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EFFECTS OF REUSING IRRIGATION RETURN FLOWS

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ABSTRACT – Irrigation is supplied primary by sources of fresh water. However, irrigating with water that has been previously used for irrigation is very common. This paper presents some basic theoretical concepts for understanding the effects of multiple reuses of irrigation water on the global irrigation consumptive use coefficient (ICUC), water pollution and crop yield. Reusing agricultural water implies an increase of the ICUC but entails the degradation of water quality. Understanding the effects of the complex hydraulic connections in water reuse on the global ICUC, on the spatially distributed agricultural production and on the pollution of surface and ground waters is imperative for optimising the exploitation of irrigation return flows. Two case studies are presented. One in Northern California, where the connection between the drainage and irrigation networks allows partial internal reuse of the water. The second applies to an irrigation sector within a larger scheme in Southern Spain.

Key words: water reuse, water quality, irrigation consumptive use coefficient

INTRODUCTION

Practically all the irrigation schemes around the world produce return flows in variable quantity that are reused downstream, but few of them reuse internally these return flows. Nevertheless, some irrigation schemes have developed simple systems that allow internal reuse of at least part of the return flows that they generate.

The reuse of return flows at the basin scale is more common, although often unregulated. Fig. 1 represents a simplified hydrological sketch of the Guadalquivir basin in Southern Spain. There are reservoirs for the regulation of the whole basin and reservoirs for serving individual irrigation schemes. At certain point, the river splits into the main natural channel and a large canal 180-km long, the Lower Guadalquivir Canal. Since the surface and part of the sub-surface drainage of all the irrigation schemes return to the river, the irrigations schemes served by the Lower Guadalquivir Canal are partially supplied by return flows of the upstream schemes. A consequence of this layout is that irrigation efficiency is less important in the schemes located upstream the canal diversion than is in the scheme near the mouth of the river.

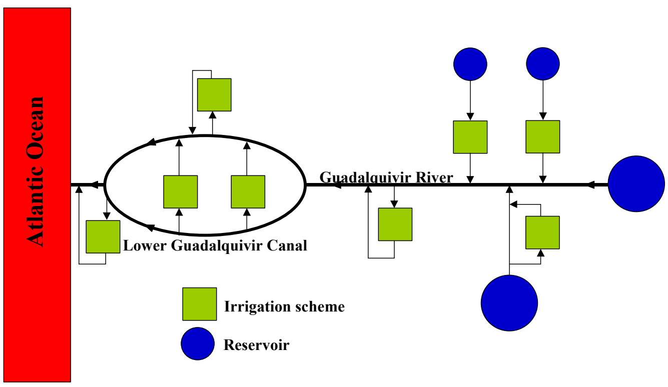

Figure 1. Simplified hydrological SciTech of the Guadalquivir basin, Southern Spain

EFFECTS OF WATER REUSE

The hydraulic arrangement of the irrigation units in a complex system can be examined by thinking on simple arrangements. The water delivered to an irrigation unit (field, farm or command area) may come from a canal common to several units or it may be return flow from upstream units. When all the irrigation units receive the water directly from a common canal, those units are said to be in parallel (Fig. 2a). When an irrigation unit supplies all the water required by another unit located downstream, this downstream unit is said to be in series with the former (Fig. 2b). Irrigation units may be partially in series and partially in parallel (Fig. 2c) (Mateos *et al*., 2000).

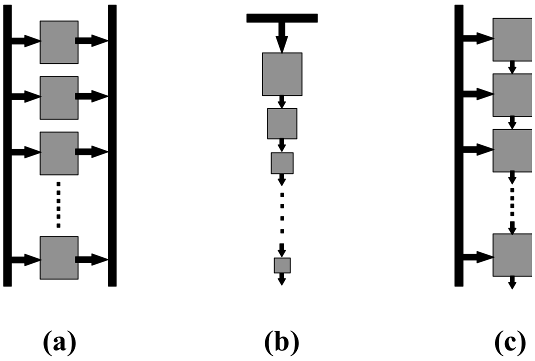

Figure 2. Spatial arrangements of irrigation units in an irrigation scheme: a) parallel, b) series, and c) mixed series and parallel (Mateos *et al*., 2000)

