Introduction
The Ebro basin, located in northeastern Spain, covers about 17 percent of the national territory and is one of the most intensively irrigated basins in Europe. The oldest systems were constructed more than two centuries ago (often many centuries ago), are located in riparian areas, and represent traditional, historical irrigation. A second period of irrigation expansion took place between the eighteenth and twentieth centuries (until the 1960s), when large collective irrigation projects, some of them exceeding 0.1 M ha (1 hectare = 2.47 acres), were developed. The last period of irrigation expansion began in the 1970s, with the development of sprinkler/drip irrigation, water pressurization, and the widespread use of plastic materials in agriculture. These pressurized irrigation projects require periodical technological updates (some of them are more than 30 years old), but show the general benefits of modern irrigation structures.

Although the Ebro Valley is diverse in its agriculture, its productive orientation is largely based on field crops, which occupy about 58 percent of agricultural production, fruit trees cover 19 percent, and olive trees and vineyards take up 4 percent of the total area. Approximately 17 percent of the irrigated area is not cropped, due to poor infrastructures, set-aside subsidies, and the existence of unproductive salt-affected soils. Farmers in the Ebro basin do not have to live with drought every year, but droughts regularly occur and require adaptations of a different nature.

Responses and adaptations
In the last years of the twentieth century, the construction of irrigation projects progressed and environmental and recreational uses started to count in the water balances. Farmers realized that water was a finite resource. Developing additional water resources became difficult due to the escalating costs and the social confrontation now accompanying many water resources engineering works.

A hydrologic and economic analysis by the authors of the effects of irrigation modernization in the Ebro Valley indicates that basin-wide productive evapotranspiration could increase by 6 percent (from 2,426 to 2,567 M m³ per year) (1 million cubic meters = 810.7 acrefoot). A very significant increase (35 percent) is expected in the gross value of agricultural production. As a consequence, water productivity expressed as the ratio of the previous variables could increase by 27 percent (from 0.828 to 1.055 € per m³). Under these hypotheses, irrigation productive consumption could increase with irrigation modernization from 17 to 18 percent of the average Ebro flow. In terms of the maximum basin storage capacity, modernization could result
in a productive consumption increase from 40 to 42 percent.

The reported increase in consumptive use is not the only consequence of irrigation modernization. The increase in the gross value of agricultural production and the increase in water productivity are both very important to ensure the economic sustainability of modern irrigated areas in the basin. The increase in economic water productivity will promote agricultural water uses among other alternative uses in the basin, and will help to maintain the water-agriculture link in the future.

An additional benefit of irrigation modernization is related to the expected decrease in pollutant loads in irrigation return flows. The improvement in on-farm irrigation efficiency and the decrease in conveyance losses will result in a very important decrease in irrigation runoff and percolation losses. As a consequence, soil leaching will be reduced, and the mass of exported fertilizers and other salts will decrease.

Finally, the modernization of the irrigation systems produces an important effect on rural societies, increasing the technical profile of rural jobs. Farmers and Water Users Association (WUA) employees will need to increase their labor skills to deal with the elements of pressurized networks and to be able to enjoy the benefits of irrigation controllers and remote surveillance and control systems. Additionally, farmers with pressurized systems will start to use the information on crop water requirements to optimize the irrigation depth. These technologies are an incentive for young professionals to engage in activities that in recent decades were in the hands of aged persons.

Irrigation management: Ador software

Ador software was introduced in 2007 as a contribution to the daily management of WUAs. Ador has three components: a comprehensive database structure, a diagram of the water distribution network, and a GIS module. Technically, Ador is a Microsoft Access™ application composed of 118 interconnected tables. The last software version, along with the user manual, produced by the Oficina del Regante can be freely downloaded from http://www.eead.csic.es/ador.

A water user is any person or company playing a role in the WUA. This role may be classified in 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 cadastral plots. Each plot is identified by a unique alphanumeric code. Farms are often divided into several cadastral plots. 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).

Ador is currently being used in some 70 WUAs, accounting for more than 175,000 ha in the central Ebro Valley. Each water use is related to two users: 1) the user paying for water; and 2) the user paying the fixed costs. For each agricultural water use, the database can store the crop grown and a detailed description of the on-farm irrigation system. Ador has been designed to accommodate delivery schedules typical in the Ebro basin: On-demand irrigation with volumetric water meters; arranged irrigation based on prepaid water; arranged irrigation based on previous water orders; and 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 WUA to reflect differences in water quality, origin or energy input. Fixed and variable costs are considered separately during the billing process. The Ador water bill informs the farmer of his individual water use, but also includes statistics about water consumption in the WUA. The contrast between water use in a certain plot, crop water requirements and the average water use in the WUA by crop, irrigation system, and soil type helps the farmer evaluating his level of irrigation water management.

