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Modern Irrigation Schemes and Impact on Drought Mitigation

Nicola Lamaddalena[1]

Abstract

The high population density and the economic activities of the Mediterranean Countries have increased pressure on water resources, causing contamination of groundwater and surface water resources and salinization of coastal aquifers due to their overuse. Therefore, protecting water resources, developing high-performing supply systems and providing decision makers with integrated management tools for improving efficiency of water use and for preserving ecosystems have be identified as priority issues. Strategies for optimizing the use of water, mainly in irrigation which, in most of the Mediterranean regions, often absorbs 60% - 90% of the total available water resource, need to be identified.

In areas where water scarcity conditions occur, on-demand large scale irrigation systems can play an important role in the distribution of a scarce resource, allowing for a sound water resource management by avoiding the uncontrolled withdrawals by farmers from the source (groundwater, rivers, etc). A number of preliminary conditions have to be guaranteed for a sound water distribution. An adequate water tariff based on the volume effectively withdrawn by farmers, preferably with increasing rates for increasing water volumes, is important as a true deterrent for water surpluses. The delivery devices (hydrants) have to be equipped with flow meter, flow regulator, pressure control and gate valve, and also the use of appropriate new technologies should be taken into account. Advanced delivery devices can greatly contribute in solving problems of farmers and problems of continuous and systematic interfacing between them and Irrigation Authorities. Furthermore, a large number of reliable data may be available through these devices and they may be used both by managers and researchers for improving their knowledge on the behavior of irrigation systems, especially under conditions of limited water availability. Last but not least, the use of new technologies allows managers to set up new tariff rules and to ask farmers to pay in advance (or partially pay in advance) water volumes, thus reducing risk in water fees collection.

Finally, modeling for network analysis can be used for improving design and management techniques in order to make on-demand irrigation systems able to operate satisfactorily within a wide range of possible demand scenarios.

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Introduction

Every year the scarcity of water is a major problem in the Mediterranean Basin as a consequence of climatic conditions, cyclic droughts as well as of the pressure caused by human activities. In fact, the high population density and the economic activities of the Mediterranean Countries have increased pressure on water resources, causing contamination of groundwater and surface water resources and salinization of coastal aquifers due to their overuse. In addition, nowadays available water resources are not rationally sound utilized. Therefore, the following issues may be identified as priorities: protecting water resources, developing high-performing supply systems and providing decision makers with integrated management tools for improving efficiency of water use and for preserving ecosystems. For doing that, a better understanding of the physical, social and economic issues related to water management is needed.

In this view, any contribution for implementing integrated strategies in water resources planning and management, that can be environmentally sustainable, is welcome. Such contributions should also allow to identify the main components of water systems, to determine the most important variables within the decision-making process, to examine problems usually occurring in the Mediterranean regions and to forward the best strategies for optimizing the use of water, mainly in irrigation which, in most of the Mediterranean regions, often absorbs 60% - 90% of the total available water resource.

Large-scale irrigation systems have played an important role in the distribution of a scarce resource that otherwise would also be accessible to few and also allow for a sound water resource management by avoiding the uncontrolled withdrawals from the source (groundwater, rivers, etc).

Traditional open canal irrigation systems have all a common shortcoming: water must be distributed by some rotation criteria that guarantees equal rights to all beneficiaries. The resulting consequence is that crops cannot receive water when needed and reduced yields are unavoidable.

Among the distribution systems, the pressurized ones were developed during the last decades with considerable advantages with respect to open canals. In fact, they guarantee better services to users and higher distribution efficiency, greater surface can be irrigated by using similar amount of water, topographic constraints may be easier overcame and water fees based on water volumes delivered effectively by farmers may be easily determined. Consequently, important quantity of water can be saved since farmers tend to maximize the net income by making an economical balance between costs and incomes. Thus, because the volume of water represents an important cost, farmers tend to conduct soundly their irrigation. Furthermore, operation, maintenance and management activities are more technical but, in a way, easier to control and to maintain a good service.

Since farmers are the ones who take risks in their business, they should have water with as much flexibility as possible, i.e., they should have water on-demand.

By definition, in irrigation systems operating on-demand farmers decide when and how much water to take from their deliver devices (hydrants), connected to the distribution network, without informing the system manager. This type of delivery schedule is more common in pressurized irrigation systems where the control devices are more reliable than in open canal systems.

The on-demand delivery schedule offers a greater potential than other types of irrigation schedules and gives a great flexibility to farmers that can manage water in the best way and according to their needs.

Of course, a number of preliminary conditions have to be guaranteed for on-demand irrigation. The first one is an adequate water tariff based on the volume effectively withdrawn by farmers, preferably with increasing rates for increasing water volumes. The hydrants have to be equipped with flow meter, flow limiter, pressure control and gate valve. The design has to be adequate for conveying the demand discharge during the peak period by assuring the minimum pressure at the hydrants able to make on-farm irrigation systems working properly. The use of appropriate new technologies should be also taken into account.

