VOLUMETRIC CONTROL FOR CONTRASTING REMOTE-SENSING, IN SUPPORT OF HYDROLOGICAL PLANNING IN SPAIN

Tatiana Ortega[1], Jesús Garrido[2,] Alfonso Calera[3] and Concepción Marcuello[4]

ABSTRACT

The Spanish General Directorate for Water hanging on the Ministry for the Ecological Transition (MITECO) is committed in the use of volumetric control for contrasting remote-sensing products as an imput for the hydrological planning process required by the Water Framework Directive (WFD). The results are temporal series maps of irrigated areas (surface) and their corresponding irrigation water requirements (net water volumes), which are based on earth observation (EO). The approach relies on dense time series of multispectral imagery acquired by the multisensor constellation arranged by Landsat-8 and Sentinel-2 satellites, jointly with meteorological data and hydrological and agronomic knowledge.The paper describes the operational application of these methodologies, including a preliminary approach for contrasting the modelled values of crop water requirements with actual mesurements of water consumption, registered in water-meters, what provides a valuable information for the management and planning of water resources. Hence, the outputs contribute to improve water governance at a basin scale.

Keywords: Hydrological planning, agricultural uses, water-meters, remote-sensing

1. INTRODUCTION AND OBJECTIVES

According to the Spanish Water Law (1985), Hydrological planning in Spain provides the consecution of good status in water bodies and the satisfaction of water demands, harmonising socio-economic development in the territory (Royal Legislative Decree 1/2001). These objectives are primarily carried out through two essential tools: the River Basin Management Plans (RBMPs), and the National Hydrological Plan (NHP), which alleviates deficits in river basin districts (RBDs) at a national scale.

The first hydrological Plans in Spain were approved in 1998 before WFD approval. Afterwards, the adoption of the directive 2000/60/EC obliges EU Member States (MS) to their revision every six years. The 1st hydrological planning cycle discussed period 2009-2015; 2nd cycle: 2015-2021, which is currently running; and 3rd cycle: 2021-2027, which initial works are on-going.

The territorial scope of each RBMP coincides with the corresponding RBD. In total, there are 25 RBDs in Spain (Figure-1), to which RBMPs are referred. The followings attribute their competences for the hydrological planning process to the Spanish Central Administration: Cantábrico, Miño-Sil, Duero, Tajo, Guadiana, Guadalquivir, Segura, Júcar and Ebro.

[1] Head of infrastructure and technology service, Ministry for the Ecological Transition. General Directotare of Water. Plaza de San Juan de la cruz s/n, 28003 Madrid; E-mail: tortega@miteco.es

[2] Researcher, Remote sensing and GIS section, Regional Development Institute, Castilla–La Mancha University, Campus Universitario s/n, 02071 Albacete; E-mail: jesus.garrido@uclm.es

[3] Remote sensing and GIS section Director, Regional Development Institute, Castilla–La Mancha University, Campus Universitario s/n, 02071 Albacete; E-mail: alfonso.calera@uclm.es

[4] Deputy Assistant- Water Director of Planning and Sustainably Use of Water. Ministry for the Ecological Transition. General Directotare of Water; E-mail: cmarcuello@miteco.es

Figura 1. Spanish River Basin Districts

The evaluation of the good status in EU water bodies applies the "one-out-all-out" principle, depending on the effects of the pressures identified in the territory. The directive 2000/60/EC aimes to the satisfaction of the environmental objectives in the superficial and underground water bodies (art.4, WFD) and it is currently under revision. The monitoring of irrigated areas and the accounting of water use are essential instruments for European policies, in order to promote water use efficiency. The European Commission (EC) has published on several occasions the necessity of safeguarding water resources in Europe (COM (2012)673 final). The EC has recognized that excessive water extraction is the second greatest pressure for the consecution of good ecological status of the European water bodies, mainly, due to overestimation of the water availability, or to economic or political pressures associated with water use. The EC report on the implementation of the WFD (SWD (2019) 42 final) detects a slight improvement in the number of groundwater bodies that reach good quantitative status. However, the extraction and exploitation of water continues to be very significant in various EU MS (Figure 2). It also highlights that most of the available data on water extraction or consumption –especially in terms of irrigation water- are based on surveys and theoretical modelling results, which are not always contrasted with actual measurements of water consumption.

