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Water Resources Report — Hydrological Management Tool in the Júcar System

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Abstract: The Júcar river has a distinctly Mediterranean behavior, characterized by a large disparity between the ordinary and extraordinary flows, and extreme flow regime of high magnitude floods causing flooding secular overflows the banks and sometimes, they cause damage considerable in the fields and towns, as produced in 1982.

Given this situation it became necessary to implement Automatic Hydrological Information System (SAIH), allowing a hydrologic-hydraulic data in real time, and predict the future behavior of the basins.

All Júcar basin is divided into sub-basins, in which are the Remote Stations (RE) and Concentration Points (CP).

The Basin's Data Processing Centre (BDPC) periodically interrogates hubs, and being the end of the data point is responsible for its organization and management. This network has a hierarchical structure with two levels: RE communicates with the CP via secondary network protocol CP and transfer the information to BDP primary network protocol.

The aim of this presentation is to present a management tool whose application makes it possible the optimization and improvement of water resources in the Júcar River.

Key words: hydrological information; systems management; means; functional software

1. Introduction

According to the executive summary of the United Nations World Water Development Report 2015 titled Water for a Sustainable World, water is at the core of sustainable development. Water resources, and the range of services they provide, underpin poverty reduction, economic growth and environmental sustainability. From food and energy security to human and environmental health, water contributes to improvements in social well-being and inclusive growth, affecting the livelihoods of billions of people.

The Júcar River Basin (Valencia, Spain) is comprised of a set of rivers clearly Mediterranean in their behaviour, characterized by a significant disproportion between ordinary and extraordinary flows; some with extreme flow regimes with excessive flow, overflowing and flooding of the banks and can be the cause of considerable damage to lands and towns and villages they reach, in the case of the river Júcar in the flood-plain areas of the counties of Ribera Alta and Ribera Baixa of the Autonomous Community of Valencia [1].

The Automatic Hydrological Information System (SAIH-Júcar, as per the Spanish initials) is a body that provides substantial technical support and assistance in decision making in relation to the two types of problems that arise as part of water management. On the one hand, flood tracking in order to prevent and minimize damage and, on the other, management of water resources, in order to optimize their allocation and operation, especially in situations of short or medium-term scarcity, requiring special control.

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The SAIH-Júcar has 262 control points (stations on reservoirs, gauging stations and rain gauges) which capture the data, storing the information and performing the initial processing of same. This remote measurement network is made up of a set of data capture points that perform the readings of the respective sensors and store the information for a variable period of up to 10 days, based on the remote station model and the number of sensors. Subsequently, all this information is sent to a processing centre (CPC) for processing.

The structure of the SAIH-Júcar, based on the contents of the information is subdivided into the following networks:

- Rain gauge network: control points for precipitation in the form of rain or snow, and temperature.
- Hydrometric network: control points for level and flow of watercourses, canals and irrigation ditches.
- Hydrological network: control points for level, volume, drainage bodies and positions of reservoir gates.

2. Objectives

The SAIH-Júcar is a real-time system for the capture, transmission, presentation and processing of descriptive hydrological and hydraulic information on the status of the basin in every moment.

With this automatic system, new applications are being developed and improved, capable of facilitating hydrological or hydraulic studies through the reception of signals received in real time (every five minutes) and efficiently planning the management of human resources and technological material needs for the maintenance of the SAIH system and the tools for the analysis of causes and faults.

These applications and the improvements introduced make it possible to optimize water management, early alerts and system management. They are classified as [2]:

- Non-water management: management of preventive and corrective maintenance (Geo_Saih) [3], of communications based fundamentally on radiolinks (Svecor) [4].
- Water management: management of the location of reservoirs, gauging stations and rain gauges through the hydrological variables display system in the windows (Saih_Win) [5].

The object of this communication is to display the results obtained in the application of water management tools indicated previously to draw up the report on the water resources within the scope of the Júcar River Basin Authority (also called the Monday report).