One of the most important uncertainties the designer has to face when designing an on-demand irrigation system is the calculation of the discharges flowing into the network. Since farmers are free to carry out their irrigation, it is not possible to know, a-priori, the number and the position of the hydrants simultaneously operating.

Important spatial and temporal variability of hydrants operating at the same time occurs in such systems according to farmers' decision over time, depending on the cropping pattern, crops grown, meteorological conditions, on-farm irrigation efficiency and farmers' behavior. This variability may cause failures related to the design options when conventional design techniques are used. Moreover, during the lifetime of irrigation systems, changes in market trends may lead farmers to deep changes in cropping patterns with regard to those envisaged during the design. Consequently, water demand also changes. Furthermore, the continuous technological progress produces notable innovations in irrigation equipment that, together with on-farm methods, which can be easily automated, induce farmers to behave in different way with respect to the design assumptions. In view of the changes in farmers socio-economical conditions, also changes in their habits over time should not be neglected. All above said is much more emphasized by the effect of climatic change, especially the effects related to the extreme events (i.e., several consecutive years of drought).

Unfortunately, many irrigation systems are operated by rotation delivery schedule, the water price that farmers have to pay to the management agency is high, and pressure and discharge characteristics at the hydrants are not adequate for appropriate on-farm irrigation. It means that performance of the distribution system is not adequate and, under these conditions, farmers usually prefer to take water from a private source (usually from wells).

Therefore, both designers and managers should have adequate knowledge on the hydraulic behavior of the system when the operating conditions change with respect to the assumptions. In this view, new criteria should be applied by using appropriate performance analysis models in order to: a) support the design of new irrigation systems (which should be able to operate satisfactorily within a wide range of possible demand scenarios); b) help managers of existing systems in understanding why and where failures might occur. In this way, rehabilitation and/or modernization of the system can be carried out in an appropriate way.

Modelling Approaches

Irrigation systems analysis is the process of using a computer simulation model to analyze performance capabilities and to define the system requirements necessary to meet system design standards for pressure and/or discharge (AWWA, 1989). The most relevant advantage of computer modeling is that it makes the network analysis feasible. In fact, without computerized techniques, analysis is impractical except for very simple systems. Based on a computer model, network analysis can be used to determine the adequacy of the existing irrigation systems, to identify the causes of their deficiencies and to develop the most cost-effective improvements.

Furthermore, network analysis may be used also for improving design techniques. In fact, before the advent of computer system analysis, over-design was the common reaction to face the uncertainties of the design stage. Actually, models for the analysis and performance criteria may contribute to support design of new irrigation systems which should be able to operate satisfactorily within a wide range of possible demand scenarios.

Many optimization models have been developed in the past to design large scale distribution systems. Nevertheless, despite the efforts in developing optimization models, they are not widely used in practice because, often, they are really very difficult to be used. The main reason is that they are developed in academic environments where the algorithm is much more important than the input-output interface. In addition, many old engineers have had no opportunity to study formal optimization techniques (Walsky *et al.*, 1987; Goulter, 1992).

For these reasons, an integrated computer package, named COPAM (Combined Optimization and Performance Analysis Model) (Figure 1), was published by the FAO in the I&D Paper n. 59 (Lamaddalena and Sagardoy, 2000).

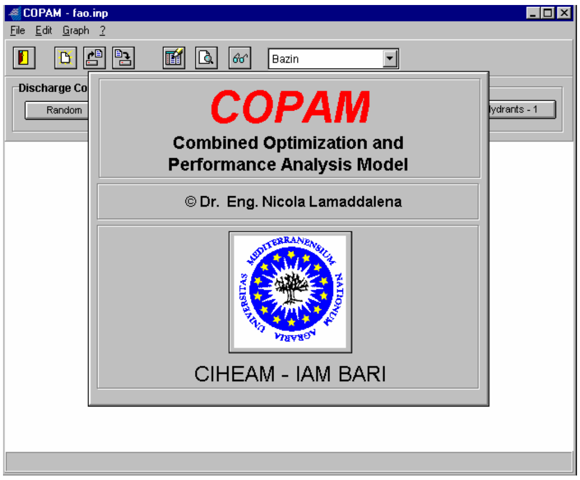

Fig 1. First screen of the COPAM software package

It enables several options for simulating and/or computing peak discharges, for computing the optimal pipe-size diameters and for evaluating the performance of irrigation systems, both at the overall level and at the hydrant level. The performance is evaluated referring to standard values of pressure and/or discharge required at the hydrants for a good hydraulic operation of the on-farm systems fed downstream.

Performance indicators, such as relative pressure deficit (ΔH) and reliability (∂), are defined in the FAO I&D paper n. 59, and presented as outputs both under table and graphical formats. They are briefly summarized hereafter.

A group of operating hydrants (j) corresponding to a fixed value of the nominal discharge Q at the upstream end of the network, is defined as a configuration (i).

