Focus

Water saving on a gravity-flow irrigation district Challenges and issues on Lis Valley, Portugal

Lis Valley Irrigation District located in the coastal center of Portugal is administered by a users' association which manages the operation and maintenance of the main pumping and water conveyance infrastructures to the plots. As part of a project supported by the agricultural European Innovation Partnership, a study carried out in collaboration with farmers and focusing on the performance of the collective supply network has identified priority courses of action for achieving water savings by reconciling rural development with environmental and economic sustainability.

In consequence of global change, society is urging water savings by irrigated agriculture, through the decrease of water consumption (Harmel et al., 2020). The major challenge is to maintain or increase agricultural production with less water. It requires the adaptation of irrigated agriculture, through a change of technology and practices compatible with the farmers' technical know-how and farms economic sustainability (Perry et al., 2009). This last issue is particularly relevant on collective irrigation districts, because they play a decisive role in worldwide agriculture and namely in the Portuguese case, in ensuring such socio-economic sustainability. The performance of the delivery system is not only assessed for hydraulic effectiveness in water transport; the off-farm conveyance and distribution system should deliver the water according to adequate, reliable, and equitable criteria, which is a precondition for good water management and land productivity (Playán et al., 2018).

Water savings on an irrigation district is a complex and challenging issue because this objective should be reached keeping the irrigated area and possibly increasing farmer's income. This implies the increase of water and land productivity, under acceptable energy consumption and, as stressed above, a satisfactory equitable water distribution on collective network system.

Periods of water scarcity are not avoided by gravity-fed conveyance systems supplied by surface water runoff, without upstream reservoirs to control the water available for irrigation during Summer. Such scarcity periods require specific water management practices, to optimize equity (Frisvold et al., 2018). To cope with the risks of lack of irrigation water, the management priorities are focused on off- and on-farm irrigation water saving and the downstream water reuse, namely by pumping from ditches, or a more effective use of soil water or groundwater by capillarity rising.

This contribution presents results of the Lis Valley Water Management Operational Group (RRN, 2020), integrated on the agricultural European Innovation Partnership (EIP-AGRI). The study aims at monitoring the collective supply network and the on-farm irrigation management, assessing the guidelines and procedures to carry out water savings, on a context of improving the rural development and environmental and economic sustainability.