With this communication it is intended to publicise the minimum content that a weekly water resources report must provide, where the real magnitudes of the major hydrological variables of a river basin are presented in terms of precipitation, reservoir volumes, inflow and outflow of the main reservoirs and flow tracking.

3. Territorial Scope and River Sub-Basins

The Júcar River Basin District (DHJ as per the Spanish initials) borders the Ebro and Segura River Basin Districts to the north and the south, respectively, and those of the rivers Tagus, Guadiana and Guadalquivir to the west, bordered to the east by the Mediterranean Sea. The total surface area of the territory of the district is 42,735.33 km^2 [6].

The scope of the Júcar River Basin District (DHJ) extends across five Autonomous Communities (Aragón, Castilla-La Mancha, Catalonia, Valencia and the Region of Murcia) and eight provinces: all of Valencia’s, a large part of Albacete, Alicante, Castellón, Cuenca, Teruel, a small area of Tarragona and a very small area of Murcia. The provinces of the Autonomous Community of Valencia account for the largest part of the basin, with 50% of its territory.

In the scope of the DHJ there are 789 municipalities, of which 751 have their urban centre located therein. 87%

of these are municipalities have a population of fewer than 10,000 inhabitants.

The operation systems are the following, ordered according to Fig. 1: DHJ river sub-basins, and Table 1: Operation systems, from North to South.

4. Methodology of Design of Water Resources Report

The water resources report is a public report published weekly and cumulatively, which is prepared from the start of the water year (October to September) and presented every Monday to observe the evolution of the basic pluviometric, hydrometric and hydrological variables, to analyze the monitoring and/or behaviour of same in each operation system and in the Júcar river basin district as a whole with regard to the following aspects [7]:

(1) Precipitation:

- Average monthly and accumulated precipitation.
- Average precipitation by operation system.
- Registered precipitation at each of the rain gauges.
- Precipitation maps.

(2) Status of reservoirs:

- Reservoir volumes.
- Reservoir volumes by operation system.

(3) Inflow and outflow of the systems:

- Circulation volumes and flows.

For this, using an IT calculation application for the analysis and processing of data and series, each of the individual values for the water year in question and for the historical series from previous years, comprising what will definitively constitute an information system that will be of assistance in making decisions.

This application captures all the different data from different applications and using an ad-hoc macro, prepares the corresponding information. Among the applications used for the receipt of data, it is worth mentioning that Saih_Win: Hydrological Variables Display System in Windows.

Saih_Win is a proprietary and independent programme that extracts data in real time (every five minutes). The data obtained from each of the gauging stations of the SAIH network represent the whole set of real and/or calculated variables in the Valencia Basin Processing Centre through its own communication system.

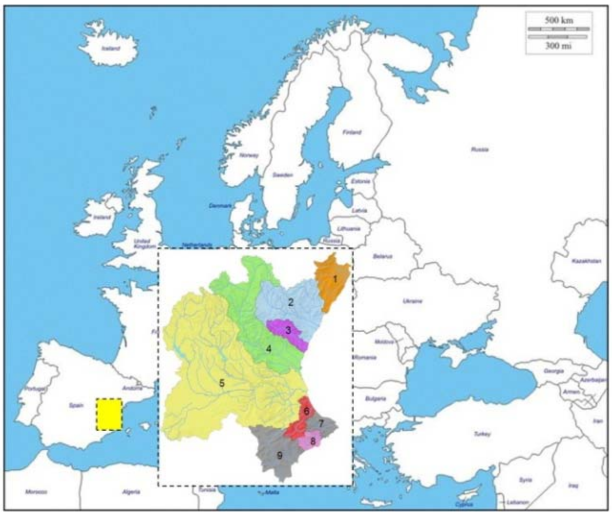

Fig. 1 DHJ sub-basins.

Table 1 Operation systems.

