes the free water and the water linked to the services or production processes. The hydrological footprint of a territory is the addition of both, the real plus the virtual water that is used in this territory.
Contribution to the State of the Art	To know the impact of the incorporated water consumption in the goods, flows, and services produced and interchanged by the Comunidad de Madrid. To determine the hydrological footprint generated by the Comunidad de Madrid arising from the calculation of the virtual water consumed in each product, service or activity. Methodological improvements have been introduced focused on obtaining a better estimation of the virtual water associated to agriculture, as it is to include the water for washing the soils to avoid the salinization.
Summary & relevant milestones of the project	The project approaches an integrated vision of the water and the territory of the Comunidad de Madrid and its flows to clarify the relations between blue water and green water, as well as between internal water, virtual water and hydrological footprint, determining the values corresponding to each concept.
Summary of obtained results and outcomes	The value of the hydrological footprint in the Comunidad de Madrid (2005) has been amounted in 9,705 hm^3/year, which leads to an estimation of 1,667m^3 per capita and year (4,566 liters per capita and day), of which 1,476m^3/capita is properly virtual water imported, and 191m^3/capita is internal water used. The first observation is that the volume of virtual water imported multiplies by three the water received in the form of precipitation and by 14 the derived water for irrigation and urban supplying. The imports of virtual water in the Comunidad de Madrid multiply by 8 the generated one in the own territory, with great weight in the nourishing sector. Also it is noticed that the green water used by the dry land crops multiplies by 4 to that used for watering irrigated crops. The comparison of the physical flows of water in 1984-1995 with those of 2005 states that the hydrological footprint has increased a 75%, for that reason, it is considered the convenience of connecting the virtual water estimations to the study of the territory and its economic systems metabolism.
Opened Lines of Research for the continuation of the project	It has been identified the convenience of improving the assessment of the virtual water depending on the meteorological conditions of the origin place of the imported goods or products. It would be important to establish a standard of assessment of the virtual water or built-in water that allows the comparison between the different scopes.

EXECUTIVE SUMMARY

The concepts of virtual water and hydrological footprint arose to underscore those aspects related with water that avoid specific thematic approaches that are normally used to orientate its management. These approaches focus attention on the water that could be collected, regulated, transported and billed, although these aspects also ignore, in some way, not only the whole concept of free water that makes up the so-called hydrosphere, but also the water linked to soils and organisms that make up the so-called biosphere -and to the relationship between both-, which are studied by ecology and other Earth sciences. This paper models and quantifies these relations, presenting the first ever estimation of the Comunidad de Madrid's virtual water and hydrological footprint, to then compare them with Spain's data and data from other countries.

In general, the virtual water of a certain product is determined as of the volume of fresh water used to obtain it and which finally does not form part of said product, and the hydrological footprint of a person, company or territory as the total volume of water used to produce the goods and services consumed by each person, company or territory. "Virtuality" does not make reference to any characteristic of the water itself, as quite fortunately this is a substance that is unequivocally defined by its chemical formulation (H_2O), but to the fact that, despite being necessary for the manufacturing of certain goods, it does not finally form part of them. The virtual nature also resides in that a great part of this water is not only free water, -which normally hoards all the attention- but it is also water that is linked to the soil and vegetation or water that is previously used in the processes for elaboration of these goods or services. Thus a sound estimate of virtual water and/or hydrological footprint requires having exact knowledge not only of the free or blue water in the territory that is object of study, but also of the linked or green water. Hence it is due to this reason that the calculations on inputs of water received by the territory are hereby presented by means of precipitation or external contributions -to blue water or to green water-, as well as the outputs involved in evapotranspiration or water loss attributable to farming lands or lands with natural vegetation. The total amount of blue water is also highlighted, identifying water destined to farming and industrial processes operating in the territory and to consumption by its population. Estimate of virtual water and of the hydrological footprint thus establishes the water requirements of the products that are consumed, manufactured, imported and exported in the territory under study, fully undertaking analysis of the processes and of the physical flows that make up its economic metabolism. As of this point it is possible to summarize the main results of this work, both in quantitative and temporary terms, as well as from a methodological and compared perspective:

