A tool for irrigation water management under drought conditions

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SUMMARY – In the last decade irrigation districts in Spain have started to use database software applications to improve their management operations. Such applications often put more emphasis on administrative issues than on water management issues. An irrigation district management software called "Ador" is presented in this paper. This database software application has been designed to promote water traceability and water allocation under conditions of scarcity. Ador can be used in irrigation districts independently of the type of irrigation system (surface, sprinkler or trickle) and the type of irrigation distribution network (open channel or pressurised). It can even be used in irrigation districts combining different types of irrigation systems and different types of irrigation distribution networks. The goals are to manage detailed information about district water management and to promote better on-farm irrigation practices. Ador is used primarily in the Aragon region of Spain. Some 70 irrigation districts, adding up to about 175,000 ha of irrigated land use Ador daily to manage water. The software has specific utilities for water allocation under drought conditions, which are applied by district managers to overcome difficult situations.

Key words: Irrigation, district, management, database, drought.

RESUME – *"Un instrument pour la gestion de l'eau d'irrigation en conditions de sécheresse". Pendant la dernière décennie les associations des irrigants de l'Espagne ont commencé à utiliser des logiciels spécialisés pour leurs opérations de gestion. Ces logiciels son souvent davantage focalisés sur la gestion administrative que sur la gestion de l'eau. Un logiciel de gestion de l'eau appelé Ador est présenté dans ce document. Ce logiciel a été conçu pour améliorer la traçabilité et l'allocation de l'eau en conditions de sécheresse. Ador peut être utilisé dans les associations d'irrigants avec différents systèmes d'irrigation (gravitaire, aspersion, goutte à goutte) et avec différents systèmes de distribution de l'eau (canaux et pressurisé). On peut même gérer des associations qui combinent différents types de systèmes d'irrigation et de distribution. Les objectifs de Ador sont enregistrer information détaillée sur la gestion locale de l'eau et promouvoir l'amélioration de l'efficience de l'irrigation. Ador est surtout utilisé dans la región de l'Aragon en Espagne. Environ 70 associations, avec 175 000 hectares irrigués utilisent Ador chaque jour pour gérer leurs ressources en eau. Le logiciel possède des outils spécifiques pour l'allocation de l'eau en conditions de sécheresse. Ces outils sont utilisés par les dirigeants de l'association quand les conditions deviennent difficiles.*

Mots-clés : *Irrigation, périmètre, gestion, base de données, sécheresse.*

Introduction

Improvements in irrigation equipment must be combined with improvements in agricultural water management to achieve excellence in the use of water resources. Recently, Burt and Styles (1999) and Vidal *et al*. (2001) highlighted the role of water management in the achievement of irrigation sustainability and functionality. Consequently, the improvement of district management standards is an investment in the future of irrigated agriculture. Water demand management can be an important tool to address the problems of water scarcity in semiarid irrigated areas.

One challenge for irrigation districts is to introduce the use of computers to manage water. In many areas of the world, the costs of water distribution are still charged to farmers per unit of irrigated area. However, society is increasingly demanding better water use policies, including billing water costs proportionally to the volume of water used. In some areas, penalty systems are used in conjunction with proportional billing to discourage the excessive use of irrigation water and to live with water scarcity. These management strategies can benefit from using computers and specialised databases. The Ebro Valley constitutes one of the most important irrigated watersheds of the Iberian Peninsula. Located in the northeast of Spain, its irrigated area exceeds 800,000 ha. Local irrigation districts are characterized by large variability in irrigation technology and management practices. This variability results from the long history of irrigation development in the region.

In this work, a database for the management of irrigation districts in the Ebro Valley – the "Ador" software – is presented. The Ador software has been designed and developed since 1998 with the objective of supporting irrigation districts efforts to improve water management in the study area. More detail on Ador development and dissemination can be found in Playán *et al*. (2007). The application of Ador to manage drought situations in irrigation districts is presented.

Water management and water use in the Ebro Valley

A number of studies have been performed on irrigation water management in the Ebro Valley. In the Almudévar irrigation district, Faci *et al*. (2000) documented problems in water allocation resulting in excessive water use. This problem was particularly relevant in the case of small plots: the smallest plots (accounting for 5% of the district area) used three times more water than the average plot. In other cases, such as in the Loma de Quinto irrigation district (Dechmi *et al.,* 2003), deficit irrigation is performed due to the high energy costs. In this particular district, the water allocation system did not permit to trace water allocation, since the district software did not permit to allocate water to more than one plot at the time.