No	System	km^2	%
1	Cenia - Maestrazgo	2.033.00	4.76%
2	Mijares - Plana de Castellón	4.818.84	11.28%
3	Palancia - Los Valles	1.086.92	2.54%
4	Turia	7.231.75	16.92%
5	Júcar	22.186.61	51.92%
6	Serpis	985.17	2.31%
7	Marina Alta	838.62	1.96%
8	Marina Baja	606.65	1.42%
9	Vinalopó - Alacantí	2.947.77	6.90%
	Total	42.735.33	100.00%

5. Description of Precipitation

The SAIH-Júcar precipitation data is captured from each of the 182 rain gauges installed across the geographic expanse of the basin.

This precipitation, in the form of rain or snow, is gathered in a bucket with a surface area of 200 cm^2 (in accordance with OMM standards) and is passed to a vessel with drop breaker and a tranquillizer system with an anti-jam gasket and runs to a collector receptacle in the form of a small or medium-sized bucket with a capacity for 4 cm^3 of volume.

Once the bucket is full to 4 cm^3 it tips over, balancing itself successively for each fill, issuing a signal each time it tips. The system issues a signal for every 0.2 mm of precipitation, equivalent to 0.2 l/m^2.

These signals are received by a control card and are processed as accumulated rainfall in the computer installed at the control point and then through the communication system and together with the rest of the variables received at the Basin Processing Centre (Valencia), to provide this variable for accumulated rainfall and intensity of the rain calculated [8].

5.1 Average Monthly and Accumulated Precipitation

According to the data obtained from the 182 rain gauges in the SAIH network during the year 2016, the average area precipitation in the territory of the Júcar River Basin Authority was 449 mm, which is a volume of precipitation of 19,307 hm^3, while the previous year's figure was 421 mm (18,103 hm^3).

The year 2016 saw area precipitation close to the average for the last 10 years (464.4 mm - 96.68%) and 20 years (457.20 mm - 98,21%), but with an average area value in CHJ territory of above (108.14%) the average for the last 5 natural years.

As observed in Table 2, the year 2016 was around average. 8 years had higher values and 11 had lower values.

When ordering the series for the last 20 years in decreasing order, in the natural year 2016 average the precipitation was around the middle of the series, in ninth position, although the average for the last 20 years is higher, as indicated in the table.

Annual precipitation for the last 20 years (1997 series to 2016) shows cyclical behaviour, alternating periods of various years with high precipitation (2002 to 2004 and 2007 to 2010) with other periods of several years of low precipitation (1998 to 2001, 2005 to 2006 and 2001 to 2015).

Table 2 Average area precipitation (mm) 20 natural years.

1997	605	**2007**	537
1998	344	**2008**	574
1999	390	**2009**	469
2000	424	**2010**	547
2001	406	**2011**	441
2002	528	**2012**	405
2003	550	**2013**	430
2004	523	**2014**	371
2005	321	**2015**	421
2006	409	**2016**	449
Maximum/Minimum last 20 years: 605 mm (1997)/321 mm (2005)			
Average last 20/10/05 years: 457.20 mm/464.40 mm/415.20 mm			

With this precipitation, the inflow into reservoirs for the year 2016 was 941 hm^3, lower than the 1,145 hm^3 for the year 2015. These figures represent a runoff coefficient of 4.87% compared to 6.32% in the year 2015.

In Table 3, we can observe the precipitation data in mm for each natural year, volumes of annual precipitation inflows to reservoirs and the runoff coefficient as a result of dividing inflows by the corresponding volumes, observing that in the years 2016 and 2012 these were the lowest in this series.

Table 4 provides a summary of the monthly accumulated rainfall data for the current water period (2016-2017).

Table 3 Evolution of annual precipitation, inflows and runoff.