A number of farmers’ strategies have been identified in water-restricted 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
favored by irrigation modernization (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 multi annual crop, alfalfa has the additional advantage that it survives severe droughts.

The future: water management

As modern irrigation structures are installed, and on-demand irrigation is made possible, farmers will become more and more responsible for irrigation decision making. Training farmers and WUA personnel in water management skills will become very important to overcome drought periods.

A parallel approach consists of the automation of irrigation scheduling and execution, a technique that is now technically possible since:

1. A network of automated agrometeorological stations has been installed in all the irrigated areas of Spain. The SIAR network, installed by the Government of Spain in cooperation with the regional governments, publishes daily crop water requirements for hundreds of stations on the Internet.

2. Irrigation modernization projects include a remote-control/supervision module. This module permits operation of all the valves in a collective pressurized network from a central computer.

3. WUA management databases – such as Ador – are now installed in most WUAs. These databases contain information on farmers, plots, crops, structures and irrigation events.

The connection of these three elements contribute to a vision in the near future in which a computer determines crop water requirements and applies them to the different farms via the remote control-system. During the 2009 irrigation season, an experiment was performed at the EEAD-CSIC experimental farm, in which an automatic scheduling system was applied to the irrigation of a corn crop following a statistical experimental design. The experiment compared two irrigation treatments: a farmer following the weekly information produced by the SIAR network, and the automatic scheduling system. Corn yield was statistically indistinguishable, with yields of 16,262 and 15,645 kg per ha (1 kilogram, = 2.204 pounds) for the farmer and automatic treatments, respectively. While the farmer applied 8,623 m³ ha⁻¹, the automatic system applied 7,036 m³ per ha. This experiment proves that automatic scheduling can result in water management as good as (or better than) the best farmer. This is very important at a time when many farmers are part-timers, and when best management practices are required to overcome drought periods. A centralized water management scheme must combine intelligent on-farm decision making with optimum management and flexible operation at the WUA, so that farmers can easily introduce their priorities in irrigation scheduling. The water management expertise contained in the current crop water simulation models, such as in the recently released AquaCrop, can be very useful to these centralized systems in order to optimize water application under drought.

Conclusions and recommendations

The irrigation modernization projects currently under development in the Ebro basin will result in social, economic, and environmental advantages. When it comes to evaluating the effect on watershed hydrology, it seems clear that evapotranspiration will increase if the rest of the variables remain constant. This is an important point, since an in-depth analysis of the effects of irrigation modernization should include aspects such as: 1) the sustainability of the traditional WUAs not involved in modernization projects; 2) the acreage of new sprinkler irrigation systems; 3) the future prices for crops, water and energy; and 4) the economic and population growth. If basin evapotranspiration increases, modernization will contribute to water scarcity and watershed closure, and drought events will increase their frequency and intensity. Irrigation modernization will however contribute to drought management at farm scale, particularly at the upper areas of the basin where water is provided directly from reservoirs. Improving application efficiency will help to protect farm income under severe water restrictions. The benefit/cost ratio will always be lower for irrigation
modernization projects than for irrigation management. The advantages of cooperative programs for management improvement go well beyond irrigation efficiency, and include endogenous, participative, and multidisciplinary progress. The case of the Ador software, with a history of more than 10 years of co-evolution between water users, water managers, researchers and consultants, illustrates this process. The transparency that Ador has introduced in water management activities has permitted conflict-free operation during drought years. The future will bring more activities in the field of management, and less structural changes. Further research will be needed to develop management tools that take advantage of the different technologies currently available for irrigation operation. Among them, the complete automation of irrigation scheduling and operation stands as a promising line of work. The irrigation modernization projects in place in Spain have required very heavy investments on the part of the farmers and the government. Today, the cost of a typical irrigation modernization project is similar to the price of the land. Such investments can not be performed in many agricultural areas of the world. As a consequence, irrigation modernization will in many places be a step-by-step process, which will have to wait for higher prices of agricultural commodities. In contrast, the prospects for the generalization of efforts in irrigation management are much better, since the cost of better management is much lower than installing new irrigation systems.

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