Once the minimum head at the hydrants, H_{min}, required for an appropriate on-farm operation is fixed, a configuration (i) is considered as satisfied when, for all its operating hydrants (j), the following condition is respected:

$$(H_j)_i \geq H_{min} \tag{1}$$

For each generated configuration (i), a hydrant (j) is defined as satisfied if the following relation is verified :

$$H_{j,i} \geq H_{min} \tag{2}$$

The state of each single hydrant is expressed using the relative pressure deficit defined as follows:

$$\Delta H_{j,i} = \frac{H_{j,i} - H_{min}}{H_{min}} \tag{3}$$

The model is based on the random generation of the operating hydrants configurations. Once the available piezometric head at the upstream end of the network, Z_0, and the operating discharge, Q_0, are set, the verification under the permanent flow condition allows to compute, for each configuration, i, the pressure head of each hydrant $H_{j,i}$ and, consequently, the relative pressure deficit $\Delta H_{j,i}$. All of these values could be classified in a decreasing order and grouped in percentage curves ranging from 10% to 100% by a 10% step in order to synthesize and to visualize graphically the results. The graphical representation (hydrants numbering; $\Delta H_{j,i}$) allows the identification of the critical zones of the system.

The relative pressure deficit is an indicator of the spatial variability of the hydrant pressure head. An additional indicator of a system performance is the reliability (Hashimoto, 1980; Hashimoto *et al.*, 1982). For irrigation systems it may be defined as the probability α, that the system (hydrant j) has a satisfactory state:

$$\alpha_j = \text{Prob}\,[H_{j,i} \geq H_{min}] \tag{4}$$

The above general definition of the reliability has been given in the case of distribution irrigation systems (Lamaddalena, 1997) using the following relation, deriving from (4):

$$\alpha_j = \frac{\sum_{r=1}^{C} Ih_{j,i}\ Ip_{j,i}}{\sum_{r=1}^{C} Ih_{j,i}} \tag{5}$$

where:

α_j = reliability of the hydrant j,

$Ih_{j,i}$ = 1, if the hydrant , j,is open in a configuration i,

$Ih_{j,i}$ = 0, if the hydrant , j, is closed in a configuration I,

$Ip_{j,i}$ = 1, if the pressure head at the hydrant j, open in the configuration i, is higher than H_{min},

$Ip_{j,i}$ = 0, if the pressure head at the hydrant j, open in the configuration i, is lower than H_{min},

C = total number of generated configurations.

The relevance of the spatial geographic component in the performance of irrigation systems imposed the need to store, aggregate, manipulate, analyze and visualize a huge amount of data. In the recent years the use of Geographical Information Systems (GIS) has been greatly diffused to this purpose.

A GIS is characterized by a unique ability of a user to overlay spatial layers, each representing one or more physical and/or functional characteristics of the studied area. Each layer is related to a table, representing the database. Using appropriate models, it's then possible to actively elaborate the information and to present results under tabular and/or maps form.

There are more than 150 different types of GIS on the market. Nevertheless, only few of them are used in the field of water resources (ESRI, 1995). One of the most commonly used is the ArcView package in Windows version. This package is developed on the easy-to-use main menu that provides the link to the map-view and tabular data management. Moreover, ArcView comes with its own integrated object-oriented programming language and development environment, which performs automated individual tasks, and creates complete applications for interaction with databases and models.

When aiming to develop a decision support system able to furnish detailed, easy reachable and interpretable information on the hydraulic performance of the irrigation systems, the GIS applications could not be underestimated. The distribution irrigation systems are in fact integrated systems involving a number of interrelated factors with a wide spatial variability (physical characteristics of the networks, distribution of the discharges in the pipes, topography, on-farm irrigation methods, farmers behavior, etc.). All of these factors require an extensive database that must be stored and managed efficiently in order to be easily associated to the analyses models.

In this view, an interface was created between the software COPAM and ArcView (Lamaddalena and Khadra, 2000), allowing to:

- Read the values of the relative pressure deficit and of the reliability at each hydrant, previously computed by using the analysis models and then stored in the database of COPAM;

- Visualize the results on a georeferenced map, previously digitized, where the critical zones and the magnitude of failure are identified by different colors.

In the next paragraphs an Italian irrigation scheme (named "Sinistra Ofanto") operating under conditions of water scarcity is described and analyzed under the following points of view:

- The effect of changing delivery schedule on farmers' behavior

- The effect of tariff rules on water consumption

- The use of new technologies as a tool for improving management activities.

Description of the "Sinistra Ofanto" Irrigation Scheme

In this section, a brief description of the "Sinistra Ofanto" irrigation scheme is reported as an example of technical and management activities. Some considerations are illustrated in order to stress the importance of the management rules on the farmers' behavior and of the farmers' reaction when the management rules are modified.

The scheme, covering an area of about 39000 ha, is sub-divided into two sub-schemes: higher zone and lower zone. The lower zone (Figure 2), covering around 22500 ha, is nearly triangular-shaped, bounded at south by the Ofanto river and at south-east by the town of Cerignola. It is divided into seven irrigation districts (numbered from 4 to 10) which are, in turn, subdivided into sectors with surface ranging from 20 ha to 300 ha.

