A Database Program for Enhancing Irrigation District Management in the Ebro Valley (Spain)

by

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Abstract

In the last decade irrigation districts in the Ebro Valley of Spain have started to use database applications to enhance their management operations. Such applications often put more emphasis on administrative issues than on water management issues. A new irrigation district management software called "Ador" is presented in this paper. This database application has been designed to overcome limitations identified in an analysis of the software used in the study area. 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 software can be used with minimum district information. The goals are to manage detailed information about district water management and to promote better on-farm irrigation practices. Ador is currently used to enhance management of 62 irrigation districts accounting for some 173,000 hectares in the Ebro Valley.

Key Words: water use, water allocation, software, geographic information system

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.

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 of the world, penalty systems are used in conjunction with proportional billing to discourage the excessive use of irrigation water. These management strategies can benefit from using computers and specialised databases.

The Ebro Valley is one of the most important 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. Previous research on irrigation districts of the Ebro Valley identified design limitations in their software applications, resulting in billing errors and limited water traceability (Faci et al., 2000; Dechmi et al., 2003; Lecina et al, 2005).

In this work, a generic database for the management of irrigation districts in the Ebro Valley - the "Ador" software - is presented. Ador is a Spanish word derived from Arabic meaning "turn". This word is still used in rural Spain to denote the irrigation turn in open channel distribution systems. The Ador software has been designed and programmed since 1998 with the objective of supporting irrigation district efforts to increase water management standards in the study area.

Analysis of the databases used in three irrigation districts of the Ebro Valley, Spain

Most irrigation districts in the Ebro Valley of Spain use computer databases in their daily operations. In the last decade, we have conducted research in irrigation districts of the Ebro Valley to analyse irrigation efficiency at the plot and the irrigation district levels. This analysis revealed limitations of the databases that significantly affect data quality.

The Almudévar Irrigation District (Faci et al., 2000)

This surface irrigation district extends through 3,600 ha. It is supplied by the Monegros canal, which periodically suffers from water shortages, resulting in area limitations for crops with high water requirements, such as maize. As a consequence, district managers record in their database the crop grown in each plot and irrigation season. However, the database structure does not describe the amount of water allocated to each crop. Non-agricultural uses are not recorded in the database. Water withdrawals from wells and the reuse of irrigation return flows are not accounted for, and therefore are not recorded as crop water use or charged to the farmers. Water allocation is based on water orders filed by the farmers. The smallest plots (accounting for 5% of the district area) use three times more water per hectare than the average plot. These results are considered unrealistic, and largely associated to limitations of the database structure and to local water allocation procedures. Much of the district land is leased. However, the district managers bill only the plot owners. This creates accounting and taxing problems for the farmers, because in many leasing agreements the fixed water costs are paid by the owner, while the variable costs are paid by the lessee.

The Loma de Quinto Irrigation District (Dechmi et al., 2003)

This sprinkler irrigation district extends through 2,600 ha. The water price is relatively high, because all irrigation water must be pumped to an elevation of 132 m from the Ebro river. The district database contains information about the crop and type of sprinkler irrigation system present in each plot. The water meter readings are associated with the plots irrigated from each hydrant. For the sake of simplicity, district managers frequently record all water used from a hydrant to just one of the irrigated plots, even if a farmer irrigates several plots from the same hydrant. As a consequence, it is often not possible to trace water use by plot, crop or irrigation system. Non-agricultural water uses are assigned to fictitious plots, because the database design only allows for one water use per plot. Large plots frequently use different irrigation systems or different crops. Because water is allocated to the plot, it is not possible to establish water allocation with more detail.

The Irrigation District V of the Bardenas Canal (Lecina et al., 2005)

This large surface irrigation district has an area of about 15,500 ha. Water is supplied by the Bardenas canal, which periodically suffers from water shortages. During its database design phase, the district managers decided not to use the plot as the water allocation unit (the number of plots is very high). Instead, they use an *ad hoc* unit: the area owned by a given farmer, irrigated from a given irrigation ditch, and with a given crop. While the use of this unit ensures adequate water traceability by farmer, crop and ditch, it hampers cartographic representation. Moreover, because crops change from year to year, the water allocation units must be changed every year. Consequently, comparisons between irrigation seasons cannot be readily established.