Despite all these difficulties in water allocation and management at the district level, there are solid grounds to conserve irrigation water in the Ebro Valley. Lecina *et al*. (2005) evaluated global irrigation efficiency at the irrigation district V of the Bardenas irrigation project during the years 2000 and 2001. While 2000 was an average year in terms of water availability and crop water requirements, 2001 was a dry year. In 2001, farmers were advised by the district managers of the water limitations they would face. Limitations were eased during the summer, and farmers did not perceive yield losses. However, the estimated global irrigation efficiency (crop water requirements *vs* irrigation water allocation) jumped from 49% in 2000 to 66% in 2001. This increase was related to a reduction in the irrigation time (which in 2000 was much longer than required). These data highlight the grounds for water conservation via irrigation management in the Ebro basin.

Quality in irrigation district management

Several authors have noted the importance of improving the service quality of irrigation districts. Clemmens and Freeman (1987) reported that irrigation districts influence the performance of an irrigation project, noting the relevance of bidirectional information flow between the district and its farmers. Dedrick *et al*. (1989) proposed the concept of the Management Improvement Program as a procedure to develop managerial skills and enforce water conservation policies in irrigation districts. Limited research efforts have been devoted in the past to the improvement of irrigation district databases. Merkley (1999) developed "Waters", a software designed to support the accounting and water delivery activities of irrigation districts. This software is intended to be a basic tool for irrigation districts operating canals and processing water orders from farmers. Sagardoy *et al*. (1999) and Mateos *et al*. (2002) presented "SIMIS", a scheme irrigation management information system. This software is in the category of decision support systems, although it includes utilities for water allocation and administrative management. Recently, Lozano and Mateos (2008) used SIMIS to analyse the usefulness and limitations of decision support systems for improving irrigation scheme management. These research efforts represent contributions to irrigation district management, but none of them is adapted to the management of the wide variety of irrigation districts present in the study area. A new development was required.

Description of the specialized database Ador

Ador has three primary components: (i) a comprehensive database structure; (ii) a diagram of the water distribution network; and (iii) a GIS module. Technically, Ador is a Microsoft Access^{TM}

application composed of 118 interconnected tables. The GIS module is implemented using the MapObjects LT^{TM} software by ESRI. Ador is being developed in the Spanish language. The current version of the software (v. 1.2.9), along with the users' manual can be freely downloaded from http://www.eead.csic.es/ador.

A water user is a person or company playing a role in the irrigation district. This role may be related to any water use category, such as: agricultural, animal farming, industrial, and urban. A water user can be a landowner, a grower or an enterprise. Water users perform their activities in district plots. The territory of Spain has been divided by the Government into cadastral plots. Each plot is identified by a unique alphanumeric code. Farms often are divided into several cadastral plots. Cadastral information is used to identify plots in Ador, because this information has legal strength and is regularly updated by Government offices. Use of cadastral information in an irrigation district is not a perfect solution to the identification of land tenure, but might be the best option available in Spain. One of the problems related to the use of cadastral information is that farmers often distribute their crops disregarding cadastral information. Finally, a cadastral plot can be the physical basis of several water uses of different categories (e.g. two crops, one animal farm, an alfalfa processing factory and the farmers' residence). The district database needs to accommodate all these features.

The irrigation distribution and drainage networks are addressed using a diagram the district manager can modify and extend. This diagram is not in scale, and is intended to represent the functionality of the irrigation and drainage networks. Primary network elements include canals, pipes, reservoirs, pumping stations and water meters. Longitudinal primary elements (pipelines and open channels) can contain secondary elements (hydrants, checks, siphons, valves, air release devices and manometers). Figure 1 presents part of the diagram of an irrigation district using both open channel and pressurized elements. The primary elements are grouped in management units (areas sharing management traits). One of the characteristics of management units is the water delivery time step. In the Ebro Valley many State-developed irrigation projects were designed to deliver water to the farmers for durations multiple of 24 hours. Other districts operate with a delivery time step of an hour. Finally, districts operating on demand using water meters are not subject to delivery time step restrictions. Management units have a maximum conveyance capacity, which sets a limit on the discharge that can be serviced at the same time within an irrigated area. The last characteristic of a management unit is the type of water delivered to the water users: two management units can be used in a district to separate areas with different water prices, perhaps resulting from different energy requirements.