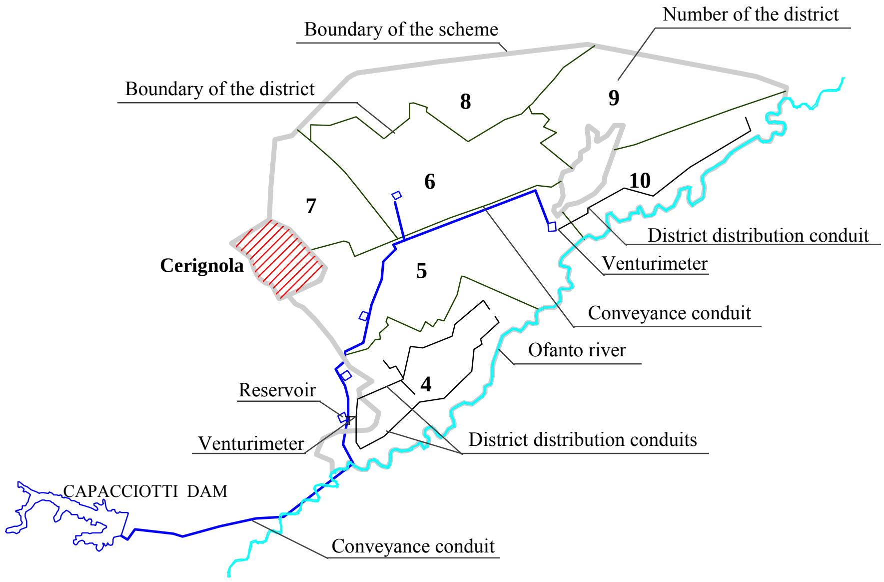

Fig 2. The "Sinistra Ofanto" irrigation scheme (lower area)

The irrigation districts are served by storage and daily compensation reservoirs supplied by a conveyance conduit which originates from the Capacciotti dam (Figure 2). The pressurized irrigation network in each district originates from those reservoirs and is designed for on-demand delivery schedule.

The district distribution conduits consist of underground steel pipes. These conduits supply the ramified sector distribution systems. A control unit is installed at the head of each sector and consists of a gate, a flow meter and a flow regulator. The sector distribution networks serve the farm hydrants, mostly designed for a minimum pressure head of 20 m and a discharge of 10 l s^{-1}. The system was designed for on-demand operation. Soils are generally sandy-loam and silty-loam (Malossi and Santovito, 1975).

Effect of changing delivery schedule on the farmer's behavior

The actual cropping patterns for two typical irrigation districts (named 4 and 10) of the "Sinistra Ofanto" scheme are reported in Table 1.

Crop patterns are not very different among the irrigation districts but they are very different from those foreseen at the design stage (Table 1). In particular, there was a strong decrease in the area occupied by olive trees, with a substantial increase of the area with table grape, which has much higher water requirements. Consequently, the irrigation demand has increased and supply is no longer sufficient to match demand under the conditions assumed at the design stage. For this reason, during the peak periods managers changed the on-demand delivery schedule into restricted demand (Altieri, 1995) by closing the water supply every three days, alternatively, to 50% of the sectors while maintaining free access to the water to the other 50%.

Table 1. Designed and actual cropping patterns in the irrigation districts 4 and 10

	DISTRICT 4				**DISTRICT 10**			
	Designed (1975)		**Actual (1991-96)**		**Designed (1975)**		**Actual (1991-96)**	
	Irrigated area		**Irrigated area**		**Irrigated area**		**Irrigated area**	
	(ha)	%	**(ha)**	%	**(ha)**	%	**(ha)**	%
vineyards	444.0	21.9	1325.9	63.4	282.0	21.9	909.7	69.7
Olive trees	1149.0	56.6	424.9	20.3	730.0	56.6	133.3	10.2
Orchards	21.0	1.0	76.2	3.6	13.0	1.0	111.7	8.6
Horticulture	------	------	265.5	12.7	------	------	150.7	11.5
Fields crops	416.0	20.5	------	------	265.0	20.5	------	------
TOTAL	2030.0	100.0	2092.5	100.0	1290.0	100.0	1305.4	100.0

Such change in delivery schedules modified both the farmers' behavior, in relation to, both, the volume withdrawn and the hydraulic performance of the system (pressure head available at the hydrants).

In fact, the rotation among sectors induce all the farmers within a sector to irrigate simultaneously, thus withdrawing as much water as they can when their sector is in charge.