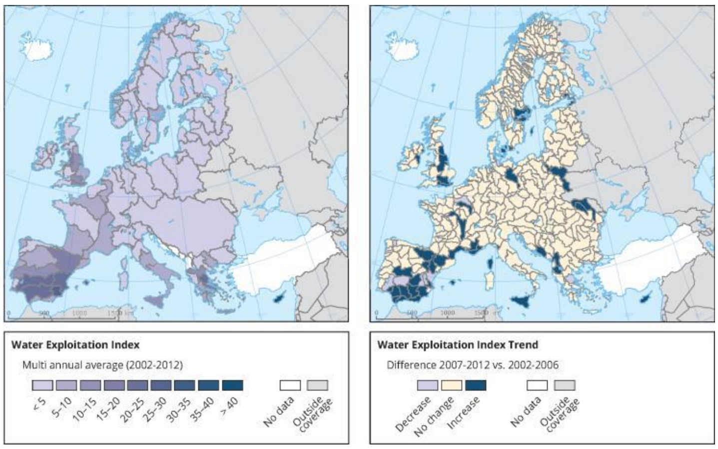

Figura 2. Evolution of the Water Exploitation Index in Europe

In this context, the Sub-directorate for Water Planning and Sustainable Water Use of MITECO (according to the Spanish acronym) in Spain, is aiming to improve know-ledge on water use in agriculture within the elaboration of the 2021-2027 RBMPs. The objective is harmonising a national shared and applicable methodology, combining the use of satellite images and water volume data recorded in water-meters.

2. METHODS

2.1 Water Demand Estimation

The quantification of the agriculture demand is a key issue for the planning and management of the water resources in the territory, and the different techniques used for their estimation, are subject to uncertainties. The Order ARM/2656/2008 approved the Spanish National Instruction for Hydrological Planning (IHP). This Instruction includes a methodology for the estimation of the agricultural demand, and requires the RBMPs to evaluate the current and foreseeable agrarian water demands based on variables such as irrigated surface, type of crop, irrigation efficiency, restrictions in water extractions management plans, etc. The Spanish 2015-2021 RBMPs, approved by Royal Decree 1/2016, estimate water demands according to this instruction. It also defines territorial management units, named the agricultural water demands units (ADU), where irrigation communities should be identified, the existence of water rights legally recognised, and a control of the water use monitored through measuring elements. In these terms, the IHP propose the compilation of temporary series of annual and monthly volumes of water collected, distributed, applied and consumed, in each ADU although the automation and quantification of the water volumes in each of these stages are currently incomplete. To this point, the Automatic Hydrological Information Systems of the RBAs are highlighted as an useful tool for the control of superficial volumes. In accordance with this methodology, last monitoring report on RBMPs and water resources in Spain (MITECO, 2017), estimates that the demand for water in 2021 is approximately 32.000 hm^3/year, which represents an increase close to 3% of the estimated value at the time of preparation of the second cycle plans (2015-2021), which was around 31.000 hm^3/year. The main use of water is irrigation and agricultural uses, which accounts for approximately 80% of this demand, representing urban supply only by 16%. More recently, the initial documents of the third planning cycle (2021-2027), submitted for public consultation for 6 months, until April 2019, present a preliminary estimation of the water demand scenarios 2021, 2027 and 2033, which will be accurate in later phases of this planning cycle.

2.2 Hydro-Climatic Environment

The Spanish climate is characterised by irregular geographical distribution, in addition to a notable temporal variability, both throughout the year as well as inter-annually. The territory has historically been marked by periods of intensive droughts that have compromised the management of water resources.Dry conditions persist along the time in Spain and low rainfall patterns might be exacerbated by climate change.

Figura 3. Distribution of the percentage of accumulated precipitation per hydrologi-cal year (among 2014/15 and 2016/17) compared to the average values in period 1980/81-2009/10. Source: Spanish National Meteorological Agency (AEMET, according to the Spanish acronym).

This average period was agreed for quantification of water resources during in the 2nd planning cycle and it would be extended for the third cycle. The year 2016/17 was a very dry year in almost all of Spain, with an overall average value in precipitation of 502 mm, 20% below the average reference value.

2.3 Data Sets

Monitoring of crops and their water requirements are possible through data derived from the EO combined with meteorological information. The EU Copernicus Earth Observation programme operates Sentinel satellites, which provide data from the Earth's surface at a spatial resolution and a temporal frequency unprecedented in the history of remote sensing. The program counts on a budget of 900 million € for 2019.

The exploitation of temporary series of satellite images helps to make the inventory of irrigated surfaces. Hence, the quantification of their water consumption is less time-consuming, which is not feasible to achieve only applying traditional procedures and field works. In this context, the SPIDER-SIAR project, together with other experiences developed by the Spanish RBAs, provide a substrate of knowledge and results that allow evaluating the real operative capacity of the techniques of EO as a tool for the revision of the RBMPs. The SPIDER-SIAR project, led by the University of Castilla-La Mancha and the General Sub-directorate for Irrigation and Rural Infrastructure of the Ministry of Agriculture, Fisheries and Food (MAPA, according to the Spanish acronym), has been running since 2014.