The spatial arrangement of irrigation units in an irrigation scheme may affect district irrigation performance and water quality. The Irrigation Consumptive Use Coefficient (ICUC, defined as the fraction of applied water that is evapotranspirated by the crops) of the whole system will be equal to the ICUC of the units if they are in parallel (the number of reuses is zero). The ICUC will increase with the number of reuses (it will approach one) if the irrigation units are in series, and it will also increase with the number of units if they are partially in series and partially in parallel, but at a rate smaller than in the perfect series system (Fig. 3). An improvement of the units ICUC will be translated into the same improvement for the whole system if the irrigation units are in parallel. However, if they are in series or partially in series, the global ICUC increase due to changing irrigation unit ICUC will be smaller as the number of units is increased (Mateos *et al*., 2000).

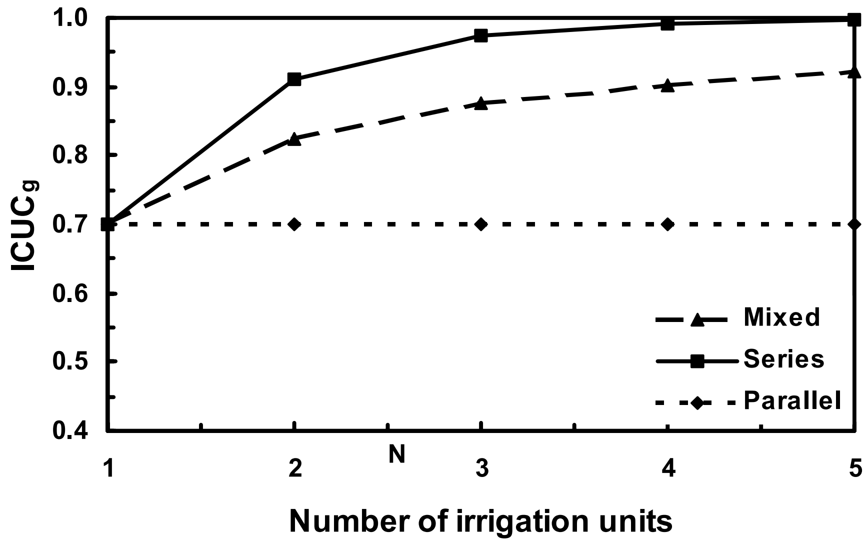

Figure 3. $ICUC_g$ (global Irrigation Consumptive Use Coefficient) variation as a function of the number of irrigation units and their arrangement for cases a, b and c in Fig. 2

On the other hand, for irrigation units arranged in parallel the irrigation water quality is equal to the canal water quality. If those units are perfectly in series, the quality of the irrigation water will be degraded for the downstream irrigation unit. The water quality degradation will be less severe if the irrigation units are arranged partially in series and partially in parallel. For quantifying the degradation of the quality of the water, we developed a simple salt balance model that assumes that the solutes moving through the soil-plant system originate from the irrigation water and the fertiliser. Part of the applied water percolates below the root zone carrying concentrated solutes. The amount of percolation and the concentration of solutes depend on the leaching fraction, i.e., the fraction of irrigation water that percolates. Part of the fertiliser that is applied to the field is taken up by the crop and the rest will be leached out, the partitioning being controlled by the fertiliser recovery fraction. As a result of this model, Fig. 4 shows an example of degradation of water quality for the series, parallel and mixed hydraulic arrangements. While the degradation of the quality of the water is small in the mixed arrangement, the concentration of salts in the water increases notably with the number of reuses in the series arrangement.