Year	mm	Volume Precipitation (hm^3)	Inflows Reservoir (hm^3)	Coefficient runoff %
2016	449	19,307	941	4.87
2015	421	18,103	1,145	6.32
2014	371	15,953	913	5.72
2013	430	18,490	1,401	7.58
2012	405	17,415	696	4.00
2011	441	18,963	1,115	5.88
2010	547	23,521	2,009	8.54
Average	**437**	**18,822**	**1,174**	**6.24**

In Fig. 2 we can observe the evolution of daily accumulated rainfall figures from the start of the current water year 2016-2017 (red dotted line) and the previous water year 2015-2016 (blue line). Also displayed are lines representing the historical maximums and minimums and the accumulated average in each of the two based on the historical series for the last 26 years.

The red dotted line in Fig. 2 traces the evolution of daily accumulated rainfall from the period of October of the previous year (2016) to 25/09/2017 (491.49 mm).

Table 4 Monthly accumulated rainfall (mm) water year 2016-2017.

Year										**2016**		
Month										**10**	**11**	**12**
mm										0,04	35,96	123,34
Year	**2017**											
Month	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**			
mm	225.91	296.30	314.60	371.54	391.49	412.55	439.77	450.34	491.49			

Note: The monthly data corresponds to the first day of each month.

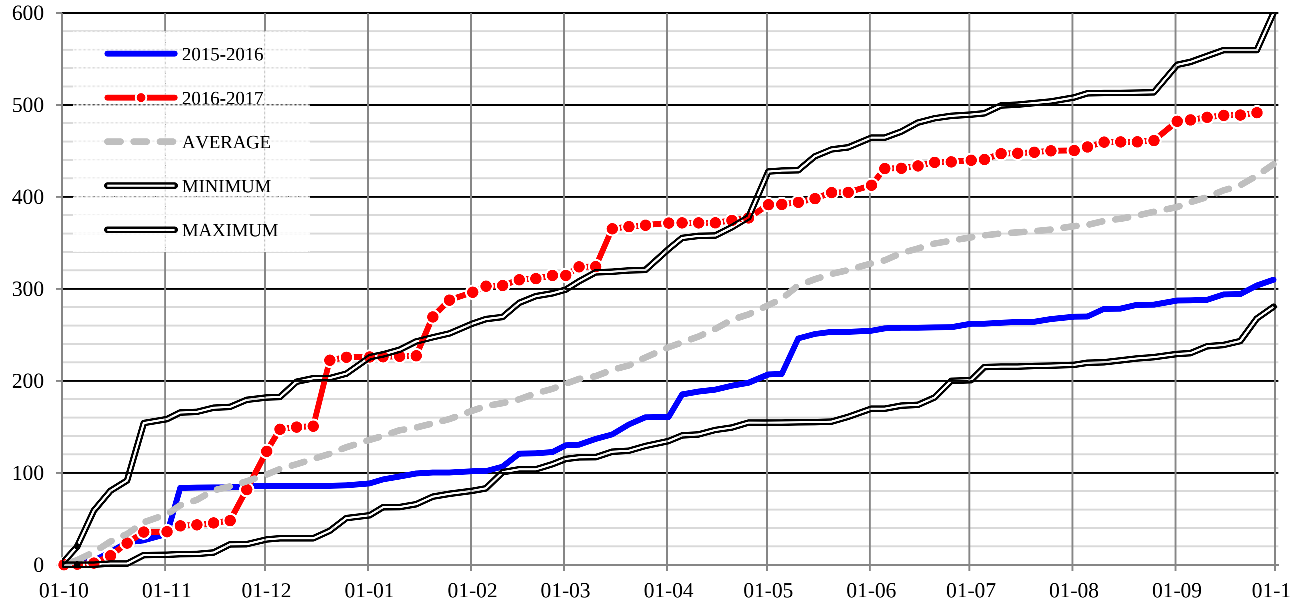

Fig. 2 Accumulated daily precipitation (mm) water years 2015-2016 and 2016-2017.