The images used are those acquired, in the area of the mainland Spain, along the period 2014 to 2017, by the multispectral sensors on board the Sentinel- 2A (S2A; 10x10m), Sentinel- 2B (S2B;10x10m) and Landsat-8 (L8;30x30m) platforms. The European Space Agency, and the National Aeronautics and Space Administration from USA operate these platforms and distribute freely the images. Once those high cloud cover images have been discarded, a total number of 13.006 images were processed. These images are then converted into the three basic SPIDER-SIAR products: (i) time series of Normalised Difference Vegetation Index, NDVI (Rouse et al., 1973); (ii) an appropriate colour composition images (RGB) to monitor irrigated agriculture; and iii) the biophysical crop parameter K_{cb}. These time series products (unless RGB) are atmospherically corrected by absolute normalization (Campos et al., 2011). Additionally, cloudy and shadows pixels were removed using L8 Quality Band and Sen2Cor algorithms for S2A and S2B.

$$NDVI = \frac{\rho NIR - \rho red}{\rho NIR + \rho red}$$

Where:

ρNIR = reflectance detected in the spectral band of near-infrared

ρred = reflectance detected in the spectral band of red

The SPIDER-SIAR project has defined 9 classes of irrigated uses which assume similar vegetative developments. These classes are ordered by the number of days in which the $NDVI_{max}$ values are identified due to the greenness of the surface. They are elapsed since the beginning of the year (starting by the month of January): spring (class-1), spring-summer (class-2), fruit (class-3), woody (class-4), summer (class-5), citrus (class-6), autumn-winter (class-7), olive (class-8) and greenhouses (Table 1). In addition, the EU H2020 Diana project (2017-2019) has improved the classification with 10 classes, and breaks down the fruit class into 2 irrigation classes: stone fruit and shell fruit.

Table 1. Classes of irrigated uses defined by the SPIDER-SIAR project

NDVI$_{MAX}$	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
	Spring	Spring-Summer	Fruit	Woody	Summer	Citrus	Autumn-Winter	Olive
Days	125	125-225	125-300	150-300	200	300-365	325	350-365

The balance is assisted by remote-sensing (S2-A, S2B and L8 images) together with the daily climatic data provided by the network of the Agro-climatic Information System for Irrigation (SIAR, according to the Spanish acronym). Using HidroMORE model (Garrido-Rubio, et al., 2018), results are computed by a daily time scale and at a pixel spatial scale (10x10m) and they are suitable to aggregate into other scales of spatial or temporal interest. Figure 4 shows an example, of the variables utilised by HidroMORE model when computing the balance for a summer crop, which includes horticultural crops, rice, cotton or maize.

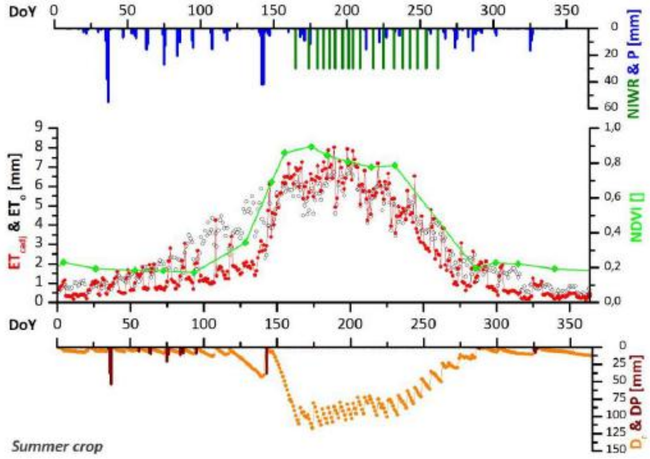

Figura 4. Daily evolution of the different components estimated by the Remote Sensing-based Soil Water Balance computed by HidroMORE® tool. Source: Garrido-Rubio, et al., 2018

Where:

NWIR= ETc-PP ; PP= Effective precipitation

ETc = Kc* x ETo ; Crop coefficient based on spectral reflectances

Kcb = 1,44 (NDVI)-0,10 (*Campos et al., 2010)

The model calculates multi-temporal and spatially distributed series of Net Water Irrigation Requirements, NWIR, [mm], derived from the Crop Water Requirements, CWR, which is the evapotranspiration, ETc, [mm] of a crop under optimum conditions: without diseases, well fertilized and in optimal conditions of water in soil, as defined in FAO56. In this way, the moisture content of water in soil cannot be lower than the stress threshold and therefore water stress is maintained under controlled conditions. Computation estimates as swell other components, like the adjusted crop evapotranspiration (ER_{cadj}), run-off (RO), deep percolation (DP) and depletion (D) at same space and time scales.