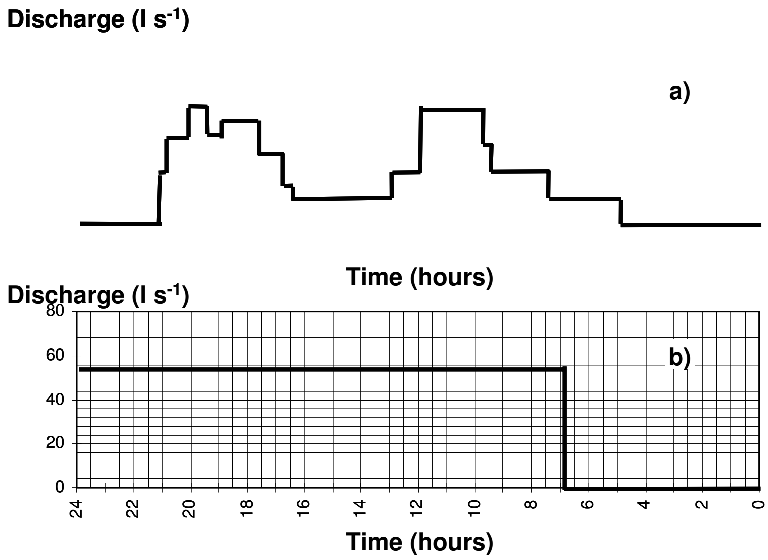

Fig. 3. Typical demand hydrographs at the upstream end of an irrigation sector. a) On-demand operation; b) Arranged demand operation.

In the Figure 3, the demand hydrographs recorded at the upstream end of a typical sector network are reported. From these graphs, it may be observed that during the on-demand operation farmers tend to irrigate when they need and according to their habit. On the contrary, when restricted demand is applied all farmers tend to irrigate simultaneously, during daytime and nighttime, by using the maximum discharge and volume allowable by the network.

This behavior often leads farmers to over irrigate their fields because of the uncertainty in water availability. Thus, operation under restricted demand does not necessarily induce water saving but rather an increase in water demand due to an abnormal behavior of farmers in the use of water (Lamaddalena *et al.*, 1996).

To solve the above described problem, rather than maintaining the practice of changing delivery schedule, it would be appropriate to develop new operation and management rules.

Shortages in existing irrigation systems could be satisfactorily, or at least acceptably, solved by inducing single farmers to modify the flow hydrographs, according to the capacity of the irrigation system. This approach is expected to be better than the drastic 50% rotational-reduction among sectors.

In addition, when the restricted demand is applied and all farmers tend to irrigate simultaneously, the demand exceeds the upper limit of the discharge allowed in the network, causing an increase of head losses and, consequently, a reduction in the available pressure at each farm hydrant. Under these circumstances, the on-farm distribution uniformity and application efficiency and, in turn, the performance of the whole system, is reduced.

Evaluation of the system performance

During the periods of restricted demand, when the discharge increases into the network, severe lacks of pressure at the hydrant level were observed and, by using the software COPAM combined with GIS, the areas of failure may be easily identified. In Figure 4, an application to the district 4 is represented. The Relative Pressure Deficit and the Reliability indicators are presented as graphical outputs. The green color represents hydrants without any problems whereas the red color represents hydrants with important failures. Within the areas of failure, it could be interesting to use new technology delivery devices (described in the next section) in order to exclude their opening during the peak hours of the day. Such peak hours can be easier identified by analyzing the demand hydrograph recorded at the upstream end of the network (Figure 5).

The discharge during such time interval might be reduced and consequently farmers with that constraint might irrigate during the other part of the day. The total volume delivered by farmers will remain the same but, because of the reduction of discharge during the peak hours, the performance of the system is going to increase. The above mentioned new hydrant technology can also help in easily improving the tariff rules. In fact, the opening and the closing irrigation time is recorded on the hydrant and different rates might be applied for the use of water during different time interval (i.e.: rates might be lower for nighttime irrigation).

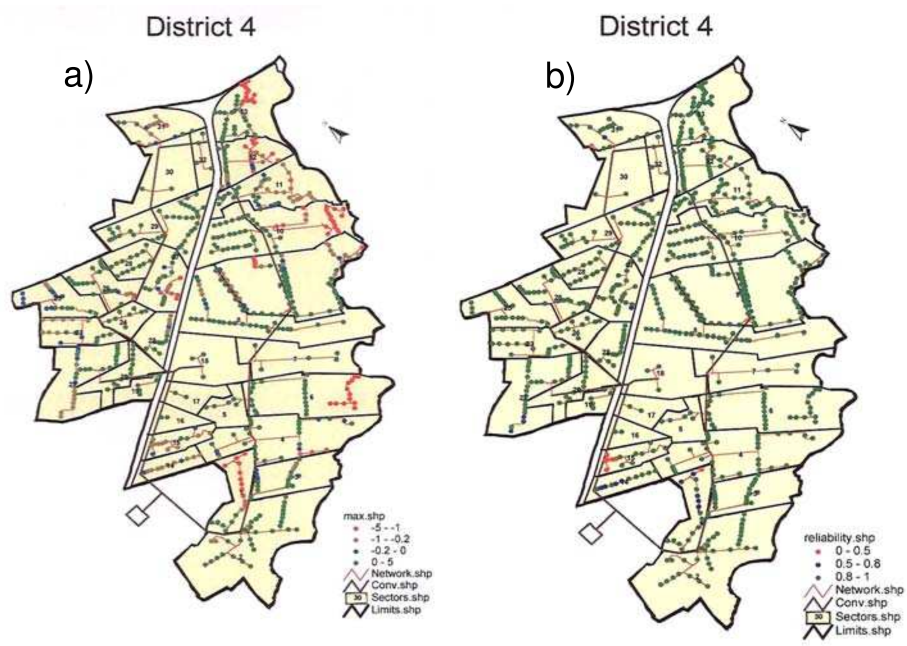

Fig. 4. District 4: Spatial representation of Relative Pressure Deficit (a) and Reliability (b) indicators.