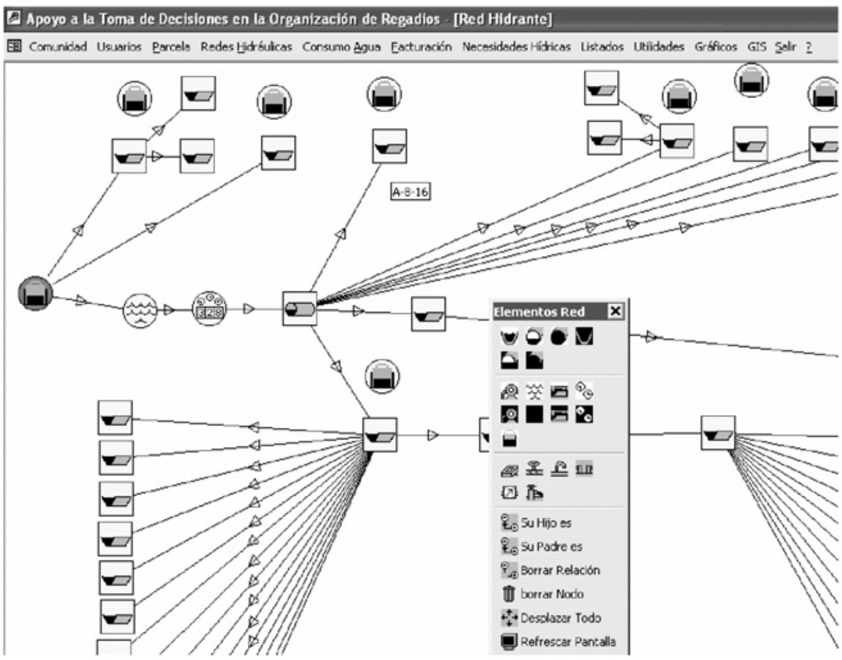

Fig. 1. The diagram of the primary elements of an irrigation network. Water flows from the icon representing the water source diversion to a branching canal network. The figure also presents the toolbox used to build and manage the diagram.

Several water uses are possible in a given plot. When a plot is created in Ador, one agricultural water use is automatically created for all of the irrigated area of the plot. Additional agricultural water uses can be created subsequently. The sum of the area of all agricultural uses must be equal to the irrigated area of the plot. Each water use is related to two users: (i) the user paying for water; and (ii) the user paying the fixed costs (by default this second user is the plot owner). For each agricultural water use the database can store the crop grown and a detailed description of the on-farm irrigation system. Figure 2 describes the linking of primary elements, hydrants, cadastral plots and water uses.

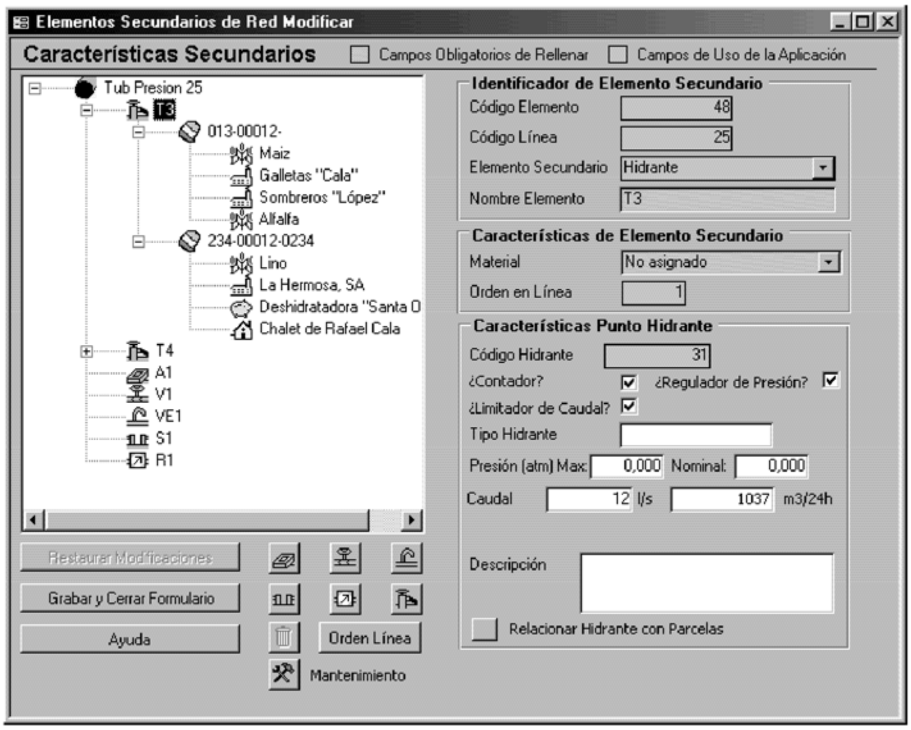

Fig. 2. Example of the detail offered by the diagram about a primary element of the irrigation water distribution network.

