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CHARACTERIZATION OF ENERGY REQUIREMENTS IN PRESSURIZED IRRIGATION NETWORKS AND EVALUATION OF POTENTIAL ENERGY SAVING MEASSURES IN SOUTHERN SPAIN

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ABSTRACT With the aim of improving the water use efficiency, many irrigation districts in arid and semiarid regions like Southern Spain have carried out modernization processes where the traditional open channels were replaced by modern pressurised networks. This change has implied significant reductions in water demand but an inversely proportional increment in energy requirements and total water costs. In order to evaluate water and energy use together, a procedure based on performance indicators for evaluating water and energy efficiency in pressurised irrigation networks is developed. This methodology has been applied to ten representative Andalusian irrigation districts with on demand pressurised networks during the 2006-2007 irrigation season. The results confirm the high energy requirements needed for operating these irrigation schemes. To apply an average depth of 2589 m^3/ha, the energy required was estimated to be 1000 kWh/ha. Average power requirements per unit of irrigated area were 1.56 kW/ha and the Pumping Energy Efficiency (PEE) was 58.1%. Also, the potential impacts of several energy saving measures proposed by the Spanish Institute for Diversification and Energy Savings (IDAE) are discussed. These energy saving measures include strategies such as sectoring the network, detection of critical points, optimization of pump stations and energy audits.

Keywords: Water supply systems, water management, energy efficiency, Andalucia

INTRODUCTION The modernization processes of irrigation districts have been basically focused on the improvement of the hydraulic infrastructure and the replacement of old open channel distribution networks by new pressurized networks arranged on-demand (Plusquellec, 2009). This improves conveyance efficiency, giving less water losses in distribution, with the new systems arranged on-demand so farmers get a much greater degree of flexibility allowing the use of more efficient systems such as trickle or sprinkler (Rodríguez Díaz *et al.*, 2009). As a consequence, in Spain the National Plan for Irrigated Areas (MAPA, 2001) has considered the modernization of more than 1 Mha up to 2008. Conversely, pressurised networks require large amounts of energy for their operation which is increasingly becoming a limited resource, in some cases even more than water. As a consequence, total water costs have been significantly increased in recent years due bigger energy requirements to supply the water.

With the aim of optimizing the energy demand, the Institute for Diversification and Energy Savings in Spain (IDAE) proposed several measures to optimize energy demand in pressurized networks. These measures include sectoring the networks according to homogeneous energy demand sectors and organize farmers in irrigation turns, the adaptation of the pump station to several scenarios of water demand, detection of critical points within the network and energy audits (IDAE, 2008).

In this work, water and energy use are evaluated in ten typical Andalusian (Southern Spain) irrigation districts. Performance indicators are defined and an analysis of the efficiency in both these resources carried out. Also the energy saving measures proposed by IDAE are simulated for Fuente Palmera irrigation district.

ENERGY USE IN ANDALUSIAN IRRIGATION DISTRICTS Ten irrigated areas were selected: Ntra.Sra de los Dolores, Fuente Palmera, El Villar, Genil-Cabra, M. D. Bembézar, Las Coronas y P. Bancos, Costa Noroeste, Palos and Piedras Guadiana. Their spatial distribution is shown in Figure 1. Collectively, the irrigation districts cover a total irrigated area in excess of 66000 ha and grow a wide variety of crops (Table 1). All of them are arranged on-demand where pressurised water is available to farmers 24 hours per day and use surface water only. In five districts (M.D. Bembézar, Palos, Los Dolores, P. Bancos and Las Coronas) there is one pumping station only while in the others there are re-elevations by means of intermediate reservoirs and booster pumps.