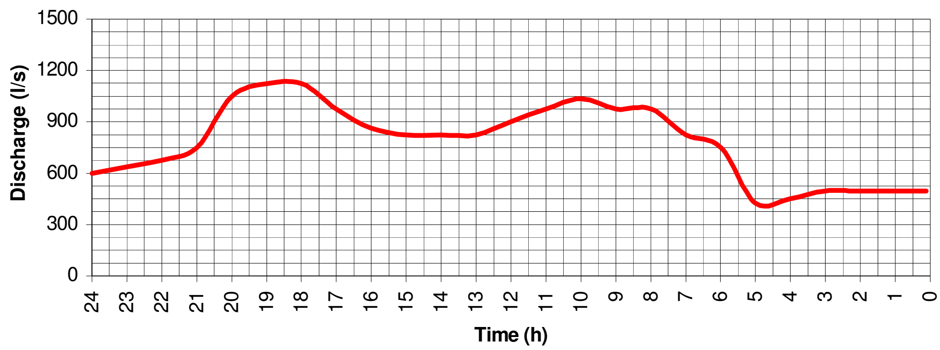

Fig. 5. Example of the discharges observed at the upstream end of the district 4.

New technology delivery device

New delivery devices were developed and installed for improving distribution and reducing water consumption by each farmer, so as to avoid wastes or unuseful concentrated withdrawals without penalizing the on-demand operation.

In particular, new delivery devices were developed in the last years (Antonello *et al.*, 1996; Megli, 1998) based on microprocessor systems that allow to regulate water withdrawals. They can be programmed with a number of functions, are mechanically resistant, reliable and not expensive. These delivery devices, installed in the field, can be activated by an electronic card used by the farmer.

The unit located in the field is composed by a microprocessor, a hydraulic group consisting of a water meter with pulse emitter and a hydrovalve, an impulsive electric valve, a ring flow limiter, a delivery connection pipe, a stain-steel box (Figure 6). It is powered by a lithium battery having lifetime of 10-15 year under normal operating conditions.

The electronic card is composed by a plastic box containing a microprocessor, a real time clock, an alphanumeric display and two selection buttons.

Each electronic card is programmed (by the manager, through a user-friendly software package) at the management office at the beginning of the irrigation season. The seasonal available water volume can be pre-loaded on each card, as well as the maximum daily volume to be withdrawn and/or the maximum daily operating time.

The card may be removed during irrigation after the opening signal is transmitted. The closure will be done automatically after reaching the maximum daily volume or in case of exceeding the maximum operating time. In this way, nobody can steal or remove the card during its operation.

These devices, properly programmed to limit the volume to be delivered and/or to limit withdrawals during the daily peak periods, may stimulate farmers to modify the flow hydrographs in such a way to be compatible with the system capacity. When farmers tend to withdraw too much water during the peak hours, the operating daily time interval may be pre-fixed, as well as the turn at the hydrant level. It will lead farmers to modify the flow hydrographs in such a way to be compatible with the system capacity.

After each irrigation, the total residual volume appears on the display of the card. In this way the farmer may realize immediately if he is using more water than the amount actually needed by the crops.

Also the time of opening and closing of the delivery device can be recorded on the card. It allows applying different tariff rules, for example, by reducing the night-time water rate with respect to the day-time one. This solution may lead to a better distribution of deliveries during the day by avoiding excessive withdrawals during the daily peak hours.

Each electronic card is coded and, therefore, several farmers can take water from the same group by using different cards with different codes. In this case, no problems of water sharing among farmers will occur.

Finally, when such technology is utilized, the management activity is strongly simplified. In fact, farmers have an interest to address to the managing agency (not the opposite, as it happens when classical hydrants are used) for declaring and showing on the card, the volume of water effectively used. Should they not address to the agency, they will be charged for the total volume pre-loaded on the card at the beginning of the irrigation season, even if they used lower amount. Once the farmers exhaust the pre-loaded volume and need an additional one, they have to address again to the managing agency for requesting it. The management staff can decide to supply the requested volume, if available, and they can also decide to charge a different rate for it. Also tariff rules related to the operation time (i.e., night-time irrigation cheaper than daytime irrigation) may be easily identified and applied.