2.4 Case Studies

The results, temporarily aggregated on a monthly and annual scale, have been obtained in irrigable pilot zones designated in different Spanish RBDs. They have been developed under the umbrella of the EU H2020 Diana project: "Detection and Integrated Assessment of Non-Authorized Water Abstractions using EO", which supports the implementation of the WFD and counts on the participation of Greece, Spain, Italy, Romania, Belgium and Portugal. Four pilot irrigable areas have been designated in Spain: Bajo Jalón (Ebro RBD), Mancha Oriental (Júcar RBD), Tierra del Vino (Duero RBD) and Mancha Occidental (Guadiana RBD), where first contrasts have already been initiated. There is also a national expert-working group on remote sensing and hydrological planning that periodically meets representatives of the National Administration, agricultural users and the universities, among others.

The case of La Mancha Oriental aquifer, located in the Júcar RBD, in the Eastern part of Spain, counts on an irrigation surface of approximately 100.000 ha. An important exploitation of underground water resources (water body 080.129- Mancha Oriental), has caused a significant decrease in the piezometric levels of the aquifer with an intense influence on the flows of the river Júcar. This situation, which has caused a very positive socioeconomic impact in the territory of Castilla-La Mancha, has affected on the other hand the resources traditionally used by previously existing water uses in the final stretch of the river, which are located in another region, the Valencian autonomous community. The increase of the extractions began at the beginning of the 60s, although the great development of new irrigation was carried out in the 70s and 80s, thanks to the impulse, of both public and private finance, consequence of the good cereal prices. Figure 5 presents an estimation of the irrigated surface of herbaceous obtained from remote-sensing techniques. The graph shows the significant growth that was recorded from the beginning of the 80s until 2013, when the irrigated area was stabilised around 75.000 ha.

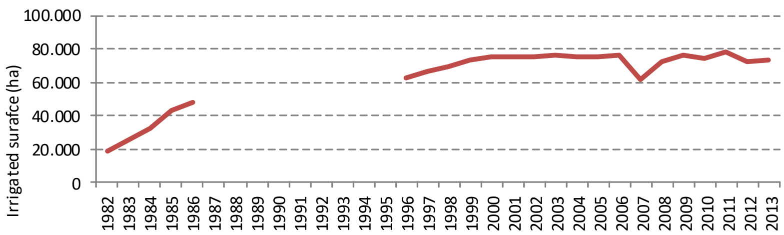

Figura 5. Evolution of irrigated area in Mancha Oriental.

Figure 6 show the maps of regional piezometry in the surroundings of the Mancha Oriental aquifer. The first figure (6.1) refers the situation for the period 1970 to 1974 and the second (6.2) summaries 2008 situation (IGME-DGA, 2009). The images use in both cases the same color palette, in which greens represent higher piezometric levels and reds lower levels. In the first figure (6.1), most of the levels of the La Mancha plain were located between the 600 and 700 meters above sea level (masl). The intense exploitation has produced a significant decrease in piezometric levels. Figure (6.2) shows a very significant increase in the area whose piezometry is between 600 and 700 masl, with the lowest levels previously limited to the final area in the river extending into the surrounding area of the city of Albacete.

Nevertheless, river Júcar combines sections in which the river bed is at a higher level than the piezometric level of the aquifer (river loser) and sections in which the bed is at a lower level (winner river). The balance between winning and losing sections have been affected by the decrease of piezometric levels, being aggravated on drought conditions due to the lack of enough eco-flow downstream of the reservoir of Alarcón, located upstream. This problem has being especially intense in 1994/95 when there was an episode of drying of the river Júcar in Albacete (Figure 7).

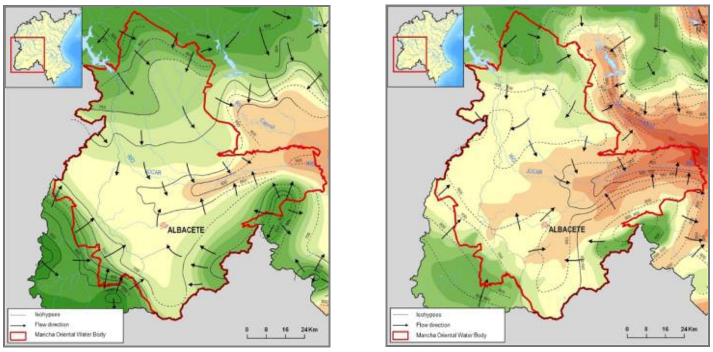

Figura 6. Maps of piezometric levels and flow direction in 1970-1974 period (6.1) and 2008 (6.2) in La Mancha Oriental aquifer