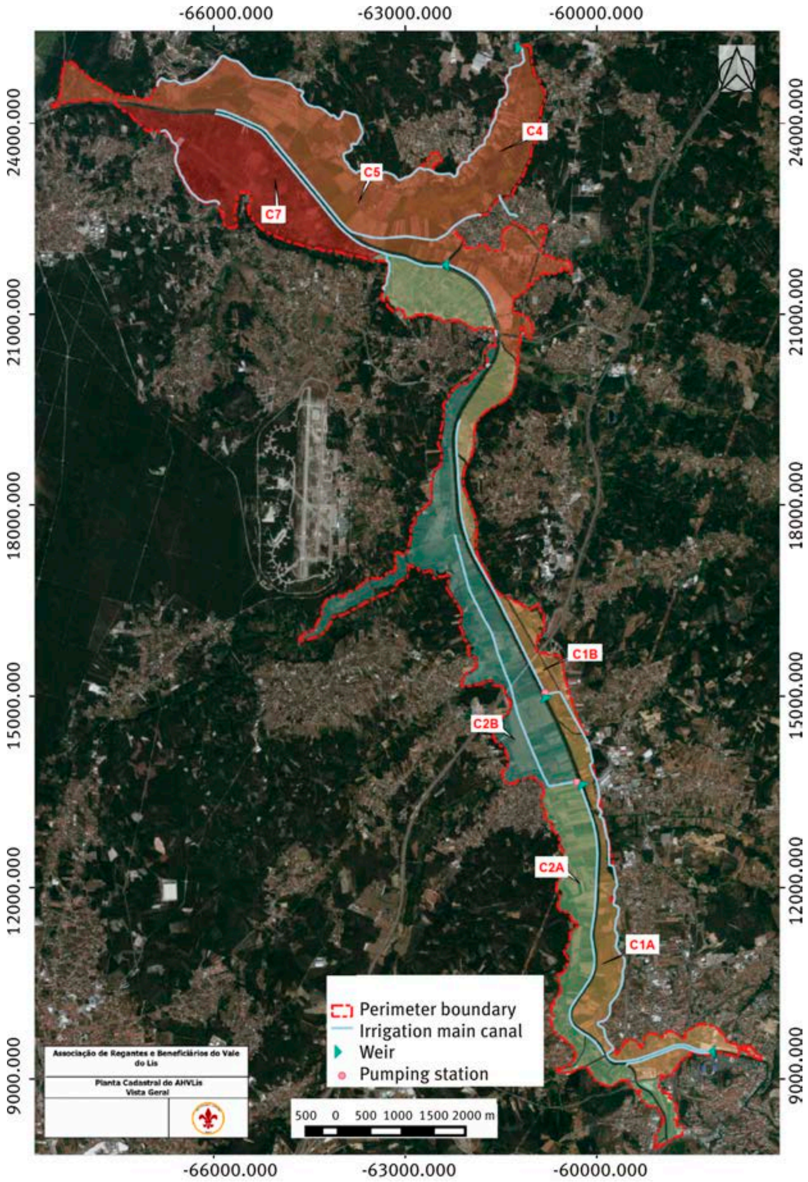
Study area and methodologies

Lis Valley Irrigation District (LVID) has a gravity-fed conveyance system supplied by Lis river and its tributaries, recharged by water pumping from rivers and drainage ditches (Figure ❶). It is a public irrigation district managed by a Water Users' Association (WUA), located in the Coastal Center of Portugal (coordinates 39°51'22.1" N 8°50'56.1" W). WUA is an associative organization of farmers, owners or tenants of field parcels within the irrigation perimeter, that manages the main hydraulic infrastrutures, weirs, pumping stations, canals and turn-outs, namely its operation and maintenance. The total area is about 2000 ha, and the main crops are forage corn, forage grass, horticultural, orchards, and rice (Figure ❷ presents some aspects of water suply, on-farm irrigation, and crops of LVID). The soils are mainly modern alluvial with high agricultural quality, but some are poorly drained, with waterlogging and salinization risks, particularly on the downstream areas. The structure of the on-farm parcel property is characterized by a majority of small parcels, with an average of 0.20 ha (Ferreira et al., 2020). The hydraulic infrastructures have the objectives of perimeter drainage defense through slope collectors and valley ditches, the irrigation water supply through a canal conveyance system, and the field drainage based on a ditch network. Water is supplied by an open-channel conveyance network from weirs installed along the Lis river and tributaries, having the primary network a length of about 44.5 km, and is also obtained by pumping from drainage ditches.

The water conveyance and distribution network for the irrigation district is subdivided into supply sectors, and each sector comprises a main canal, gravity-fed by a river diversion from a weir. During the irrigation peak period, the downstream irrigated areas of some sectors are not fully supplied. To overcome this problem, recharging water is pumped from the river or drainage ditches. The supply sectors are the main elements of the system operation by the WUA, which controls the inflow from the weir, the pumping recharge and the distribution to the secondary irrigation network, which consists of small lined or earthen channels to distribute the water to the field hydrants. This secondary component of irrigation network is managed by groups of local farmers, in articulation with the WUA. Critical issues to be addressed are the water scarcity, particularly in dry years, the related environmental risk related to soil salinization, and the economic impacts due to irrigation pumping from the drainage system and yield losses. The lack of automation mechanisms to control water levels in the network channels lead to malfunctions and a high labor load, which is partly mitigated with the participation of farmers in the operation of the main and secondary networks.

The prevailing dominant on-farm irrigation technology in LVID is the surface irrigation, by graded furrow or by flooding level basins, applied essentially to fodder maize and permanent pastures. In some cases, it is characterized by a poor land leveling and water distribution by unlined channel, resulting in reduced efficiency; however, the laser precision leveling is applied in the larger fields, which allows a great efficiency improvement. In the majority (79.3%) of the cultivated area maize, pastures, and rice are grown (Table ❶). Pressure systems are becoming of great importance with autonomous pumping. Examples are the drip or microsprinkler, which is the most representative, used for fruit plants, horticultural and nurseries, and sprinkler systems, including pivots, used for corn, meadows, and horticulture.

❶ Location of supply sectors in Lis Valley Irrigation District (source: Lis Valley Water Users' Association, WUA, 2020).



❶ Irrigated area and crops grown by Sectors, in 2018, in LVID.

Sector	C1A	C1B	C2A	C2B	C4	C5	C7	Total
Total area, ha	175.6	104.4	189.7	286.2	418.4	2017.6	257.1	1639
Irrigated area, ha	114.2	82.8	159.5	214.7	292.8	166.1	205.7	1236
Irrigated area, %	65	80	85	75	70	80	80	75.5
Maize, %	20	18	43	33	61	60	9	38.4
Pastures, %	48	30	7	24	29	10	77	32.5
Horticulture, %	5.5	13	14.5	13	5	0	0	6.7
Rice,%	0	5	0	15	5	30	1	8.3
Vineyard, %	20	15	15	15	0	0	3	7.9
Fruits, %	6.5	19	20.5	0	0	0	10	6.2

The monitoring methodology of collective irrigation supply systems followed the methodology presented by Replogle et al. (2007), including the observations of operative practices and the measuring of supply discharges, to evaluate the water derived for irrigation and the energy consumed on pumping stations. The most relevant measured data are on the affluence discharge to each sector. For this purpose, the canal section velocity method was used (Figure ❸a), where the point velocities were measured with an electromagnetic current meter, about once a week, allowing the determination of 10 days' time base for sector inflow volume. Some sectors also have data on the pumping recharge. The water balance method was applied, both at sector or field levels, following the procedures presented by Gonçalves et al. (2020), being soil moisture assessed by TDR method (Figure ❸b). The meteorological and crop coefficients decennial data are presented in Table ❷, based on FAO 56 (Allen et al., 1998).