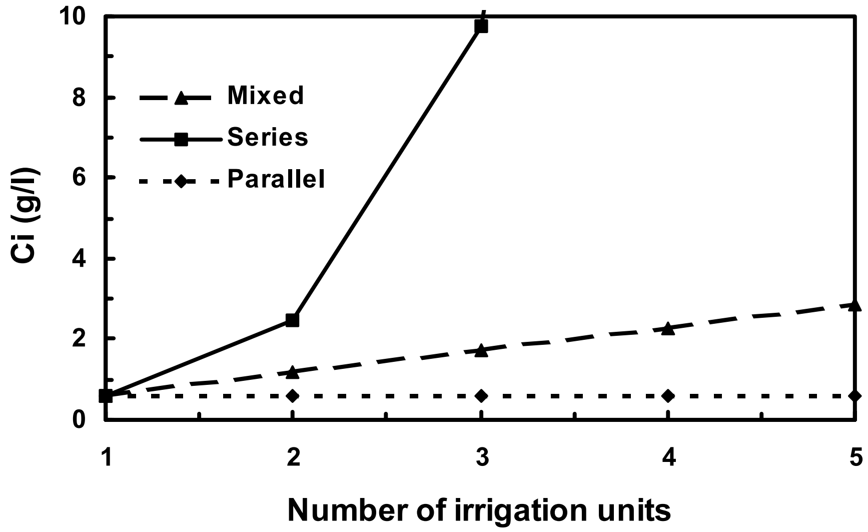

Figure 4. Irrigation unit irrigation water salinity as a function of the arrangement and number of command area for cases a, b and c in Fig. 2

The effect on crop yield of the degradation of the quality of the irrigation water can be examined using a simple, widely accepted model that relates yield to soil salinity (Maas and Hoffman, 1977). This model assumes that yield is not affected until a soil salinity threshold is surpassed. Beyond this threshold, yield decreases linearly with the soil salinity. The relative yield – soil salinity plan can therefore be divided into regions according to the sensitivity of the crops to the soil salinity. For the example that follows we assumed a moderately sensitive crop. Coupling the yield response model with the water and salt balances, we simulated the relative yield for irrigation units arranged in series, parallel and both mixed (Fig. 5). Yield was not affected in the parallel system. In the series arrangement yield decreased with one reuse and it dropped to zero after two reuses. In the case of mixed arrangement, yield was also reduced, but much less than in the series case.

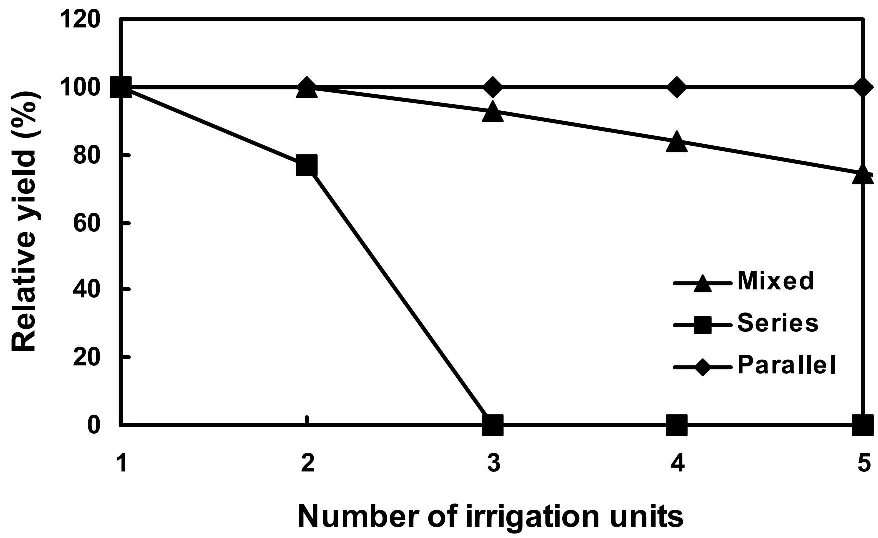

Figure 5. Irrigation unit relative yield as a function of the arrangement and number of irrigation units area for cases a, b and c in Fig. 2