The databases used in these three irrigation districts have design limitations that restrict the value of the data stored by district managers and introduce errors in the estimation of water use. The most important limitation in the reviewed database structures and/or in their use by district managers is the lack of water traceability through the distribution network and at the plot-crop level. In some cases, the database interface is not user friendly. As a consequence, district managers use simplified procedures to record water allocation, resulting in errors and loss of detail.

The analysed databases were designed to solve specific water management circumstances of particular districts, and cannot be used in other districts without modifying their management and water allocation procedures. These findings led to the idea of developing a generic database for the study area, which could be used to enhance management of districts with different irrigation technologies and water allocation procedures. This new database should promote quality in irrigation district management, ultimately leading to water conservation and irrigation sustainability.

Developing quality in irrigation district management

Several authors have noted the importance of improving the service quality of irrigation districts. Clemmens and Freeman (1987) analyse how 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) propose the concept of the Management Improvement Program as a procedure to develop managerial skills and enforce water conservation policies in irrigation districts. When the problems of irrigation districts are analysed from the perspective of managerial quality, the basic reference is the ISO 9000 standard (Anonymous, 1998). The implementation process of ISO 9000 is based on the pillars of efficiency, customer satisfaction, intraorganisational communication, expectations, assessment and feedback. These are virtually the same principles that inspired the Management Improvement Programs for irrigation districts. One of the objectives of ISO 9000 is to ensure the traceability of raw materials and products. This concept can be applied to irrigation districts, where the traceability of water should be a major concern. Water traceability in an irrigation district implies being able to relate each unit of water used by the district to a water-using activity. The above mentioned principles were considered while designing the database structure and the interface of Ador.

Limited research efforts have been devoted in the past to the improvement of irrigation district databases. Jiracheewee et al. (1996) present a database structure for irrigation districts linked to an optimisation routine. Merkley (1999) developed "Waters", a computer 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) present "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. SIMIS adds to the basic district management utilities tools based on crop water requirements, irrigation scheduling and scenario analysis. It was designed primarily for open channel distribution systems, although it can accommodate pressurised systems. SIMIS also includes a module for the control of maintenance activities and a Geographic Information System (GIS). 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.

Design of the specialized database Ador

Ador has three primary components: 1) a comprehensive database structure; 2) a diagram of the water distribution network; and 3) a GIS module. Technically, Ador is a Microsoft Access™ application composed of 118 interconnected tables. The GIS module is implemented using the MapObjects LT™ software by ESRI. Ador is being developed in the Spanish language. The software and the users' manual can be freely downloaded from http://www.eead.csic.es/ador.

Water users and cadastral plots

A water user is a person or company with 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 industrialist. 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. For instance, one farmer might always perform the same cultural practices on a group of five adjacent cadastral plots (as if they constituted just one farming plot), while another farmer might grow five different crops at the same time in just one cadastral plot. In some cases, cadastral plots are irrigated from more than one water source, have two different irrigation systems or are leased to more than one farmer. Finally, a cadastral plot can be the physical basis of several water uses of different categories (two crops, one animal farm, an alfalfa processing factory and the farmers' residence). The district database needs to accommodate all these features.

Irrigation and drainage network

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). A maximum conveyance capacity is assigned to each longitudinal element. Construction and maintenance data for each network element complete this section of the database. Figure 1 presents a simplified example 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 can also differ in the daily irrigation period. In some areas water delivery is performed 24 hours a day, while in other areas water delivery is restricted to a number of daytime hours. 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.

Water uses

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. There are several reasons to have more than one agricultural use in a plot. In general, this happens when there is more than one crop, lessee, irrigation system or hydrant in a single plot. Each water use is related to two users: 1) the user paying for water; and 2) 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. One plot can receive water from different hydrants and one hydrant can provide water to more than one plot. Figure 2 describes the role of primary elements, hydrants, cadastral plots and water uses.

Water delivery

Water distribution can be performed in an irrigation district following a number of different delivery schedules (Clemmens, 1987; Clemmens and Freeman, 1987). The following paragraphs report how the most common water delivery schedules in the study area are accommodated in Ador.