The performance indicators applied was the Total Irrigation Allocation (TIA), summing the Gravity (GIA) and Pumping (PIA) allocations. The Global Irrigation Efficiency (GIE) is the ratio of irrigation water used beneficially (NID) to TIA. GIE is an integrative efficiency indicator, which relates water consumptively used by crops to the water used on irrigation at district scale (Nam et al., 2016). It takes into account several processes of water flow, including the water diverted from its source trans-

❷ View of the irrigation district: a) inflatable weir (to supply sector C7); b) main lined canal (sector C2B); c) secondary canal and surface irrigated field (sector C7); d) maize furrows irrigation with distribution by siphons from a earth canal (sector C5); e) field irrigated by traveller-gun sprinkler irrigation (sector C1A); f) pepper field drip irrigated (sector C1B).

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ported to the farm, the application on the field, and the use by crop, being an assessment of the district-wide irrigation efficiency.

Results and discussion

Supply hydrographs, including gravity and pumping-fed, were compared with decendial net irrigation demand. Results showed that the peak supply period occurred in decendial (10 days periods) sequence between the 20th (July the 2nd) and the 24th (August the 3rd). The pumping recharge uses water from rivers or ditches, implyied a notable water use efficiency and the recovery of nutrients from drainage water, although at the expenses of an increase in the salinity and health risks, which are being monitored.

The TIA values for the 2018 irrigation season per sector varied between 6470 m^3/ha and 9220 m3/ha (C1A and C2A, respectively), with an average of 7400 m3/ha (Figure ❹). The NID values ranged between a minimum on sector C2A (4670 m^3/ha), and a maximum on sector C7 (5130 m^3/ha), with an average of 4950 m^3/ha. The pumping allocation recharge corresponds to 60% in the C1B sector, 10% in sectors C4 and C5, and 7.6% in the C2B sector, with a global average of 9.3%.

The values of GIE vary between 0.53 and 0.72 (in Sectors C1A, C2A, and C7, respectively), with an average of 0.69 (Figure ❹). Generally it can be conclude that the supply was adequate, according to the on-farm irrigation demand, with a satisfactory water distribution equity, as a result of strong collaboration between WUA and farmers. The GIE average value of 0.69 (varying from 0.53 to 0.72) is considered satisfactory (Wolters, 1992). However, these data did not provide enough information to allow splitting this efficiency in the off- and on-farm components. On one hand, the main canals transport efficiency is quite variable, sometimes lower than 70%. On the other hand, the observed field irrigation leads to the conclusion that on-farm application efficiency varies between 65% and 90%, according to the irrigation method from the surface to the drip systems. As previously mentioned, major water losses by surface runoff had conditions to be reused downstream. Therefore, these apparent losses became beneficial water use, thus allowing an increased efficiency.

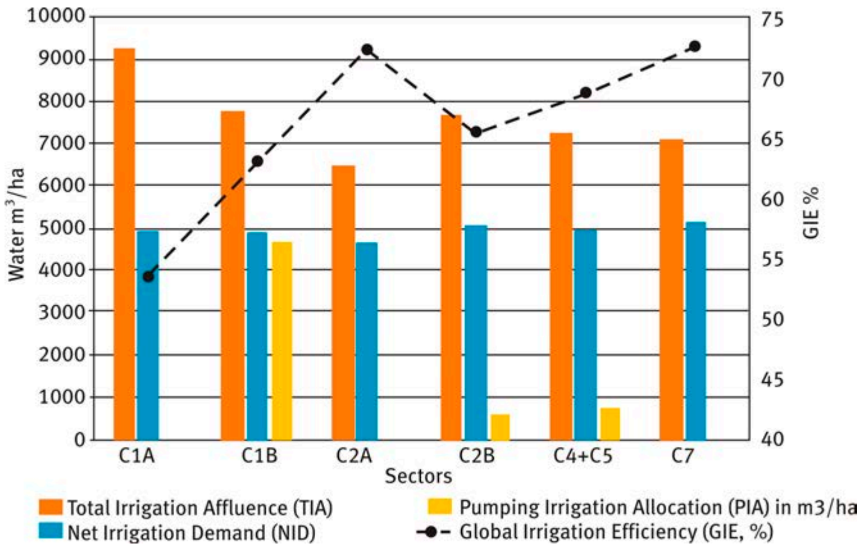
❸ View of field monitoring activities: a) canal flow rate with electromagnetic current meter; b) soil moisture with TDR.