Water distribution can be performed in an irrigation district following a number of different delivery schedules (Clemmens, 1987; Clemmens and Freeman, 1987). Ador has been designed to accommodate the delivery schedules typical in the Ebro basin: (i) on demand irrigation with volumetric water meters; (ii) arranged irrigation based on prepaid water; (iii) arranged irrigation based on previous water orders; and (iv) rotation irrigation.

Water prices are described in Ador using a two-dimensional matrix including the type of water and the category of water use. Different water types can be established in a district to reflect differences in water quality, origin or energy input. Each management unit delivers a particular type of water. In the Ador software fixed and variable costs are considered separately during the billing process. The increasing complexity in irrigation districts and escalating water costs require flexibility when assigning costs, so that fixed costs can be billed – for instance – to the users of a particular canal that has undergone rehabilitation work.

Many district managers consider the water bill as the main goal and the end of their activity. In our opinion, the bill is the starting point to promote the improvement of irrigation water management. This is possible if the bill provides information about how water is used by the farmer and by other farmers in the district. The Ador water bill informs the farmer of his individual water use, but also includes statistics about water consumption in the district. The contrast between water use in a certain plot, crop water requirements – computed by Ador according to Allen *et al*. (1998) –, and the average water use in the district by crop, irrigation system, and soil type helps the farmer to evaluate his level of irrigation water management.

Several reports and charts have been built in Ador to provide information on the status of the district. To customize the information, the forms for reports and charts include a wide range of options, enabling the filtering of information to particular items like users, plots, primary network elements, or dates. Additionally, the information displayed in Ador charts can be grouped by management units, primary network elements, or crops.

Geographic Information System (GIS) coverages of the cadastral plots and irrigation network can be used to display the database cartographically. GIS coverages of cadastral plots are available in many irrigated areas of the Ebro Valley. However, districts must adapt the coverages by selecting plots belonging to the district and producing a water conveyance coverage. The maintenance of the GIS information cannot be performed from Ador, because the module does not include coverage editing utilities. Figure 3 presents the GIS interface of Ador.