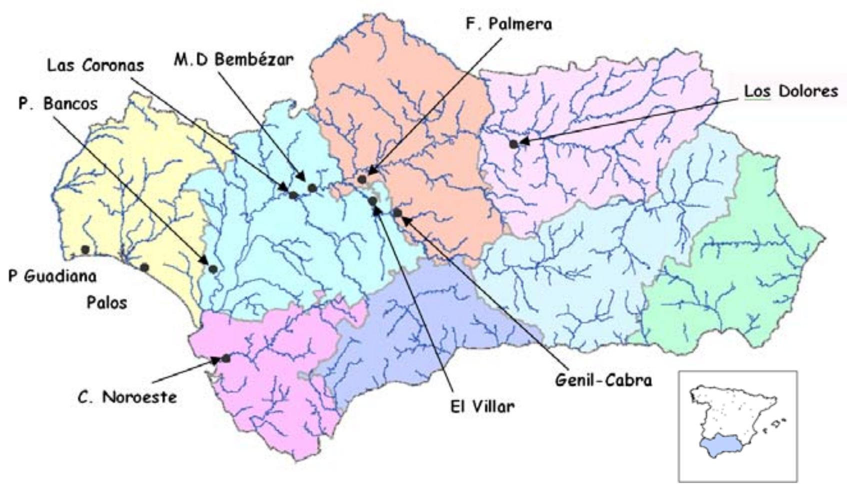

Figure 1. Location of the selected irrigation districts

Table 1. Main characteristics of the selected irrigation districts

Irrigation district	Irrigated area (ha)	Dominant crop types
Fuente Palmera	5611	Cotton, sunflower and wheat
Palos de la Frontera	3343	Strawberry
Las Coronas	450	Citrus and fruit trees
El Villar	2726	Cereals and cotton
Piedras Guadiana	4520	Strawberry and citrus
Los Dolores	4500	Olive trees
C. Noroeste	8383	Horticultural crops and vegetables
P. Bancos	1336	Horticultural crops, watermelon and melon
M.D. Bembézar	11262	Citrus and maize
Genil-Cabra	16100	Cotton, sunflower and wheat

A set of performance indicators useful for measuring the efficiency in water and energy use was developed. For each district, the data required to calculate the indicators were collected for the 2006-07 irrigation season. In this particular irrigation season, rainfall was around 25% below the average and therefore irrigation was particularly necessary.

Some of the obtained results are summarized in Table 2. Water consumption ranges from 1435 m^3/ha in El Villar to 5138 m^3/ha in Las Coronas, with an average of approximately 2600 m^3/ha. RIS informs the relationship between irrigation water applied and theoretical irrigation needs. Values less than 1 indicate deficit irrigation and larger values show over-irrigation in the district. Most of the districts are slightly under 1, implying deficit irrigation and efficient use of irrigation water.

The average energy consumption per irrigated area was approximately 1000 kWh/ha but in the case of the Las Coronas irrigation district it was is almost double that figure. When analyzing energy consumption per cubic meter of water pumped, the average was 0.41 kWh/m^3 but with significant variability among districts (ranging from 0.15 kWh/m^3 in M.D. Bembezar to 0.89 kWh/m^3 in El Villar).

IDAE (2005) reported that an average power of 2 kW per hectare was needed for modernized pressurised irrigation districts. In the districts studied, the average is slightly lower (1.56 kW/ha) but in some of them such as Fuente Palmera or Genil Cabra it is considerably higher

Altough there are significant differences among districts, the average power requirements are 1.56 kW/ha. PEE (Pumping Energy Efficiency) is the relationship between the hydraulic power and electricity, so it takes into account the efficiency of the pump station/s. Although the average PEE is around 60% there are some big contracts among the districts. In five of the ten districts where PEE was calculated, the efficiency was under 60% being in three cases less than 50%. Thus there are possibilities for reducing the energy consumption by means of an improvement in the PEE.

Table 2. Energy and power use in the selected irrigation districts

Irrigation district	Annual irrigation water supply per unit irrigated area (m^3/ha)	RIS	Energy consumption per unit of irrigated area (kWh/ha)	Energy consumption per unit of irrigation water supplied (kWh/m^3)	Power per unit of irrigated area (kW/ha)	PEE (%)
F. Palmera	1782	0.41	1268	0.73	2.24	49.99
Palos	2824	3.70	797	0.25	1.80	48.32
Las Coronas	5138	0.96	1901	0.34	0.98	58.94
El Villar	1435	0.24	1232	0.89	1.10	50.94
Genil-Cabra	1450	0.85	654	0.33	3.48	63.69
M. D Bembezar	3264	0.85	766	0.15	0.88	na*
P. Guadiana	3154	0.78	957	0.33	1.55	na*
P. Bancos	2620	0.46	1387	0.53	1.02	30.89
Los Dolores	1571	0.50	617	0.39	1.67	76.39
C. Noroeste	2653	0.51	455	0.17	0.92	85.74
Average	2589	0.93	1003	0.41	1.56	58.11

* not available

Despite the differences in pressure head, a good correlation (R^2=0.7128) was found between the irrigated areas and total annual energy consumption (Figure 2).