❷ Meteorological data and average crop coefficients per Sector, in 2018.

Month	May			June			July			August			September			October		
Decendial Number	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
ET_o, mm*	35.4	41.6	31.6	25.5	44.7	37.9	37.0	38.6	43.9	37.0	76.3	82.0	35.8	35.4	33.9	34.8	21.3	19.8
P, mm*	0.0	0.5	26.0	38.9	1.8	17.6	1.7	0.1	0.1	0.7	0.3	0.7	0.9	0.0	0.1	0.0	27.4	42.9
K_c* (C1A)	0.62	0.65	0.74	0.81	0.83	0.85	0.89	0.91	0.91	0.91	0.91	0.91	0.87	0.83	0.77	0.72	0.71	0.71
K_c (C1B)	0.61	0.64	0.72	0.79	0.83	0.85	0.89	0.90	0.90	0.90	0.90	0.90	0.87	0.84	0.77	0.72	0.70	0.70
K_c (C2A)	0.43	0.47	0.58	0.69	0.75	0.79	0.88	0.92	0.92	0.92	0.92	0.92	0.86	0.81	0.68	0.61	0.58	0.58
K_c (C2B)	0.61	0.63	0.71	0.78	0.81	0.85	0.92	0.95	0.95	0.95	0.95	0.95	0.90	0.85	0.77	0.72	0.72	0.72
K_c (C4)	0.53	0.53	0.59	0.66	0.72	0.78	0.91	0.97	0.97	0.97	0.97	0.97	0.91	0.84	0.72	0.66	0.66	0.66
K_c (C5)	0.57	0.57	0.63	0.69	0.75	0.81	0.93	0.99	0.99	0.99	0.99	0.99	0.93	0.87	0.75	0.69	0.69	0.69
K_c (C7)	0.79	0.80	0.82	0.84	0.86	0.87	0.89	0.90	0.90	0.90	0.90	0.90	0.89	0.88	0.85	0.83	0.82	0.82

* Leiria data (www.ipma.pt), in decendial (counts from the beginning of the year); ETo, reference evapotranspiration; P, precipitation; Kc, crop coefficient per Sectors: C1A, C1B, C2A, C2B, C4, C5, C7.

❹ Total Irrigation Affluence (TIA), Net Irrigation Demand (NID), and Pumping Irrigation Allocation (PIA) in m³/ha; Global Irrigation Efficiency (GIE, %); Seasonal values per Sector, in 2018.



LVID's practical conditions highlight a set of problems that limit the best system performance. As the network of conveyance system is by open canal, one problem is the existence of a high quantity of debris on water, namely aquatic vegetation, due to the nutrients charge on water from its original source on rivers. This problem requires high maintenance hand labor and cost, making it a lowly effective task because the network is very extensive, with a total of 180 km including the secondary canals, and this work is only well feasible during the non-irrigation period. Its impact is a reduction of canals discharge capacity, gates clogging, and loss of accuracy of managing water control. Equipment to remove this debris is required, like screens and trash racks, and these have been developed for screening irrigation water.

The actions to improve the conveyance system should consider the following future research topics: a) A framework to develop irrigation management operational plans, based on monitoring, simulation, and forecasting tools to integrate multiple information, and to provide water demand and supply data to operate the conveyance system (Salomón-Sirolesi & Farinós-Dasí, 2019). b) Actions directed at farmers carried out by WUA and other stakeholders, to improve irrigation on the field by experimenting and demonstrating the various irrigation technologies, with the best adaptation to local conditions (Ricart et al., 2018). c) Modernize the canal supply system, aiming higher reliability, efficiency, and automaticity, and to achieve a higher level of water, energy, and labor savings (Luppi et al., 2018), as well with information and communication technologies (Soto-Garcia et al., 2013).

Conclusions

The irrigation water management is based on quasi-real-time supply adjustment in the very short time of a few hours or a few days. It is relevant that the relative independence of the supply of several sectors allows the decision-making to be made with higher proximity of the users, creating higher management flexibility. In its turn, cooperation behavior among the group of users at the secondary canal level facilitates the management and favors the equity of water distribution, particularly on the downstream ones. WUA's position of arbitration and regulation is fundamental to guarding and moderating the possible focus of conflict between users. This example meets many cases in which participatory irrigation district management has shown good results.

A conclusion points to priority actions to consolidate improved water management, being the technological innovation an element of the modernization of irrigation district. This modernization justifies the development of multiple efforts and synergies amongst stakeholders, namely farmers, water users association, and researchers. The Operational Group, in particular, through the monitoring of the conveyance system and the evaluation of the on-farm irrigation, in a deep colaboration with active farmers, provides information and knowledgment, enabling WUA to progressively improve district water management. ■

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