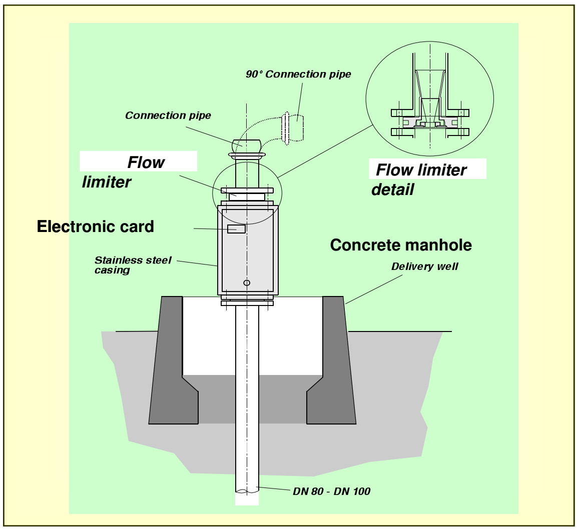

Fig. 6. Scheme of a delivery device controlled by an electronic card.

These devices were successfully installed and used lately in the "Sinistra Ofanto" Irrigation scheme (Altieri *et al*., 1999), where their field reliability and the farmers reaction to such new technology were largely investigated. Also a number of those devices were installed in some Tunisian (Ghezala) and Moroccan (Loukkos and Souss-Massa) irrigation schemes; the success of such installations is often related to the actual needs within the area where the devices are installed. For example, in the Ghezala irrigation scheme (Tunisia) each hydrant serves several farmers and many conflicts were usually occurring among them. In fact, the water meter installed on the hydrants can only measure the total delivered volume and no information were available on the volume consumed by each user that always complained for the attributions done arbitrarily by the management office. The installation of the new device, thanks to the coded card associated to each farmer, successfully solved the above problem and made farmers satisfied of irrigation service. Different reaction was observed in Loukkos irrigation scheme (Morocco). In fact, in that case the new device was installed in a farm with only one farmer and where no problems occurred; the installation was presented to the user as an experiment of the management agency. In this case the farmer didn't accept the device, asking to move the experiment to another field.

These types of delivery devices can strongly contribute in solving the problems of continuous and systematic interfacing between Irrigation Authorities and farmers. Management of irrigation systems can also benefit, especially under conditions of limited water availability. Furthermore, a large number of reliable data can be available as a result of the installation of such devices and they may be used both by managers and researchers for improving their knowledge on the behavior of irrigation systems.

Last but not least, according to the political strategies of the irrigation management agencies, each card might be asked to be pre-paid by farmers and risks in collection of water fees might be greatly reduced.

Tariff rules

In irrigation schemes under water scarcity conditions appropriate tariff rules need to be defined and applied in order to obtain a better control on farmers' withdrawals. In the case of the "Sinistra Ofanto" irrigation scheme, for example, farmers usually pay for irrigation service a tariff that is composed by two parts (Figure 7):

- a fixed rate;
- a variable rate.

The first is proportioned directly to the area served and the resulting fee is related to the hectare, whereas the second depends on the volume of water taken from the hydrant (all the hydrants are equipped with water meters).

The fixed rate (US$/ha 15) has to be paid even if the owner decides not to irrigate, since in any case the Consortium carry out every year maintenance in order to keep the structures in a good operational state; moreover, even though the user doesn't grow irrigated crops, he gets a benefit in terms of the re-evaluation of the estate served by irrigation. This benefit has to be necessarily associated with a fee. Also, by paying a fixed rate the farmer is stimulated to convert his farm to irrigation and to invest.

The variable rate depends on the volume of water used. Actually, the yearly average water duty is 2 000 m^3 ha^{-1}. In order to prevent water wastes, due to not rational use of water by farmers, the following rising tariffs are established for water surpluses as a true deterrent:

- up to 2 000	m^3 ha^{-1}	0.08 US$/$m^3$
- from 2 000 to 2 500	m^3 ha^{-1}	0.10 US$/$m^3$
- from 2 500 to 3 000	m^3 ha^{-1}	0.14 US$/$m^3$
- more than 3 000	m^3 ha^{-1}	0.20 US$/$m^3$

Relevant differences between water volumes effectively supplied to crops and volumes calculated by using theoretical formulations were observed in the "Sinistra Ofanto" irrigation scheme (Table 2).

Table 2 shows that, from 1991 to 1996, the water volume supplied to vineyards was ranging around 2000 m^3 ha^{-1} (corresponding to the available duty). The same situation was observed for olive trees where the measured supplied volume was lower than 2000 m^3 ha^{-1}. Both of the measured volumes were significantly lower than the computed ones. It may be due to the information campaign carried out by the technicians of the Consorzio of Capitanata and by the deterrent effect of the applied tariff rules, inducing farmers to rationalize the use of water. In fact, for the volume of 2000 m^3 ha^{-1} farmers pay the lowest rate (0.08 US$/$m^3$).