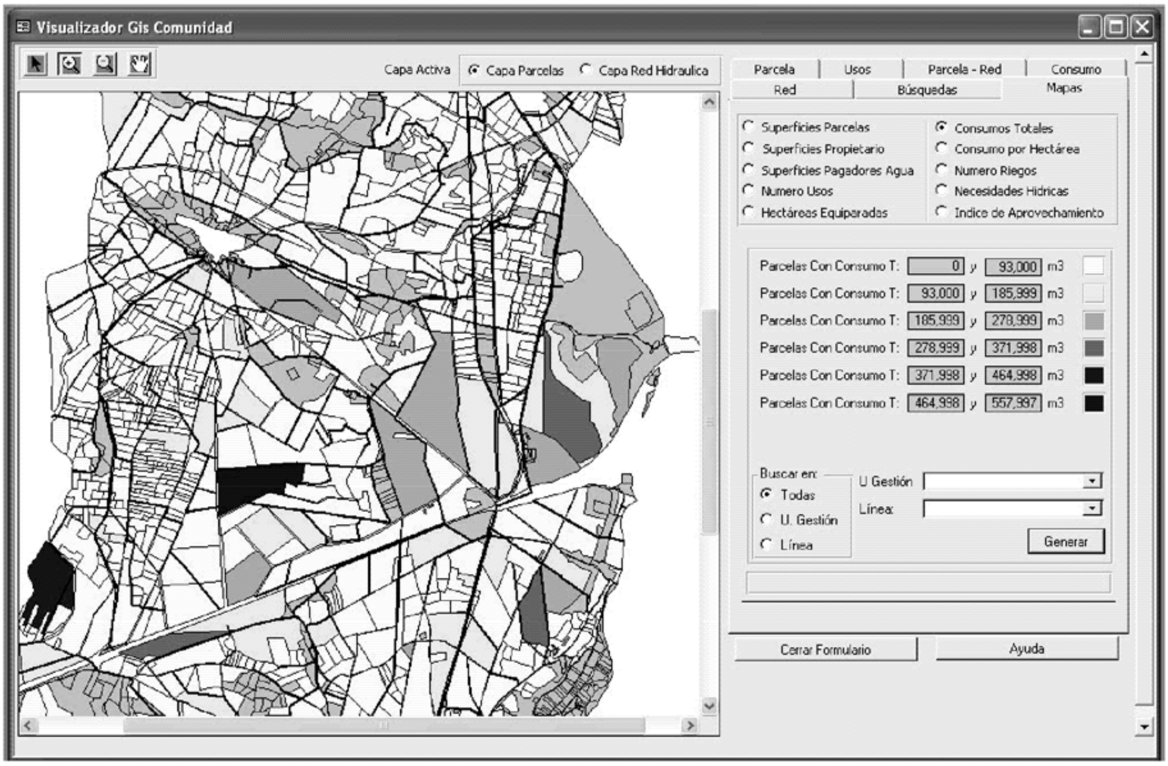

Fig. 3. GIS interface to Ador, showing a graduated colour map of water use per cadastral plot. Other options permit to display land ownership, types of water uses or the hierarchy of the conveyance network.

Dissemination of the specialized database

Ador is being used in some 70 districts accounting for more than 175,000 ha. These districts cover a wide range of irrigation technologies and water delivery schedules. Software dissemination started in the "Comunidad General de Riegos del Alto Aragón" Project (CGRAA), which includes 53 irrigation districts and 124,000 ha in the provinces of Huesca and Zaragoza. CGRAA also supplies urban water to more than 100,000 persons, and to several industrial factories and animal farms. In 2001, CGRAA decided to make Ador the standard software for managing their irrigation districts.

The objectives of the Ador-CGRAA project were to: (i) implement Ador progressively in the CGRAA irrigation districts; and (ii) develop a specific data centralization unit at the main CGRAA office. Achieving these objectives required contracting the services of companies specialising in Ador application and development. By the end of 2001 the *Oficina del Regante* (OdR, the irrigation extension office of the Government of Aragón) started its operations, and took part in the activities of Ador in CGRAA. Since its onset, the project has been managed by a multidisciplinary steering board.

This type of steering board was identified by Dedrick *et al.* (1989) as being critical to the success of management improvement in irrigation districts. The discussions held in the steering board and the bi-directional communication with district managers have made Ador a widely participative programming effort. Virtually all CGRAA irrigation districts currently use Ador. Since 2002, the OdR has been performing several tasks related to Ador. In addition to hosting most of the Ador software development and supporting the activities at CGRAA, the OdR has implemented Ador in more than twenty additional irrigation districts in the Aragón region of the Ebro Valley.

Establishment of water restrictions in the CGRAA project using Ador

Measures can be adopted in Ador to manage scarce water during drought periods. The software incorporates a tool to establish water demand limitations fixed at a certain allocation threshold expressed in units of m^3/ha. A report is produced listing agricultural water users and their current level of water use. The report is ordered by water use, separating the users exceeding the allocation threshold, those who are close to the threshold and finally those who have used a limited amount of water. The report is then used to guide further water allocation in the district. Figure 4 presents the dialog box used to establish water demand limitations.