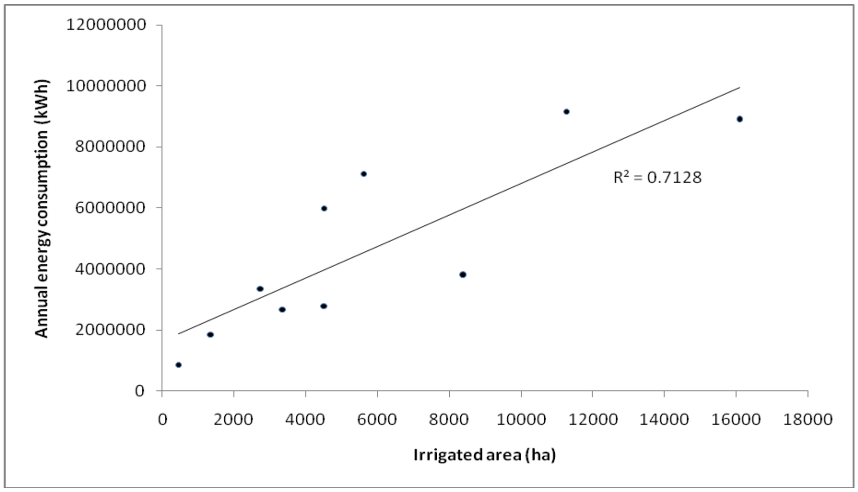

Figure 2. Correlation between irrigated area (ha) and annual energy consumption (kWh)

EVALUATION OF POTENTIAL ENERGY SAVINGS

Study area In the evaluation of potential energy savings measures the Fuente Palmera irrigation district was selected. It has a typical pressurized network that supplies water on-demand to 85 hydrants. Topography is quite steep and the difference of hydrants´ elevation is 79 m.

Methodology for evaluating the energy saving measures In order to simulate the energy saving measures proposed by IDAE (2008) the algorithm OPTIEN was developed and programmed in Visual Basic 6.0. Thus it evaluates the energy requirements in pressurised networks under different management strategies. With this purpose, four scenarios were defined in order to evaluate possible energy savings (Rodríguez Díaz *et al.*, 2009). The first scenario represented the current situation with a fixed pressure head with the three others examined as alternative management strategies. The main characteristics of every scenario are described below:

<u>Scenario 1. Fixed pressure head</u> This represents the current management of the pumping station. The pressure head is fixed to ensure that in the most unfavourable situation, with all the hydrants working, the most pressure supplied to hydrant is a minimum of 30 m. The network is organised on demand so all the hydrants are enabled to irrigate 24 h per day.

<u>Scenario 2. Dynamic pressure head</u> This is similar to Scenario 1 but now the pressure head is not static but changes depending on the hydrants operation to a certain extent. It ensures that only the open hydrants receive the required pressure of 30 m. Thus, when the most pressure demanding hydrants are not consuming water, the pressure at the pumping station could be reduced.

<u>Scenario 3. Network sectoring and fixed pressure head</u> The irrigated area is organised into two independent sectors according to a homogeneous elevation criterion. The first sector consist of hydrants under 131 m height, while in the second, hydrants above that elevation are enabled (Figure 3). In this scenario the network is managed under semi-

arranged demand and each sector can irrigate for only 12 h per day. In order to ensure that every farm receives the same amount of water as in scenarios 1 and 2, but has only half a day to irrigate, the base demand in every hydrant is doubled regarding, so farmers would have to apply higher flows but in a shorter period of time. The pressure head is fixed to ensure that the most pressure demanding hydrants in the sector receives a minimum pressure of 30 m.

Scenario 4. Network Sectoring and dynamic pressure head As in scenario 3, the network is organised in two different sectors (under and over 131 m head) but with a dynamic pressure head at the pumping station which is calculated to ensure that only the operating hydrants get the required pressures as in scenario 2. Base demand is calculated in a similar way to scenario 3 and the working period per sector is set to 12 h.