5.2 Average Precipitation by Operation System

Average precipitation by operation system is expressed in a table, which includes three water years including the current year to date, and the weekly period prior to the date of issue of the report for the current week. Thus, the corresponding values for this week are compared in each of the systems, as indicated in Table 5.

5.3 Precipitation Maps

For precipitation maps, the SAIH IT tool called Interpomap is used, which provides an interpolation of rainfall, in the form of a raster map representing areas of similar accumulated precipitation at a specific time.

In Fig. 3, accumulated rainfall for the period from 10 March 2017 at 00:00 to 15 March 2017 at 00:00 is represented, with average area rainfall of 40.9 mm.

Instantaneous precipitation (calculated variable) is obtained directly from the accumulated by differences of intervals of five minutes, as represented in Fig. 4, for a specific rain gauge station.

Table 5 Average precipitation per operating systems (mm).

No	Systems	Current week	Accumulated annual period		
			2016-2017	2015-2016	2014-2015
1	CENIA	16.60	466.53	362.11	655.71
2	MIJARES	3.86	533.67	369.25	677.01
3	PALANCIA	0.32	543.03	318.27	567.53
4	TURIA	5.73	480.90	271.96	493.55
5	JUCAR	0.82	430.56	298.35	414.63
6	SERPIS	0.34	810.65	248.00	474.59
7	M. ALTA	0.04	679.80	232.34	306.03
8	M. BAJA	0.01	1065.64	339.53	538.49
9	VINALOPÓ	0.42	424.29	198.73	358.85
Total CHJ		2.57	491.49	303.27	468.10
Current week: September 18th 2016 to September 24th 2017 inclusive					
Annual period: October 1st to September 24th inclusive					