Drought status in the Jucar resources system									
Month	iSI	SPI-24	SPI-12	SPI-6	SPI-3	SPI-1	PDSI	iIH	iIH-3
oct-93	-1,54	-1,23	-0,40	0,11	0,13	0,79	-1,29	0,06	0,35
nov-93	-1,28	-1,10	0,02	0,50	0,37	0,51	-0,83	0,88	0,77
dec-93	-1,61	-1,31	-0,40	-0,22	0,00	-1,45	-1,61	-0,31	0,50
jan-94	-0,93	-1,35	-0,29	-0,56	-0,65	-0,19	-1,71	-0,41	0,01
feb-94	-1,24	-1,46	-0,91	-0,69	-1,37	-0,24	-1,89	-0,76	-0,54
mar-94	-0,48	-1,50	-1,27	-1,09	-1,94	-2,39	-3,11	-1,18	-0,81
apr-94	-0,77	-1,21	-0,88	-1,10	-1,07	0,37	-2,66	-0,76	-0,94
may-94	-0,87	-1,37	-0,82	-1,60	-1,12	-0,98	-3,32	-1,07	-1,08
jun-94	-0,87	-1,72	-1,25	-1,90	-1,10	-2,14	-3,34	-1,67	-1,19
jul-94	-0,83	-1,69	-1,47	-2,07	-2,09	-0,79	-2,61	-1,61	-1,55
aug-94	-0,52	-1,77	-1,46	-2,08	-2,12	-0,96	-2,19	-1,06	-1,67
sep-94	-0,55	-1,35	-1,23	-1,14	-0,15	0,50	-1,73	0,05	-0,99
oct-94	-0,83	-1,19	-1,20	-0,71	0,56	0,82	-0,91	0,58	0,25
nov-94	-0,50	-1,05	-1,54	-0,32	0,47	0,00	-1,12	-0,27	0,16
dec-94	-0,77	-1,44	-1,75	-0,65	-0,55	-1,90	-2,05	-1,58	-0,63
jan-95	-0,47	-1,54	-2,03	-0,70	-1,56	-0,54	-2,39	-1,36	-1,27
feb-95	-0,60	-1,93	-2,01	-0,81	-2,00	-0,49	-3,05	-1,59	-1,59
mar-95	-1,46	-2,04	-1,69	-1,48	-1,87	-0,86	-3,72	-1,32	-1,50
apr-95	-1,64	-2,12	-2,28	-2,32	-2,59	-2,14	-4,40	-1,52	-1,53
may-95	-1,70	-2,10	-1,89	-2,38	-2,07	-0,79	-4,97	-1,38	-1,49
jun-95	-1,67	-1,92	-1,37	-1,63	-0,81	1,03	-4,29	0,05	-1,35
jul-95	-1,56	-1,99	-1,30	-1,48	0,10	0,12	-3,81	-0,13	-0,85
aug-95	0,41	-1,68	-0,69	-0,33	1,31	1,69	-3,85	1,83	0,09
sep-95	0,49	-1,76	-1,21	-0,67	0,18	-1,86	-3,95	-0,90	0,31

Drought status in the Jucar resources system									
Month	iSI	SPI-24	SPI-12	SPI-6	SPI-3	SPI-1	PDSI	iIH	iIH-3
oct-95	0,40	-2,23	-1,93	-0,58	-0,65	-0,96	-4,62	-1,08	-0,21
nov-95	-1,71	-2,53	-2,06	-0,26	-1,64	0,01	-4,61	-1,17	0,35
dec-95	0,31	-1,84	-0,96	0,27	0,39	1,30	-3,02	0,26	0,77
jan-96	1,26	-1,62	-0,39	0,71	1,29	1,08	-2,04	0,59	0,50
feb-96	1,18	-1,31	-0,08	0,34	1,44	0,51	-1,56	0,95	0,01
mar-96	1,03	-1,08	0,06	0,63	0,68	-0,25	-1,68	0,47	-0,54
apr-96	0,59	-1,24	0,21	0,69	-0,40	-0,48	-2,03	-0,06	-0,81
may-96	0,53	-0,93	0,47	0,81	-0,21	0,57	-1,61	0,17	-0,94
jun-96	0,54	-0,81	0,22	0,23	-0,27	-0,35	-1,59	-0,38	-1,08
jul-96	0,68	-0,74	0,24	-0,27	0,18	0,41	-1,41	-0,19	-1,19
aug-96	0,54	-0,70	-0,07	-0,42	-0,14	0,27	-1,19	-0,16	-1,55
sep-96	0,72	-0,40	0,61	0,51	1,12	1,33	-0,04	1,70	-1,67
oct-96	0,62	-0,80	0,56	0,14	0,21	-1,70	-1,05	-0,81	-0,99
nov-96	0,59	-0,59	0,85	0,43	0,66	0,91	-0,29	0,35	0,25
dec-96	1,24	-0,13	0,77	1,17	0,70	1,07	0,96	1,63	0,16
jan-97	1,46	0,55	1,24	1,78	1,90	1,65	3,03	2,12	-0,63
feb-97	1,50	0,45	0,90	1,57	1,39	-1,69	1,89	0,71	-1,27
mar-97	1,33	0,37	0,72	0,73	0,57	-1,90	0,59	-0,58	-1,59
apr-97	0,94	0,73	1,00	1,21	-0,72	0,98	0,66	-0,17	-1,50
may-97	0,78	0,88	0,95	1,03	0,36	0,78	1,03	0,27	-1,53
jun-97	0,80	0,95	1,32	1,23	1,42	1,36	1,41	1,57	-1,49
jul-97	0,99	1,02	1,39	0,61	1,41	1,32	0,59	2,19	-1,35
aug-97	0,81	1,00	1,53	1,27	1,64	1,55	0,12	2,11	-0,85
sep-97	0,59	1,43	1,68	2,30	1,86	1,42	1,12	2,35	0,69