From a quantitative point of view, the Comunidad de Madrid's hydrological footprint reached 9,705hm^3 in the year 2005, which in per capita and per year terms represents 1,667m^3, in turn broken-down into 191m^3 of water used in the Comunidad de Madrid and 1,476m^3 of virtual water assigned to obtaining of import products minus the amount corresponding to export products. If we transform these annual amounts into daily per capita terms, we have a total footprint of 4,566 liters per capita and day, composed by 523 l/capita/day used in the territory and 4,043 assigned to net importing of products from outside of the Comunidad de Madrid. We also have to take into account that gross imports of 13,193hm^3 of virtual water multiply the water coming from the Comunidad de Madrid territory itself by twelve -with its corresponding virtual part- and estimated in this paper in 1,114hm^3 (adding up the urban component -in an ample sense- plus the industrial and farming component). Indeed, the virtual water that is added by goods and services generated by the Comunidad de Madrid itself is relatively modest in comparison with imported water, which leads to importing of virtual water destined to the Comunidad de Madrid multiplying by more than ten that generated by the territory itself. Finally, if these figures are combined with the total of virtual water associated to the Comunidad de Madrid's own exports (4,601hm^3), then the final total water consumption is obtained, or the hydrological footprint, which amounts to 9,705hm^3, that is to say, almost eight times the water used within the territory of the Comunidad de Madrid. From this amount, 9,292hm^3 could be classified as the hydrological footprint of an agricultural origin, 64hm^3 of an industrial origin and 423hm^3 resulting from the urban and services sector. The great unitary importance that virtual water has in agriculture and the food sector, along with the important food industry dependence that the Comunidad de Madrid has, is of capital significance in order to explain the orders of magnitude that have been commented.

The volumes of virtual water that the Comunidad de Madrid handles are, therefore, very superior to those corresponding to water that is really incorporated in the goods that are consumed or water that is captured and extracted in the territory itself. For example, in this sense the volume of virtual water that is imported multiplies by three the volume of water that is received in the shape of precipitation and that derived for irrigation and supply purposes by fourteen. It is indeed true that almost a third of these imports does not have the Comunidad de Madrid as the final destination, but are in fact re-exported to other territories. Thus, another important conclusion that can be reached is the one that highlights the position occupied by the Comunidad de Madrid as a logistic enclave for re-distribution of goods to other territories, which pass through industry and Madrid services where variable doses of elaboration, commercialization and transport are then applied.

From a temporary point of view and thanks to prior estimates made during the mid-eighties over the metabolism of the Comunidad de Madrid, a notable increase is observed in both imports and exports of virtual water: inputs (imports) have increased in 2.2 times, going from 5,806 hm^3 in 1984 to 13,193hm^3 in 2005; while outputs (exports) have tripled, going from 1,465 hm^3 to 4,601 hm^3. This aspect can, in part be explained, by the double combination that takes place in the Comunidad de Madrid, which has a powerful agricultural-food industry and represents a notable logistics redistribution center to the rest of the territories.

It agrees to notice that the considered hydrological footprint estimated for the Comunidad de Madrid in this work is not comparable with the considered one by Chapagain and Hoekstra (2004) for Spain. The hydrological footprint of the Comunidad de Madrid is a 28% inferior to the average considered for Spain by Chapagain and Hoekstra, (being this one the unique source of contrast) that is explained by the disparity in the sources and the statistics used, besides of the different criteria used in each estimation. The analysis carried out allows to infer an overvaluation on the hydrological footprint considered by Chapagain and Hoekstra (2004) for Spain since it uses data that overvalue this footprint.

In the case of the industrial and urban footprint, the overvaluation of the number seems to be due, essentially, to the statistical sources. It could be said that, estimations based on the sources used in the present study would have reached similar conclusions than those obtained by Chapagain and Hoekstra (2004). In the case of the industrial footprint the Spanish average number would stoop, happening of 299m^3/capita to 30-40m^3/capita. The same discrepancy in the numbers is appraised in the case of the urban water; while Chapagain and Hoekstra from the figure of 4,242 hm^3 (average 1997-2001) total uses reach the number of 105m^3/capita, the INE[1] (Survey on the Supply and Treatment of the Water) set it in 2,779hm^3 which would amount an urban footprint of 68m^3/capita.