The peak daily irrigation demand, occurred on August 14th with a daily average pumped flow of 1478 l/s, was used to establish the base demand in all the hydrants accordingly to their supply area. Using a Monte Carlo simulation, OPTIEN generates thousands of patterns of open and closed hydrants in order to analyze several degrees of simultaneity of demand (making the probabilities of open outlet change between 0.3 and 1). In each, the program simulates the network, determining at each instant the flows, pressures at each hydrant, power requirements and energy.

Also a module for detecting the critical points is included. The critical points are those hydrants with especial energy requirements because of their elevation or distance to the pump station.

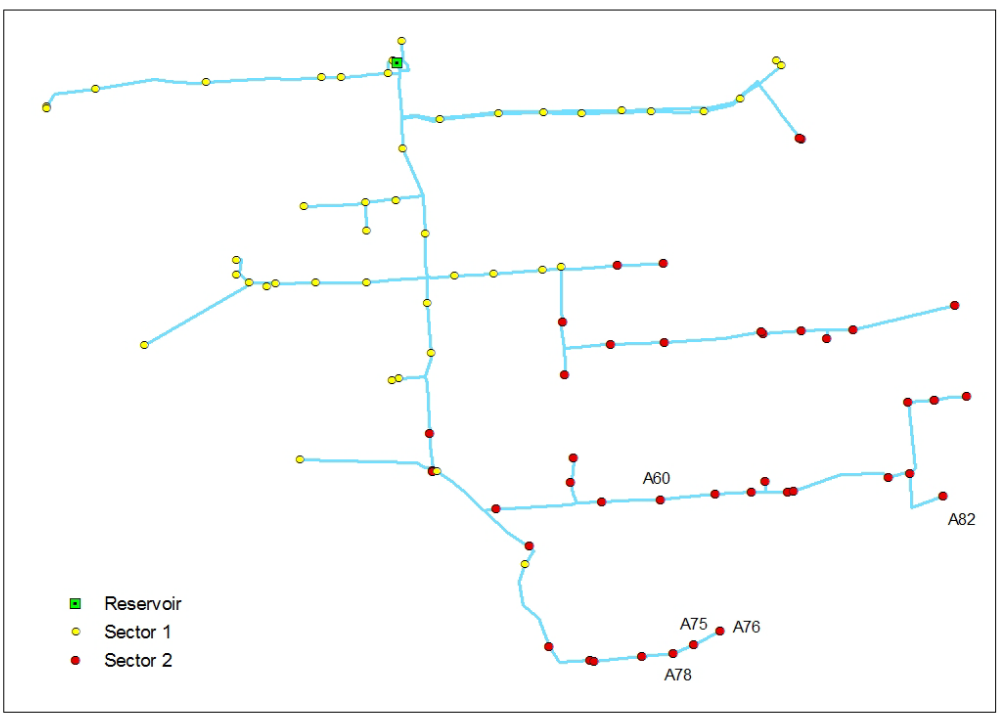

Figure 3. Proposed sectors for scenarios 3 and 4 and five first critical points (A76, A75, A78, A82 and A60)

Energy savings Scenarios 2, 3 and 4 generally reduce the maximum pressures in the network, ensuring that the hydrants get at least the required 30 m. When in scenario 1 (current management) the average pressure in the hydrants is 64.1 m, in the scenario 2 is 61.2 m, while in the scenarios 3 and 4 (sectored) maximum pressures are in the range of 40 and 50 m in both sectors.

In terms of power consumption, scenarios 3 and 4 show significant reductions in peak power when hydrants from sector 1 irrigate (lower elevations). Thus, if in scenario 1 the average power is 1032.8 kW, in scenario 3 is of 1033 kW for the sector 2, but only 633 kW in sector 1.

Thus, is possible to achieve significant savings in energy consumption (Table 3). In fact, scenario 2 would save 8% of energy when the simultaneity of the demand is low. In scenarios 3 and 4, the energy savings range from 20% to 30%. This is because the power requirements are reduced to almost half when water is supplied to sector 1 (hydrants with lower elevations).