Figura 7. (7.1-7.2) Evolution of meteorological (SPI), edaphic (PDSI; iIH), and operational drought indices (Normalised Status Index, iSI) in the Júcar water resources system. Source: Ortega-Gómez et al., 2017

The decrease in flows contributed by the agricultural use has resulted in a lower availability of regulated resources in the Tous reservoir, located downstream, with a possible impact on users of the final stretch of the river (the Acequia Real del Júcar).

3. RESULTS AND DISCUSSION

Temporal series maps of irrigated areas (surface) and corresponding maps for irrigation water requirements (water volumes) are obtained in period 2014-2017.

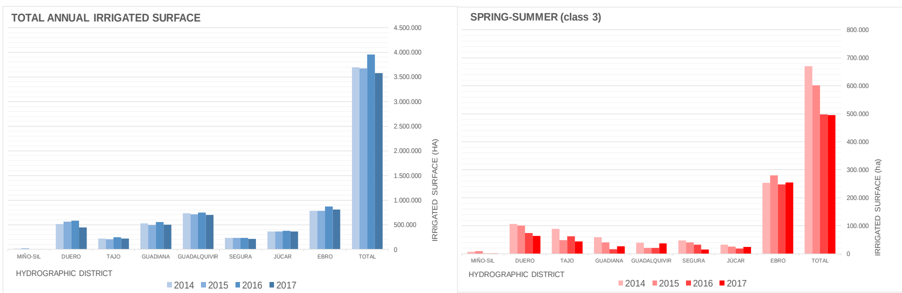

Figura 8. Evolution of: total yearly-irrigated surface (8.1) and spring-summer yearly-irrigated surface (8.2) in 2014-2017 by Spanish RBDs

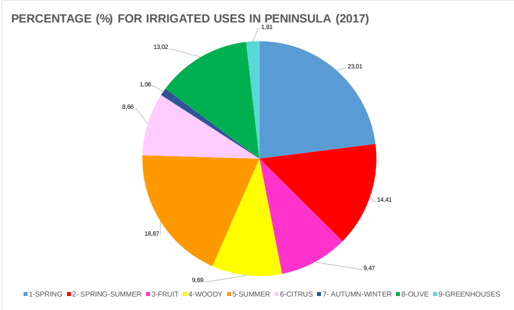

Figura 9. Percentage of each type of irrigated use in the Peninsula in 2017.

Derived from remote-sensing techniques, Figure 8.1 represents the evolution of the annual irrigated surface by RBDs. In addition, further results, have been obtained by type of irrigated use. Figure 8.2, represents the case of spring-summer. Total irrigated surface is around 3.7 M ha in Spain, being the Ebro and Guadalquivir RBDs, the biggest representatives for the agricultural use. Wheat, barley, maize, vineyard, olive (upper to 350.000 ha in Guadalquivir RBD), fruit trees, and citric as main crops, and mainly irrigated by drip and sprinkle systems (around 75 %). The NWIR for the four pilot zones studied in DIANA project are summarised in table 2, between 2016 and 2018. Maps have been also edited for pilot areas (Figure 10).