On demand irrigation with volumetric water meters

In this delivery schedule, water use is calculated according to water meter records. Provisions have been included in Ador to manage the substitution of a water meter, using the last record of the old meter and the first record of the new meter. When a water meter is shared between several water uses, the volume of water can be divided automatically (proportionally to the area of the different uses) or manually (according to farmers' records). Staff members can use Ador to import water meter readings from handheld computers.

Arranged irrigation based on prepaid water

Prepaid water has become popular in many districts with pressurized networks where volumetric water meters are not available. This method ensures full water payment and recovers water costs at the same time that water is used during the irrigation season. Farmers make payments at a local bank and obtain a receipt for a given volume of water (generally in multiples of 1,000 m^3). The receipt is delivered to the irrigation district office, where the farmer chooses the targeted water use(s) and negotiates with district management the irrigation starting day and hour. In districts using prepaid water, hydrant discharges are regulated at the network construction phase so that multiples of 1,000 m^3 are delivered when the hydrants are operated for periods of 3, 6, 12 and 24 hours. This delivery schedule enables volumetric measurement of pressurized water in the absence of water meters. The negotiation phase matches the interest of the water user with that of the district. To guide its decisions, the district can use the network analysis tool of Ador, which provides district personnel with a graphical assessment of the future evolution of water allocation for the concerned primary element and for the management unit. The graphs also alert of any violation of the system conveyance capacity.

Arranged irrigation based on previous water orders

Water delivery to surface irrigation systems often is based on previous water orders. Farmers fill in a water order form where they state the date, the particular water use(s) and the volume (discharge and duration) of water required to perform the irrigation. The district files the water order and fits this order in the water delivery schedule for the following days. The Ador network analysis module can be used to determine if a water order can be physically delivered. During the process of order confirmation the parameters of a water order can be altered by the district. In a final step, following water delivery, the district can verify and record the actual date and volume of water applied. This three step process (order, confirmation and verification) is recorded in the database.

Rotation irrigation

Surface irrigation districts might change to a rotational delivery schedule responding to water restrictions. Once restrictions are set (in the form of a maximum duration or discharge per hectare), an opportunity is given to all concerned water users to file water orders sequentially. When all users have received their water allocations, district managers can reproduce in time a set of confirmed water orders for a number of times or up to a given date.

Crops, crop water requirements and the estimation of irrigation efficiency

The Ador software contains a database with reference crop water requirements (reference evapotranspiration, ET_0, in mm/day) calculated with the average climatic data for different locations. Precipitation data are also contained in the database. Precipitation data recorded at the irrigation district can be introduced and used instead of long-term precipitation records to determine irrigation water requirements more precisely. The software contains a library of crop coefficients for several crops and zones, which are used for the calculation of water requirements. Additional crops can be added following the standard FAO rules (Allen et al., 1998).

The Seasonal Irrigation Performance Index (*SIPI*, %) is a simple irrigation performance concept that can be considered as an estimate of irrigation efficiency (Faci et al., 2000; Dechmi et al., 2003). The *SIPI* can be determined as follows:

$$\mathrm{SIPI} = \frac{\text{Crop water requirements}}{\text{Water billing}} 100 \qquad [1]$$

Water traceability in Ador enables calculation of the *SIPI* index for every plot or for larger spatial units. Maps of *SIPI* can be produced using the GIS module. Areas or crops that are under- or over-irrigated can be identified, thus providing advanced water management tools to district managers.

Water billing utilities

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. Currently, the most frequent option in the study area is to use one type of water, but different prices for different categories of water use.

In the Ador software fixed and variable costs are considered separately during the billing process. The reason for separation is that often irrigation water must be paid to a higher Public Entity (the Watershed Authority) by the district, while fixed costs are generated and distributed internally. Another reason to separate both costs is that some farmers often decide not to irrigate their farms, but still want to secure their right to irrigate in the future. By paying fixed costs farmers retain their water right without incurring additional variable costs.

In general, fixed costs are proportional to the area of each agricultural use. Fixed costs also can be applied to each individual water user, each water use of a given category, or to the “equivalent area” assigned to non-agricultural water uses. Animal farms, industries or residences can have an equivalent area assigned. This procedure is equivalent to a flat rate.