STUDY CASE 1. TULELAKE IRRIGATION DISTRICT, CALIFORNIA

In complex irrigation districts such as the example case in Mateos *et al*. (2000), irrigation units appear in a combination of arrangements. Therefore, the impact of reusing return flows on the global ICUC and on water quality is more complex than cases a, b, and c in Fig. 2. However, knowing the topological relationships between irrigation units, variables such as ICUC and salinity may be estimated using measured data and mass balance models. The analysis of the water circulation in the scheme resulted in global ICUC equal to 0.91, while the average ICUC of the individual irrigation units was 0.63. The water quality was poorer in the central, also lower, part of the scheme, where the soil is richer in organic matter and the irrigation water is a mix of canal and drainage water (Mateos *et al*., 2000).

STUDY CASE 2. GUADALMELLATO IRRIGATION SCHEME, SPAIN

The second study case refers to the Guadalmellato irrigation scheme. This scheme is located in the middle Guadalquivir valley, in Southern Spain. The scheme covers about 6500 ha and started operation in 1931. The analysis we present herein is restricted to a sector of the scheme that occupies 1740 ha planted to maize, winter cereals, sunflower and cotton. This sector lies between the main canal supplying the irrigation water and the Guadalquivir River, that collects the return flows of the sector.

The irrigation water is distributed through an open canal system in need of rehabilitation. In fact, the scheme water users association is planning a major upgrading project. One of the alternatives under consideration is the conversion of the open canal system into a pressurised pipe system, and from the rotation to on-demand delivery. The alternative that we explored in this analysis was a low investment alternative that also aims to increase irrigation flexibility, reliability and efficiency but based on the reuse of the return flows generated within the sector. For that purpose we grouped the fields in six areas, each served by one canal or set of canals. The sector was also divided into drainage areas. The resulting hydraulic sketch is presented in Fig. 6a. Then two reservoirs for collecting and delivering drainage water were added to the sketch (Fig. 6b), thus irrigation groups 5 and 6 could reuse a greater part of the return flows generated upstream of them, and the effect of the reservoirs was analysed using a model similar to the one described above. The model assumed that the crop water requirements and some distribution rules, always fulfilling the water balance with its capacity constraints, drove water circulation. The salt circulation was governed by the salt content of the irrigation water and by a load – flow function that increased at a decreasing rate until reaching a constant slope given by the solute concentration of the irrigation water.

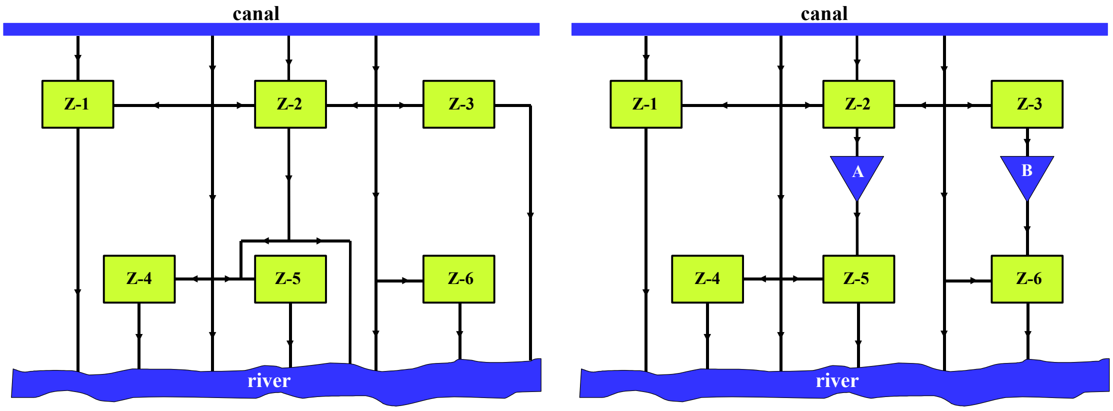

Figure 6. Hydraulic sketch of the sector analysed in the Guadalmellato irrigation scheme: left, current situation, and, right, assuming reservoirs are constructed

Fig. 7 shows that the ICUC of the sector could be increased from the current 0.48 to 0.68, a notable increase, which compares with the ICUC equal to 0.9 that can be achieved if the system was transformed into a pressurised pipe network working on-demand.