Table 2. NWIR in pilot areas

Use/Year	***M. Oriental***				***Tierra del Vino***			***Bajo Jalón***			***M. Occidental***
	2016	2017	2018	*Mean*	2016	2017	*Mean*	2016	2017	*Mean*	2017
Spring	3.200	3.400	2.600	*3.050*	2.200	3.200	*2.600*	2.400	3.200	*2.800*	2.370
Spring-Summer	7.200	7.700	6.200	*7.030*	6.300	7.100	*6.680*	6.900	7.200	*7.040*	7.280
Stone Fruit	2.700	3.900	3.400	*2.890*	3.800	5.500	*4.210*	5.800	6.600	*6.160*	1.780
Shell Fruit		2.200	2.400	*2.300*		2.500	*2.500*		3.200	*3.200*	
Woody	1.400	1.200	1.000	*1.230*	1.200	1.300	*1.250*	1.600	1.200	*1.400*	1.410
Summer	5.000	5.200	4.400	*4.860*	5.200	5.300	*5.250*	4.900	4.900	*4.900*	4.450
Olive	2.000	1.600	1.400	*1.620*				2.200	2.200	*2.200*	1.660
WEIGHTED AVERAGE	3.430	3.740	3.000	*3.380*	3.580	4.360	*3.930*	4.140	4.200	*4.170*	3.345

Main agricultural uses in Mancha Oriental belong to classes: spring in blue colour, woody (mostly vineyard, in yellow) predominantly in the north part of the area, followed by summer and spring-summer uses, which present higher values of NWIR (mm/year), as shown in the map ahead.

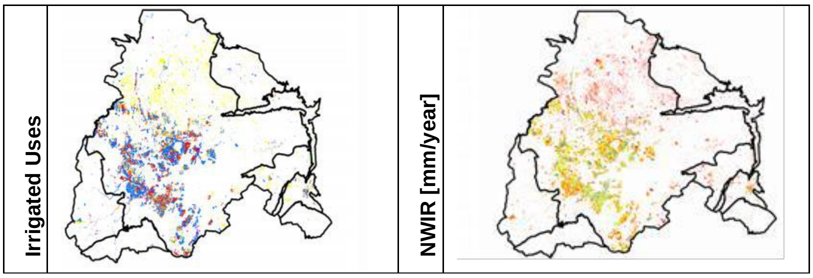

Figura 10. Main uses in irrigation and NWIR values in Mancha Oriental

Table 3. Classes of NWIR [mm/year] defined by the SPIDER-SIAR project

NWIR [mm/year]	1-100	100-200	200-300	300-400	400-500	500-600
	600-700	700-800	800-900	900-1.000	1.000-1.100	1.100-1.200

3.1 Control of water volumes

The Spanish ARM/1312/2009 Order regulates the effective control of water volumes (abstractions and discharges) authorised by water Law, classifying them into four categories. It defines a frequency in terms of measurement, registration and communication of the data to RBAs by users. To this purpose, Spanish administration is developing in collaboration with water users a collaborative work for obtaining these data flows what is difficult and requires excellent skills on water governance.

Table 4. Categories for the reporting to RBAs and control of water volumes

Category	**Q_{max} (l/s)**	**V_{max} (m^3)**	**Frequency**
C1	< 4	< 20.000	Yearly
C2	[4 – 99]	[20.000-499.999]	Monthly
C3	[100 – 299]	500.000-1.499.999	Weekly
C4	≥ 300	≥1.500.000	Daily

The present article summarises a methodology for contrasting the modeled values of water needs for crops, with the irrigation volumes used by irrigators, registered by water-meters in compliance with the Spanish ARM/1312/2009 Order. Three general steps are essential:

I. Harmonising a shared-applicable methodology for estimating NWIR throughout the territory, validating the SPIDER-SIAR classification of agricultural uses in Spain. The agricultural parcel has been defined as common spacial scale.

II. Harmonising a shared-applicable methodology for contrasting NWIR with water volumes registered by water meters. The agricultural parcel has been assigned for controlling the irrigated surface

III. Establishing a common information exchange system which includes access to remote-sensing products and processing with GIS tools.

For accurating the SPIDER-SIAR classification, the mehodology proposes the use of the annual declarations of irrigated uses (type of irrigated crop) in the Spanish Geographic Information System of agricultural plots (SIGPAC, according to the Spanish acronym) hanging on the MAPA. The system is annualy updated by farmers profiting EU financing aid. Furthermore, the Spanish Survey on Surfaces and Crop Yields

(ESYRCE, according to the Spanish acronym), elaborated as well by the Spanish MAPA is a statistical operation, within the Spanish National Statistical Plan, that utilise a systematic stratified sampling. Three territorial segments (700m x 700m) contained in a grid (1km x 1km) of a block (10x10 km), are analysed. Along with this tools other areas might be designated for the contrast with fieldwork.

For contrasting NWIRs values, initial analyses have been started in the irrigation area of the Acequia Real del Júcar, which is located downstream of Mancha Oriental use, at the final stretch of the Júcar river basin. This irrigation area has recently applied modernisation works and a systematic organisation of flows information is available. Further areas will be analysed for covering the whole spectrum of agricultural uses and hydro-climatic areas in Spain.