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. An effort has been made to enable selective billing for each fixed cost item.

Many district managers regard 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, 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.

Database reports and charts

Several reports and charts have been built in Ador to provide information on the status of the district. Table 1 presents a catalogue of Ador reports. 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.

The GIS interface to Ador

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. The main features of the GIS interface are presented in Table 2.

Dissemination of the specialized database

Ador is being used in 62 districts accounting for more than 173,000 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 regional government of Aragón supported this project with a grant.

The objectives of the Ador-CGRAA project were to: 1) Implement Ador progressively in the CGRAA irrigation districts; and 2) 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. A total of 40 CGRAA irrigation districts (115,000 ha) 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 22 additional irrigation districts (58.000 ha) in the Aragón region of the Ebro Valley.

A generic database: limitations and benefits

Ador has been developed as an alternative to many irrigation databases developed for the particular characteristics of just one irrigation district. The initial programming effort for Ador was very important, because the generic database had to include information for different types of irrigation districts in the study area. Despite the variety of management options available in Ador, districts always must modify their management procedures to use the software. Because Ador has been designed to promote excellence in water management, these changes lead to improvements in management standards.

Our experience shows that Ador has enabled many managers to upgrade their procedures. For instance, districts charging farmers by the hectare have realized that the new software can perform proportional billing with limited additional managerial effort. The district image to the farmers also has been improved. Districts now provide water users with complete information on their water use, thus strengthening the district position on water management, and providing public recognition to their work.

Farmers appreciate the activities of the district in information management, and therefore feel inclined to supply the district with the information they require.

While the general structure of the Ador database can be applied to many irrigated areas in the world, many operational procedures are specific of the legal framework of Spain and water management procedures in the Ebro Valley. Expanding applicability to all of Spain would require implementing additional water management schemes. Using Ador in countries other than Spain would require additional programming effort, because the identification of plots, users and banking accounts would need to be completely modified.

Future developments in Ador will focus on improving GIS capabilities, producing additional indicators for benchmarking exercises, developing a multi-user environment, and publishing general and individual information through the internet.

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

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List of tables

Table 1. *Summary catalogue of Ador reports.*

Type	Reports
Users	- Users - Users and their votes - Owners and plots - Users, water uses and plots - Owners, management units, primary elements and plots - Users, plots, hydrants and uses
Plots	- Cadastral reference, cadastral area and irrigated area - Cadastral reference, uses

Irrigation network	- Management units
	- Management units and primary elements
	- Management units, primary elements and plots
	- Management units, primary elements, plots and owners
	- Hydrant, plot, owner and uses
	- Debugging:
	    - Hydrants without plots
	    - Hydrants without uses
	    - Plots without hydrants
	    - Uses without hydrants

Water allocation	- Primary element, day, volume - Hydrant, day, volume - Management unit, day, volume - Prepaid water, day, volume - Management unit, primary element, plot, use, volume, volume per ha
Labels	- Users and their address for mailing purposes

Table 2. *Capabilities of the GIS module of Ador.*

Type	Details
Plot	Selecting a plot returns tabular data on cadastral code, total and irrigated area and detailed data about the plot, the owner and the soil type.
Irrigation network	Selecting an irrigation line (primary element) returns tabular data (dimensions, material, capacity), and gives access to the display of secondary elements and to three cartographical representations: - The plots receiving water from the primary element; - The irrigation lines conforming the management unit where the primary element is included; and - The plots receiving water from the management unit.
Water uses	Selecting a plot returns tabular data on all water uses registered for the plot, gives access to the forms for each type of water, and details water allocation per water use.
Searches	Identifies in the cadastral map the plots satisfying conditions on different categories of data (particular owners, lessees, crops, types of water use, precarious *vs.* full right irrigation rights, soil types and irrigation systems).
Plot-Irrigation network	Selecting a plot returns a hierarchical representation of the relationship between: management unit, primary element, hydrant, plot and water use(s).
Maps	Graduated colour maps can be created for the following variables: - Plots acreage; - Total area owned by the owner or managed by the lessee; - Number of water uses per plot; - Equivalent acreage (for non agricultural uses); - Seasonal water use (m^3); - Seasonal water use ($m^3\ ha^{-1}$); - Number of water allocations (irrigations); - Crop water requirements ($m^3\ ha^{-1}$); - Seasonal Irrigation Performance Index