The differences found, in the case of the agricultural footprint, come from, both the statistical information, and the heterogeneous criteria for the calculation of the real agricultural evapotranspiration ETR[2] (with a discrepancy with respect to the calculations of Chapagain and Hoekstra of 21%). The differences are based on not merely the diverse statistical sources, but also in the dissimilarity in the calculation of coefficients and methodology for obtaining the ETR in Spain and in the Comunidad de Madrid. Moreover, in the Spanish case, the numbers of foreign trade flows only incorporate those of international trade. Whereas, in the case of the Comunidad de Madrid, they incorporate data, as much of international trade (with the rest of the world), as of interregional commerce (with the rest of the Spanish regions) and the availability and segmentation of these last data are much smaller than in the case of the Spanish global data, giving rise, altogether, to a certain underestimation for the Comunidad de Madrid.

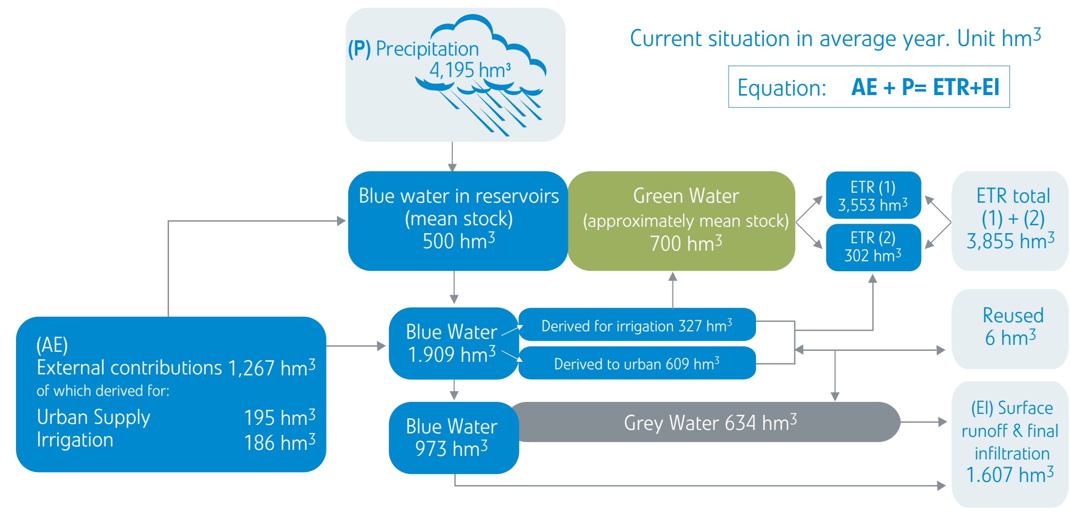
General methodological contributions

The present study not only estimates virtual water and the hydrological footprint of the Comunidad de Madrid, but also relates these estimates to more extensive estimates and analysis of the water flows, energy and materials operating in the territory that is object of study. Apart from this the study not only focuses on a single year, but in fact follows the long term tendencies that observe the physical flows that configure the Comunidad de Madrid's metabolism. This analysis covers the hydrological cycle in its whole, taking into consideration and estimating its main components, which not only improves the quality of the estimates of virtual water and the hydrological footprint, but also allows finding the limitations that these types of analysis offer in order to complete them with more extensive considerations that are related with the whole of water, materials and energy that is used. From a more formal perspective, the graph charts, and synthesis schematics illustrating this chapter constitute an effort in conceptual clarification and formalization that contributes to understand the scope and limitations of the virtual water methodology. This clarification facilitates both the desirable link of virtual water with water used in its whole (blue and green), as well as in the territory and with the flows of material and energy that make up the metabolism of the economic systems.