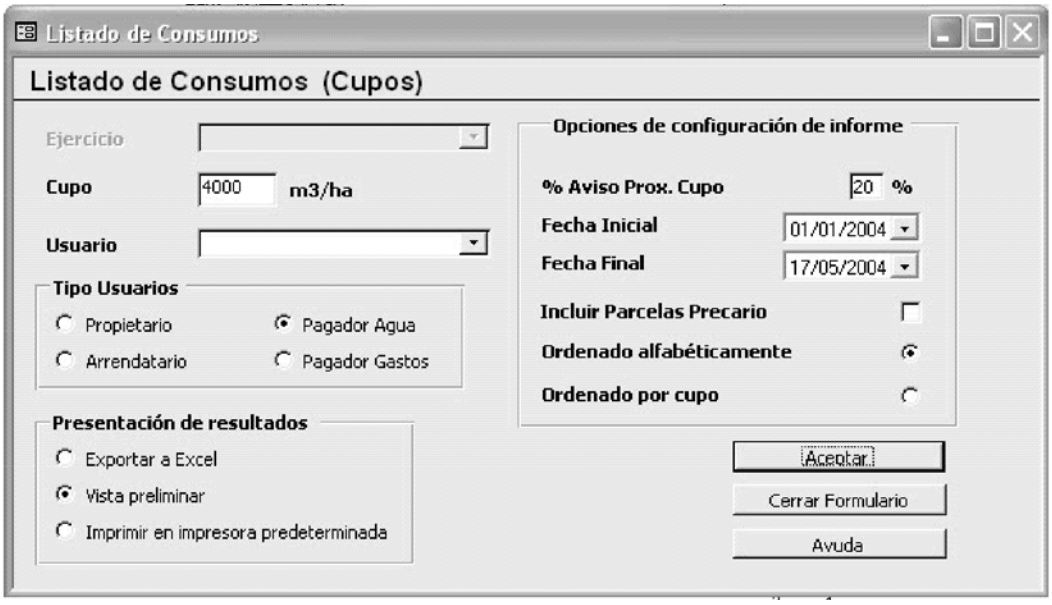

Fig. 4. Dialogue box for the establishment of a limitation of 4 000 m^3/ha. A report is produced indicating the users who have reached the limitation, the users within 20% of the limitation and the rest of the users.

In the recent years drought has been a common trait in the Ebro valley, and it has severely affected CGRAA (among other irrigation projects). CGRAA farmers have seen water allocation restricted in a number of years. If restrictions were an exceptional situation just a few years ago, nowadays the question farmers pose is no longer if a restriction will be imposed, but rather, what will the restriction be? Due to strong restrictions in some years farmers have had to concentrate the available water on part of their farming land. In other years, prospects have been quite hard at the beginning of the season, but periods of precipitation have permitted to ease restrictions along the season. In this surface water project, restrictions are very variable in time.

The CGRAA project decides the seasonal volume of water allocation in their steering board meetings. Every time a modification in water allocation is agreed upon, irrigation districts need to adapt to the new situation. In practice this means obtaining a new report using the dialog box in Fig. 4. This new report is communicated to farmers, who can then modify their cropping and irrigation plans accordingly.

A number of farmers' strategies have been identified in these difficult years. Some farmers have decided to plant all their land to barley, an early harvesting, low water use and drought resistant crop. In the worst case scenario, barley can be harvested in June and that puts an end to the season. If the situation improves during spring, a second crop of corn or sunflower can be established. This double cropping scheme is greatly favoured by sprinkler irrigation and by direct sowing machines. These technologies are required to quickly plant the second crop and therefore take advantage of the warm, sunny July days. Other farmers grow alfalfa with the intention of applying irrigation depths lower than required. Alfalfa shows a linear relationship between irrigation and yield. Being a pluriannual crop, alfalfa has the additional advantage that it survives severe droughts.

The differences in irrigation technology have resulted in very different solutions to drought. Surface irrigation farmers using border or basin irrigation in CGRAA often need between 1 000 and 3 000 m^3/ha to complete the first irrigation of the season. In a water-limited situation, this water is comparable to the seasonal allocation. As a consequence, these surface irrigation farmers usually plant barley or wheat if drought can be anticipated at sowing time. Sprinkler irrigation farmers are free to decide the irrigation depth they want to apply in each irrigation, and can adapt better to drought situations and to changes in meteorology. This flexibility in water application is very important to protect farm income in drought years.

Conclusions

(i) The key to the success of the Ador software is its participative nature. If it had not been for the close cooperation with the irrigation districts, administration and private companies, the software would have been just another research product without practical application. The *Oficina del Regante* has been particularly important to the implementation of Ador. It has developed the trust required to advise districts and to maintain mutually beneficial communication.

(ii) Ador has resulted in better water management in the irrigation districts. Water is now more traceable, and farmers receive bills indicating every water diversion to their fields. The bills establish local water benchmarks (average water use) that farmers can use to evaluate their water use. In water scarce years, the establishment of water demand limitations has helped to avoid conflicts and to guarantee equity in the access to water.

(iii) In the years of Ador application district managers have developed skills that have improved their water management, and have given them more recognition among the farmers and the water administration. As a consequence, a group of motivated, skill water managers have emerged and are becoming relevant in local water discussions.

(iv) These water managers have had to endure difficult years lately. Drought has been common in the first years of the 21st Century and managers often have used the water restriction tool in Ador. This tool classifies water users according to their past access to water and compares their past water use (m^3/ha) to the current restriction imposed by the irrigation district. This classification of users permits to determine who has completed access to water for this season, who is close to complete and who can still plan for further irrigation before reaching the restriction threshold. Despite the difficulties created by drought, the transparency promoted by Ador has permitted to complete the past irrigation seasons in a peaceful, cooperative environment.

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software and the users' manual can be downloaded at no charge at the following web site: http://www.eead.csic.es/ador.

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