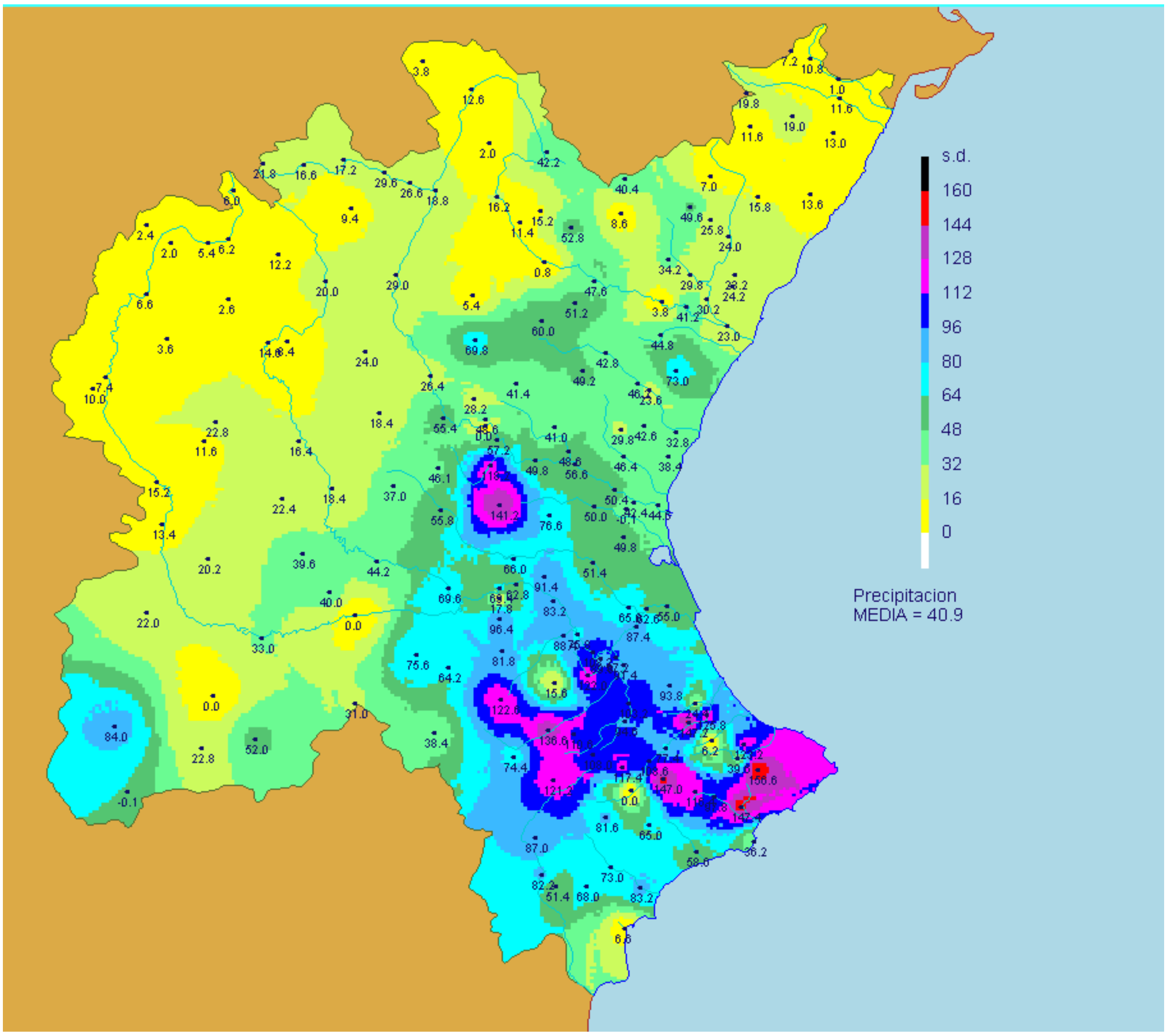

Fig. 3 Interpomap raster map.

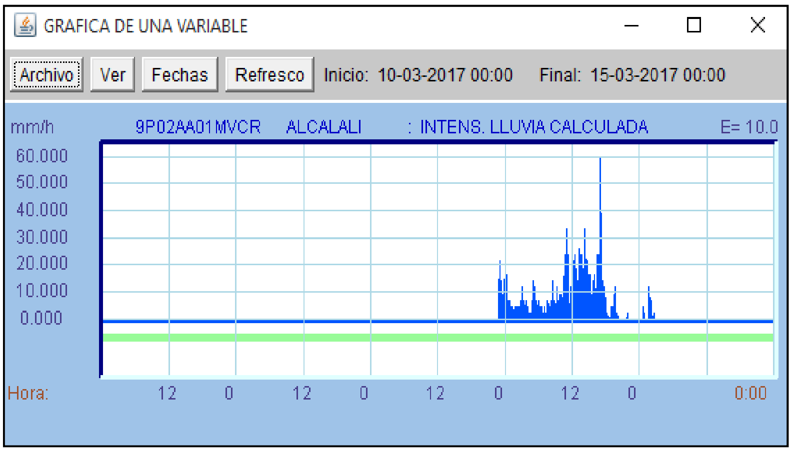

Fig. 4 Intensity of calculated rainfall (mm/h) at a control point.

6. Status of Reservoirs

The volume available in the 33 reservoirs (proprietary and concessionary) at 1 January 2017 was 1,064 hm³, 13% below the volume stored at the beginning of the natural year (1.224 hm³) and 13% below the average volume on 1 January for the last 10 natural years (1.220 hm³). This is equivalent to 32% of the total reservoir volume (3,348 hm³), which implies a reduction in reserves of 4.8% of the total reservoir volume considering the figures reached in the previous natural year.

During the year 2016, there were two important precipitation episodes in November and in December, which allowed for the volume stored in reservoirs in the south of the province of Valencia and the north of Alicante to increase significantly at the same time as the high levels were maintained in other systems further north.

A rainfall episode also occurred in Cuenca city in the month of February which generated certain increases in reservoir volumes in Alarcón and Contreras, but without constituting important values in relation to total reservoir volume.