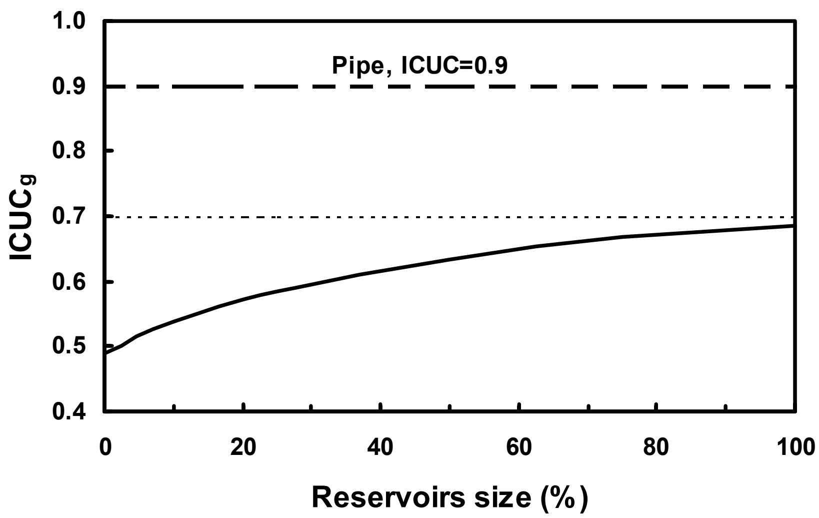

Figure 7. ICUC of the sector analysed in the Guadalmellato irrigation scheme as a function of the relative size of the simulated reservoirs. The upper bound at $ICUC_g$=0.9 corresponds to a pressurised pipe system

However, as it was pointed out before, the increase in ICUC had a cost in terms of water quality. Obviously, for the groups connected solely to the irrigation canal, the water supply would have the quality of canal water, and this would also apply to the pressurised pipe network. By contrast, the groups of plots supplied with reused water (Z5 and Z6) received water of lower quality, as shown by the curves depicted in Fig. 8 that indicate that the quality of the water would depend on the mix.

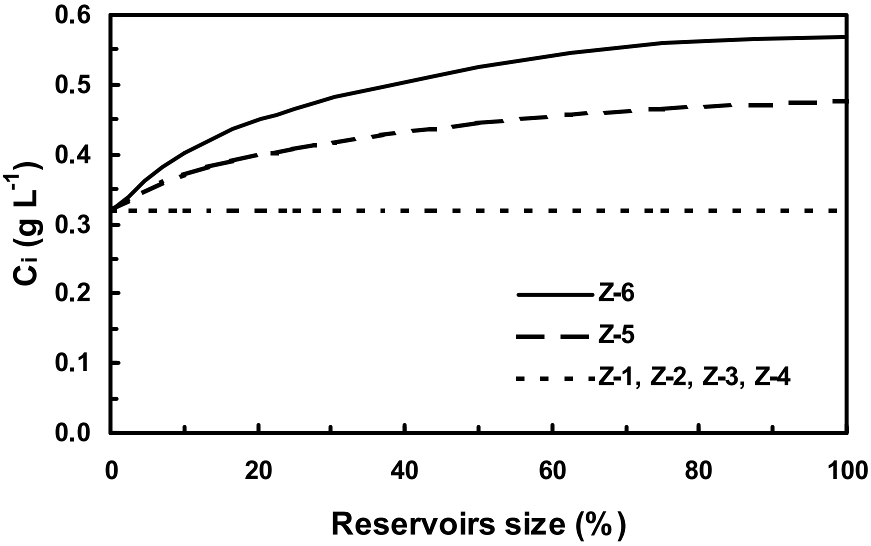

Figure 8. Concentration of salts in the irrigation water of the 6 irrigation groups of the sector analysed in the Guadalmellato irrigation scheme as a function of the relative size of the reservoirs

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