Nonetheless, the sustainable exploitation of the aquifer *Mancha Oriental* is based on:

i) Progressive replacement of abstractions by surface resources to promote piezo-metric recovery

ii) Creation of Central Board of Irrigators *Mancha Oriental* (JCRMO, according to the Spanish acronym), for the management of water ressources in the area. The JCRMO was created in 1995

iii) Elaboration of an (bi)annual exploitation plan for the aquifer. The Júcar RBMP (1998), estimated a maximun annual value of 320 Hm^3 for the allocation of under-ground water resources in *Mancha Oriental*. These allocations should be gradually reduced until 260 Hm^3/year (2027), according to Júcar RBMP (2014).

iv) Monitoring of water use, and regularization of water rights conditioning water permits to renewable freshwater ressources

v) Improvement of water governance between Central Administration and agricultural users (JCRMO), mainly developped through the implementation of collaboration agreements, with an approximate average budget of 90.000 €/year

4. CONCLUSIONS

The General Directorate for Water hanging on the Spanish Ministry for the Ecological Transition is aiming to improve knowledge on water use in agriculture, combining the use of satellite images and data of water volumes to feed the hydrological planning process (2021-2027) required by directive 2000/60/EC. According to Spanish legislation, an effective control of water volumes (both abstractions and discharges), must regularly be informed to water authorities by water users. However, relevant action in extending metering, water abstraction controls and reviewing licenses, have been found in EU Member States.

Despite the difficulty of having records of measurements of water consumption, the present study define a methodolofy for contrasting the modelled values of Net Water Irrigation Requirements computed by HidroMore with actual values of water flows recorded by water-meters in areas recently modernised. In this way, these works complete the traditional estimations of irrigated water demands that water authorities carry out according to Spanish National Intruction for Hydrological Planning (IHP). The product of crops surface by the average agricultural supply allows calculating the net water demand for agriculture. Hence, the procedure for estimating water consumption in agriculture using remote-sensing techniques follows the same basic concept as that used in the IHP, and incorporates the contrast with metered volumes.

5. REFERENCES

Allen, R., Pereira, LS., Raes, D., Smith, M. 1998 Crop evapotranspiration -Guidelines for computing crop water requirements- FAO Irrigation and drainage paper 56.

Campos, I., Odi, M., Belmonte, M., Martínez-Beltrán, C., and Calera, A. 2011 Obtención de series multi-temporales y multi-sensor de índices de vegetación mediante un procedimiento de normalización absoluta, XIV Congreso de la Asociación Española de Teledetección

EC 2012. Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Plan for Safeguarding Water Resources in Europe, COM(2012)673 final

EC 2019. Report from the Commission to the European Parliament, the Council, on the implementation of the Water Framework Directive (directive 2000/60/EC), and the Floods Directive. River basin management plans for the 2nd cycle and Risk management plans for the 1st cycle SWD (2019)30 final

Estrela, T., Ferrer, FJ., Pérez, MA., y Font, E., 2004 Modelo hidrogeológico del acuífero de la Mancha Oriental para el análisis de los efectos de las diferentes alternativas de sustitución de extracciones por aguas superficiales. VIII Simposio de Hidrogeología. Asociación Española de Hidrogeólogos, Zaragoza (NIPO: 657-04-028-5; Dep.legal: M-41868–2004)

Garrido-Rubio, J., Calera Belmonte, A., Fraile-Enguita, L., Arellano Alcázar, I., Belmonte Mancebo, M., Campos Rodríguez, I., Bravo Rubio, R., 2018 Remote sensing-based soil water balance for irrigation water accounting at the Spanish Iberian Peninsula. Proc IAHS 380:29-35 doi: 10.5194/piahs-380-29-2018

IGME-DGA 2009. Encomienda de gestión para la realización de trabajos científico-técnicos de apoyo a la sostenibilidad y protección de las aguas subterráneas

MITECO 2017. Monitoring report on the 2015-2021 RBMPs and Water Resources in Spain

Order ARM/1312/2009, 20th May, which regulates the effective control of water volumes used in public hydraulic domain, water returns and discharges

Order ARM/2656/2008, 10th September, which approves the Spanish National Instruction for Hydrological Planning

Ortega Gómez, T., Pérez-Martín, MA, Estrela, T., 2018. Improvement of the drought indicators system in the Júcar River Basin, Spain. Science of the Total Environment 610–611 (2018) 276–290

Rouse, J.W., Haas, R.H., Deering, D.W., and Schell, J.A. 1973 Monitoring the vernal advancement and retro-gradation of natural vegetation.

Royal Decree 1/2016, 8th January, which approves the revision of the Hydrological Plans of the Spanish hydrographic districts “Cantábrico Occidental, Guadalquivir, Ceuta, Melilla, Segura and Júcar”, and of the Spanish part of the hydrographic districts of the “Cantábrico Oriental, Miño-Sil, Duero, Tajo, Guadiana and Ebro”