6.1 Reservoir Volumes

Looking only at the 24 reservoirs operated by the Júcar River Basin Authority, the volume available on 1 January 2017 was 908 hm³, which represents 29% of the total, almost 15% lower than the previous year and 15% lower than the average for the last 10 years. After 6 years above the average for the last 10 years, the overall CHJ reservoir volume for this year, 2017, fell below the average figure. Despite the large volumes over recent years, due in large part to the location of the Júcar System, the last 3 years have seen a continued reduction in reserves.

Table 6 Reservoir volumes (hm^3) per calendar year.

1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1,069	1,135	1,376	799	311	487	259	567	602	736
1987	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
791	1,171	1,328	1,296	1,194	845	549	387	349	728
1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
1,286	1,103	727	596	719	741	1,073	1,161	666	478
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
680	915	1,094	1,724	1,722	1,359	1,603	1,371	1,220	1,064
Maximum/Minimum last 40 years: 1,724 (2010)/259 (1983)									
Average last 40/30/20/10 years: 914/998/1,065/1,275									

6.2 Reservoir Volumes per Operation System.

For reservoir volumes in operation systems indicated in Table 1, weekly monitoring is carried out, in the form of the water resources report applying the following template model/scheme (Table 7).

Table 7 Template model/scheme.

Total volumes stored hm³	Reservoir volum	hm³	hm³	hm³
	Week	Year n-2	Year n-1	Year n
	n	---	---	---
	n-1	---	---	---
	n-2	---	---	---
	Change (%)	---	---	---
Headwater flows weekly averages (m³/s)		---	---	---
System flows (m³/s)		---	---	---

Note: n parameter that applies to the current week and current year of the report. Week n and Year n.

7. Inflows and Outflows of Systems

Another important question to include in the water resources report is the inflows and outflows for each one of the reservoirs and for the CHJ as a whole.

Fig. 5 shows the accumulated daily volumes of inflows (IV) and outflows (OV) in the Júcar System in hm³ for the different water years prior to the current one (2014/2015 and 2015/2016). In red is the date of the report for the current water year (2016/2017), the evolution of the different values and their comparison over the course of the year, while also representing the difference between the inflow and outflow volumes for the current water year (IV-OV) CY on the secondary scale in hm³.

The inflows and outflows for the Júcar system are calculated through the reservoirs:

- Júcar inflow and outflow volumes: Alarcón inflows + Contreras inflows + (Tous inflows - Alarcón outflows - Contreras outflows).
- Volumes of outflows in the Júcar system: Tous outflows.

Outflow rates (OF) of the Júcar Systems represented in the form of five-day data in Fig. 6, calculated through the difference in consecutive volumes and conversion to m³/s, from the daily accumulated outflow volumes in Fig. 5.