Specific methodological contributions

This paper also includes some methodological improvements with regards to the usual procedure for calculation of virtual water and the hydrological footprint that are worthy of being highlighted. In the first place, the estimate of virtual water associated to farming (ETR)–through evapotranspiration of crops- includes an estimate of the water that is necessary to wash the soils with the aim of avoiding the danger of salinization of them that are characteristic in arid and/or Mediterranean climates. In the second place, the nature of the soils in which the crops are grown has also been taken into consideration (based on the maps used to classify Agrological Capacity Classes and Crops and Harvests), given that the nature of the soils is what determines the selection and framework for planting of crops and, consequently, the yield or productivity and the water used per hectare. This spatial analysis has been jointly carried out with an estimate of the green water that is present in the soils and vegetation of the territory, the same by using edaphoclimatic information that is available about them. In the third place, apart from the more refined and exact estimates of virtual water thus obtained, in the present paper other estimates have also been calculated, using a simpler route to apply the usual procedures and ratios employed for Spain in this type of research. In a similar way, the same in order to compare the difference in results obtained in the Comunidad de Madrid's case: the conclusion that was reached was that the discrepancies observed between both estimates at an aggregated scale were not particularly important, given the degree of uncertainty that said estimates involve. In the fourth place, it has been distinguished between water that is finally consumed at homes, industries or irrigated lands -used in the calculation of virtual water- and water that is to be abstracted at headwaters in order to supply these uses. The quantitative importance of this, in general, uncontrolled difference (diverse losses, in particular in irrigation systems) between abstracted water and water that is used recommends that it should be taken into account when comparing the balances of virtual water and water for activities and the territories. And in the fifth place, the estimate of virtual water linked to industrial imported and exported products has been improved in view of the fact that generic inputs of water per dollar of gross value added (GVA) taken from other studies has been amply surpassed, apart from choosing a specific calculation based on coefficients in physical terms that have their base in the water needs per ton of product of the manufacturing processes that effectively take place in the Comunidad de Madrid.

Figure a. Water Balance (Blue & Green) in the Comunidad de Madrid



ETR (1): Real spontaneous Evapotranspiration from the soil and the natural vegetation and from the arid crops.

ETR (2): Evapotranspiration induced by uses, includes both consumption to evapotranspiration of irrigation lands, as well as the consumer part corresponding to urban-industrial.

Grey Water: Includes urban and industrial dumping, as well as farming leachate.

Maximum flows for the last 14 years and mean derived water for the last 5 years.

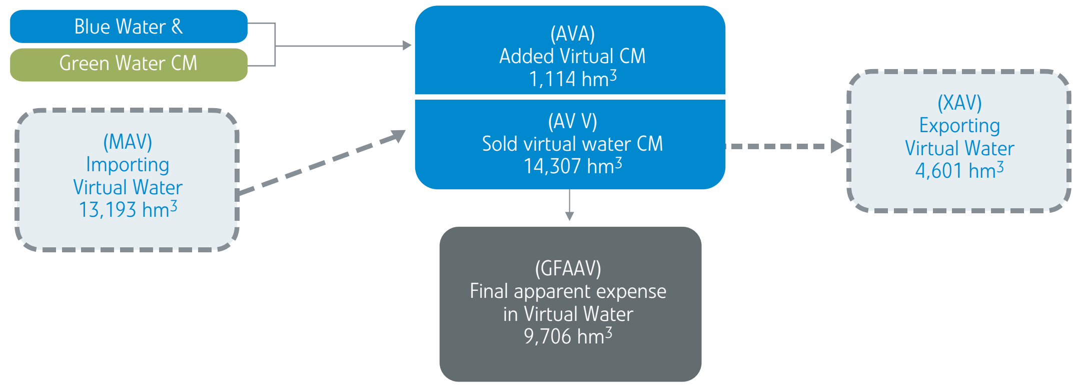
Source: Own Elaboration

[1] INE: National Institute of Statistic of Spain

[2] ETR: It is used to talk about to the amount of water that is used by the effective evapotranspiración. It takes part into its calculation, besides the atmospheric conditions that influence in the potential evapotranspiration ETP, the magnitude of the humidity reserves of the ground and the requirements of the crops. ETP, is a concept introduced by Charles Thornthwaite in 1948, like the maximum amount of water that can be evaporated from a ground completely covered with vegetation, that is developed in optimal conditions, and in the assumption case of not existing limitations in the water availability. According to this definition, the magnitude of the ETP is only regulated by meteorological or climatic conditions.