Table 3. Energy requirements per day (kW h) and potential energy savings (%)

Probabilities of open hydrant	Scenario 1	Scenario 2		Scenario 3		Scenario 4	
	kW h	kW h	% savings	kW h	% savings	kW h	% savings
0.3	11435.5	10533.0	7.9	9293.0	18.7	8422.4	26.3
0.4	15322.8	14250.6	7.0	12258.2	20.0	11526.8	24.8
0.5	19099.0	18198.5	4.7	15342.7	19.7	14523.0	24.0
0.6	22837.3	22022.6	3.6	18473.2	19.1	17646.6	22.7
0.7	26641.7	26016.7	2.3	21555.0	19.1	20774.9	22.0
0.8	30518.8	30009.8	1.7	24610.4	19.4	23909.6	21.7
0.9	34325.7	33991.9	1.0	27669.9	19.4	27385.2	20.2
1.0	38110.0	38102.2	0.0	30746.8	19.3	30735.6	19.4
Average	24786.4	24140.7	2.6	19993.7	19.3	19365.5	21.9

Critical points Using the algorithm previously described the critical points were detected (their location is shown in Figure 3). Also the effect of each critical point on the energy requirements was analyzed. Figure 4 shows the relationship between water demand and the pressure head that would be needed in the pump station when each of the critical points is working (the first 15 critical points are included). Only 3 of the 85 hydrants of the network are responsible for 10 m high water elevation.

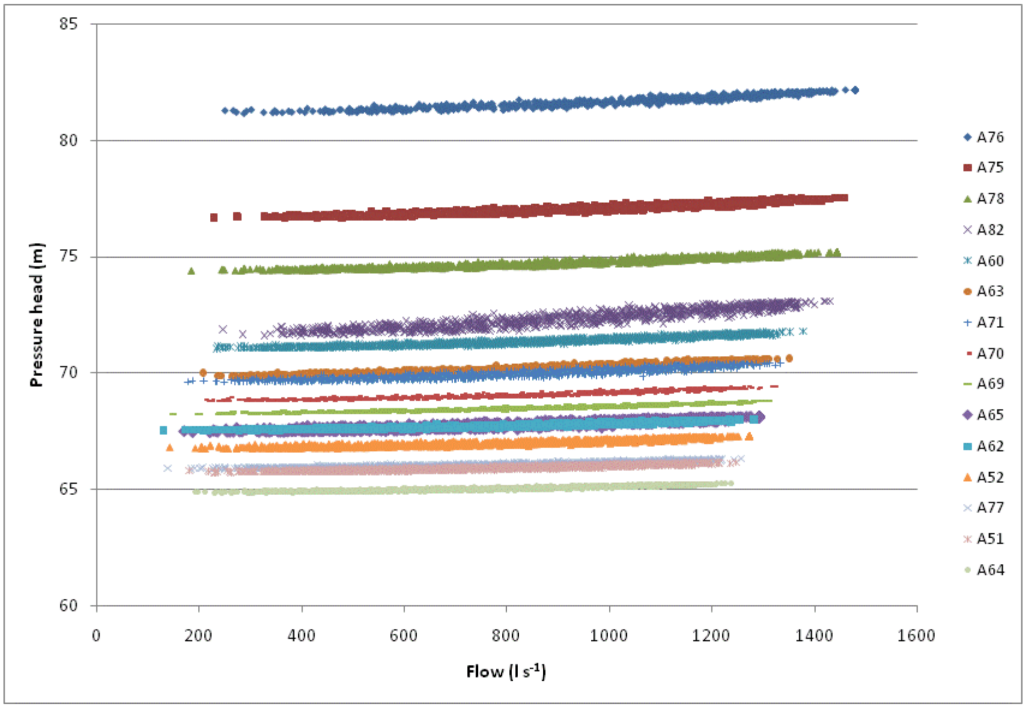

Figure 4. Effect of sequentially removing the critical hydrants on the pressure head requirements at the pump station

CONCLUSION On-demand irrigation represents a step forward in flexibility for water users but it implies a significant expenditure in energy. In this work energy requirements for ten typical Andalusian pressurized irrigation networks have been evaluated. The average annual energy consumption was 1000 kWh per ha while power was 1.6 kW/ha.

This work shows that significant energy savings can be achieved adopting alternative management measures such as semi-arranged demand. It could be that we should lose one degree of flexibility in order to improve the overall sustainability of irrigated agriculture. Further energy savings could be achieved by sectoring the network in several sectors or by improving the pumping station and other energy infrastructure.

Results have highlighted the importance of the location of critical points in pressurised irrigation networks. Sometimes just a few points are responsible for large fractions of the total pressure head at the pumping station.

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