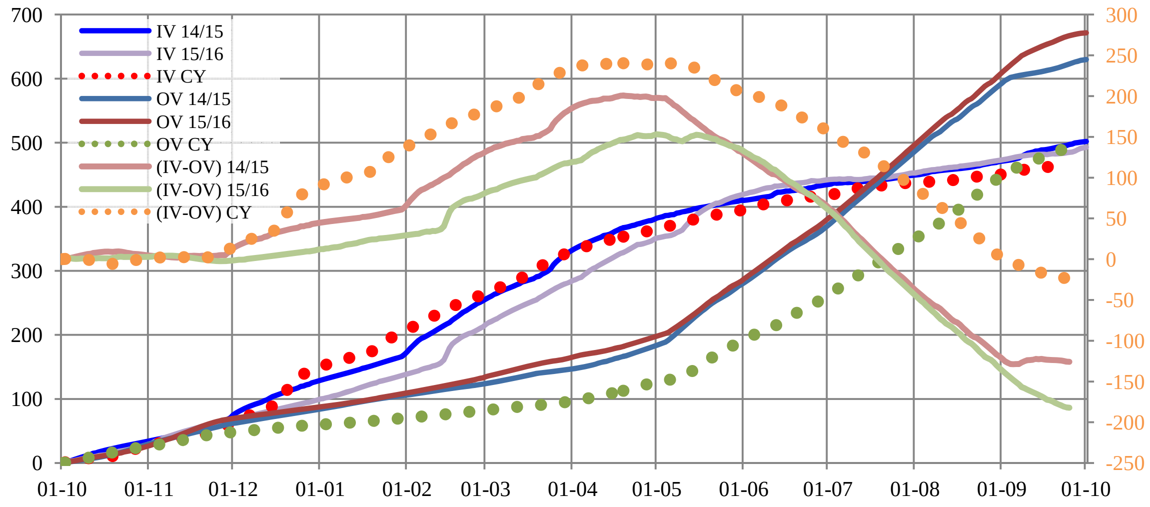

Fig. 5 Daily accumulated volumes of inputs and outputs Júcar System (hm³).

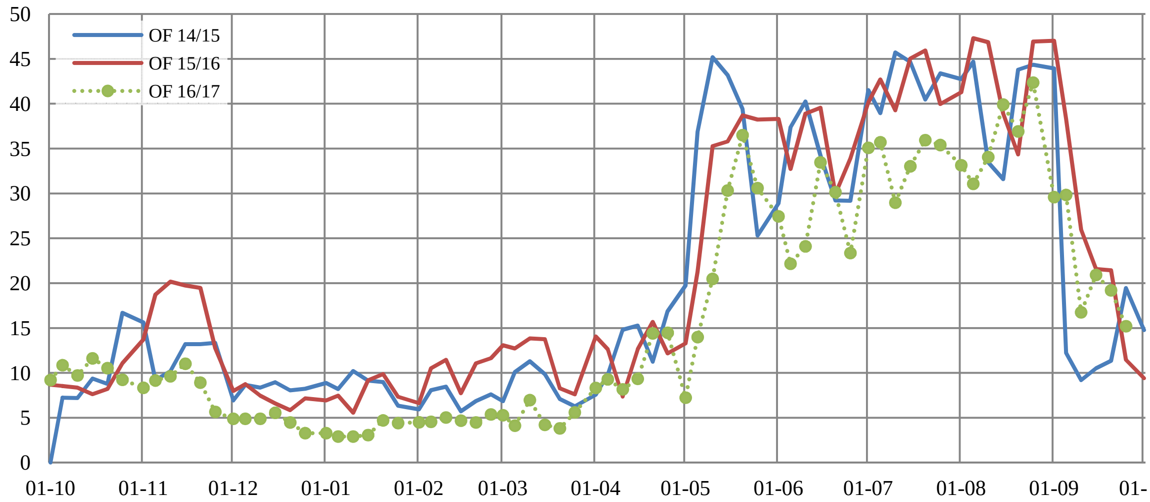

Fig. 6 Five-day outflows Júcar System (m^3/s).

In Figs. 5 and 6 we can also observe the change in the cyclical trend of inflows (rainfall) and the discharge cycle (outflows) between the different periods of storage and utilization of the resources in the different water years.

8. Conclusions

In the different sections of this presentation related to the water resources report or the Monday report, firstly, the influence of precipitation over the course of different water years on the storage of water resources necessary to supply human consumption and for the irrigation needed to satisfy demand has been demonstrated. It is a resource that it is necessary to plan in order to avoid or mitigate the consequences arising from situations of drought, occurring more and more frequently in this area, without forgetting the possible risks of overflowing and flooding caused by heavy rain.

We have also presented the management tools for these water resources, administered by River Basin Authorities, examining the evolution of both inflow and outflow volumes and their respective flows, so that the data available from historical series for different water years and their behaviour allow more appropriate decisions to be taken, and the security of the system to be preserved.

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