Figure b. Virtual Water in the Comunidad de Madrid

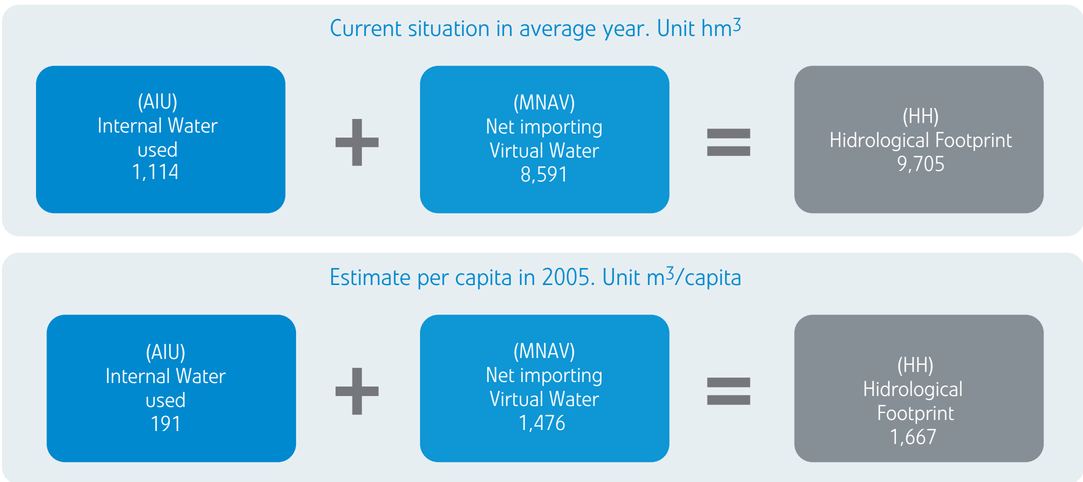
Current situation in average year. Unit hm^3



Equations: **MAV + AVA= GFAAV + XAV**
AVV= GFAAV + XAV

Source: Own Elaboration

Figure c. Hidrological Footprint in the Comunidad de Madrid



Equation:	**AIU + MNAV= HH**	
Evidently:	**HH= GFAAV,**	given that the sam es obtained as the balance in Figure b.
In like manner to:	**(AIU)= (AVA)**	when the Virtual Water of goods and services is defined as that used to obtain said good or service, minus the content of the products. However, as is well known, this latter amount can be disregarded in view of the fact that it is not considered to be very significant.

Source: Own elaboration

Table a. Breakdown of the hydrological footprint in the Comunidad de Madrid, 2005

	hm^3	m^3/capita	liter / capita / day
Agricultural	9,217	1,583	4,336
Industrial	64	11	30
Urban & Commercial	423	73	200
TOTAL	**9,704**	**1,667**	**4,566**
Virtual water imports	13,193	2,266	6,208
Virtual water exports	4,601	790	2,163

Source: Own Elaboration

Table b. Evolution of the total hydrological footprint in the Comunidad de Madrid, (hm^3)

Years	Internal water used (AIU) (1)	Net imports virtual water (MNAV) (2)	Hydrological footprint (HH) (3) = (2) + (1)	Population (millions inhabitants)
1984	1,249	4,341	5,590	4.78
(%)	(22)	(78)	(100)	
2005	1,114	8,591	9,705	5.82
(%)	(11)	(88)	(100)	
Ratio: 2005/1984	**0.89**	**1.97**	**1.73**	**1.22**

Source: Naredo and Frías (2003) and own elaboration

Table c. Evolution of the total hydrological footprint in the Comunidad de Madrid, (m^3 per capita and year)

Years	Internal Water used (AIU) (1)	Net imports Virtual water (MNAV) (2)	Hydrological footprint (HH) (3) = (2) + (1)
1984	261	908	1,169
2005	191	1,476	1,667
Ratio: 2005/1984	**0.73**	**1.62**	**1.42**

Source: Naredo and Frías (2003) and own elaboration

Table d. Evolution of deficit in materials and virtual water in the Comunidad de Madrid
(Deficit = Imports - Exports)

Years	Materials Million of t (1)	Virtual Water hm^3 (2)	Intensity in Virtual Water m^3/t (3) = (2) / (1)
1984			
-Food and beverages	2.5	4,320	1,728.00
-Rest	14.0	21	1.50
TOTAL	**16.5**	**4,341**	**263.10**
2005			
-Food and beverages	4.5	8,580	1,906.60
-Rest	26.5	11	0.37
TOTAL	**31.1**	**8,591**	**276.20**

Source: Naredo and Frías (2003) and own elaboration

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