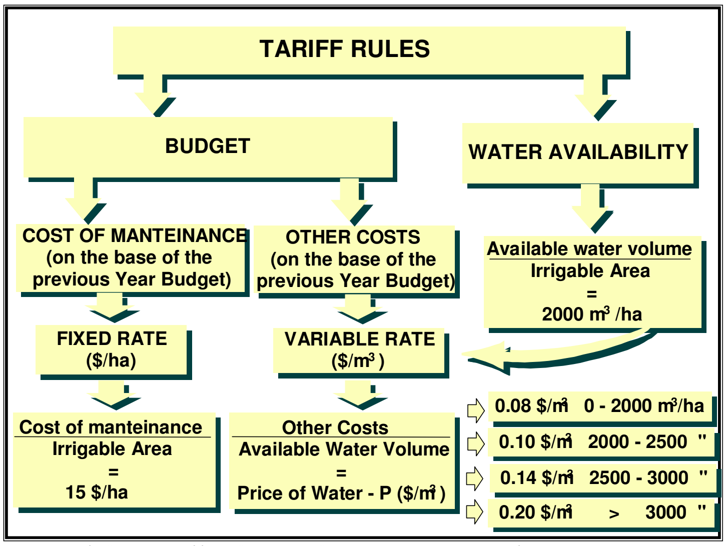

Fig. 7. Scheme of the tariff rules at the Consorzio of Capitanata.

As for tomato, farmers supplied about the double of the duty. In this case, in order to reduce the water volume that should be paid at a higher rate, farmers cultivated only half of the farm with tomato. In this way they could supply 4000 m^3/ha by paying only 0.08 US$/$m^3$. On the other half they cultivated wheat without irrigation.

Finally, comparing the irrigation costs of a farm located within the distribution irrigation scheme with the cost resulting in another farm outside the irrigation scheme (where farmer takes water from groundwater through his local own well), it was observed that the large scale system is highly competitive as compared to private sources (Lamaddalena and Altieri, 1998). Therefore, farmers are induced to take water from the distribution system instead of withdrawing water from local sources. In this way, the environment can be controlled better.

Table 2. Farmer's behaviour respect to water consumptions, in the Sinistra Ofanto irrigation scheme

CROP	1991 (m^3 ha^{-1})	1992 (m^3 ha^{-1})	1993 (m^3 ha^{-1})	1994 (m^3 ha^{-1})	1995 (m^3 ha^{-1})	1996 (m^3 ha^{-1})
Vineyards (measured)	2064	2151	2287	2480	1458	2315
Vineyards (calculated)	4848	3967	5185	4650	3153	5637
Olive trees (measured)	1606	1734	1486	1909	893	1431
Olive trees (calculated)	3062	2439	3301	3118	1736	3772
Tomato (measured)	4586	4060	4486	4964	4654	4699
Tomato (calculated)	5425	4347	5849	4719	5078	6387

Farmers take into account the suggestions of the managers and use water within the limits of their duty, even when water is supplied on-demand. In fact, they know that when they exceed in supplying water, they have to pay much more money and they risk to be in dry conditions in the middle of the irrigation season because of water scarcity (it happened in 1990 when water in the dam depleted at the beginning of August and farmers didn't have the possibility to complete the crop production cycle). On the other side, the Consorzio of Capitanata provides all the conditions for supporting farmers, like the organization of training sessions, extension service activities, suggestions, use of new technologies, etc.

Also the procedure for collecting the fees to be paid by users are important in order to have enough budget for maintaining the system in good operating conditions and for assuring all the necessary services to farmers. Collection is carried out through the yearly tax-roll emission, and made thus executive in full respect of the law.

On this matter, for the variable rate, the irrigation sector transmits to the Land Register and Tax office – that in turn works in close co-operation with the Data Processing Unit – data relative to the consumption of each user. The said sector up-dates the consortium land register, according to the type of taxation adopted and converts the volumes taken into fees to be paid, by applying the planned tariffs in relation to the unit discharges.

The technical time required for the emission of the tax-rolls determines that the water used during an irrigation season is then paid at the beginning of the subsequent irrigation season.

Conclusions

In areas where water scarcity conditions occur, large scale irrigation systems can play an important role in the distribution of a scarce resource, allowing for a sound water resource management by avoiding the uncontrolled withdrawals by farmers from the source (groundwater, rivers, etc).

A number of preliminary conditions have to be guaranteed for a sound water distribution. An adequate water tariff based on the volume effectively withdrawn by farmers, preferably with increasing rates for increasing water volumes, is important as a true deterrent for water surpluses. The delivery devices (hydrants) have to be equipped with flow meter, flow limiter, pressure control and gate valve, and also the use of appropriate new technologies should be taken into account. In fact, new delivery devices working trough electronic cards can greatly contribute in solving problems of farmers and problems of continuous and systematic interfacing between them and Irrigation Authorities. Furthermore, a large number of reliable data may be available through these devices and they may be used both by managers and researchers for improving their knowledge on the behavior of irrigation systems, especially under conditions of limited water availability. Last but not least, the use of new technologies allows managers to set up new tariff rules and to ask farmers to pay in advance (or partially pay in advance) water volumes, thus reducing risk in water fees collection.

Finally, modeling for network analysis can be used for improving design and management techniques in order to make irrigation systems able to operate satisfactorily within a wide range of possible demand scenarios.

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