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Figure 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. One of the canals flows into a reservoir. Water flows out of the reservoir to a low pressure pipe and to a branching network of pressurized pipes, through by a pumping station and a general water meter. The figure also presents the toolbox used to build and manage the diagram. The upper part adds primary elements; the middle part adds secondary elements to the primary elements; and the lower part manages the hierarchy between primary elements.*

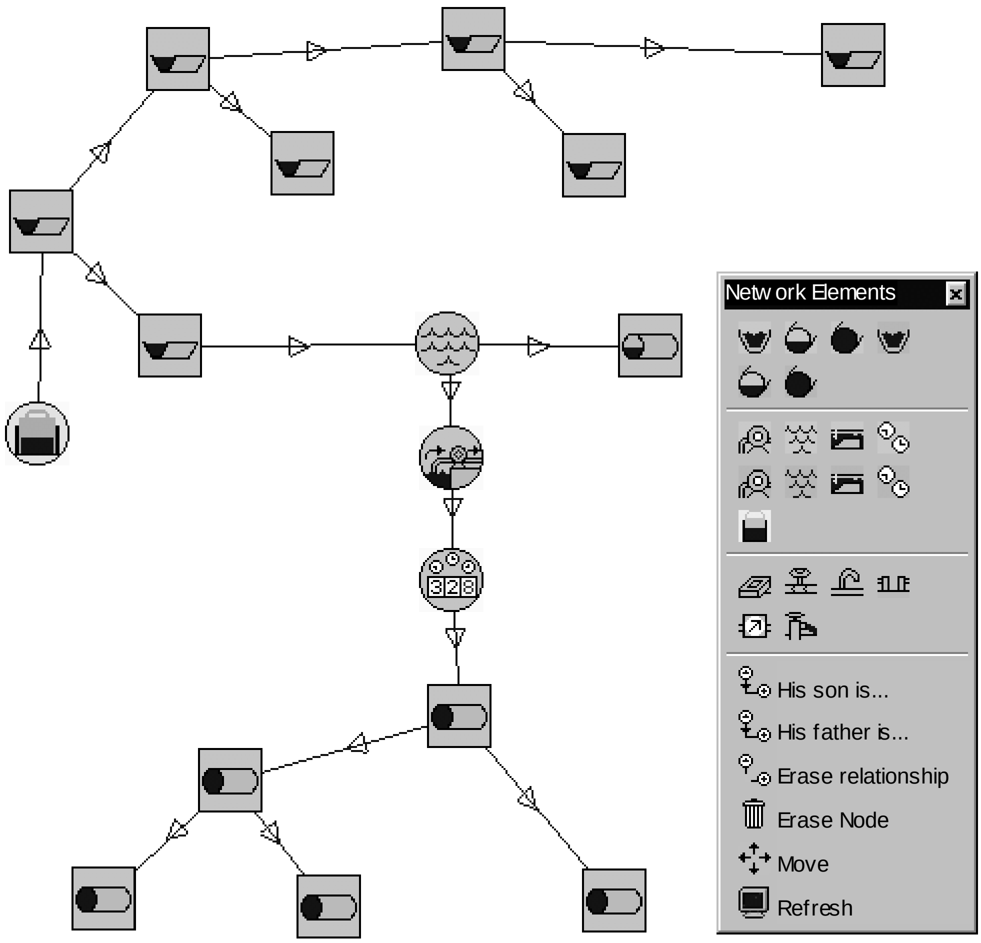

Figure 2. *Example of the detail offered by the diagram about a primary element of the irrigation water distribution network. In this case, the primary element "Loma baja" (a canal reach) has three hydrants (turnouts), related to one, one, and two plots, respectively. Plot 004-00002-0011 receives water from hydrants T11 and T12. The four types of water use are presented in this example. A secondary element of the type siphon is represented between T10 and T11.*