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Modern strategies and tools for water saving and drought mitigation in Southern Italy

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SUMMARY – This work is focused on the strategies and modern tools applied in Apulia region (Southern Italy) for water saving and mitigation of drought. The operative programs for improvement of land and water management embrace the principles of sustainable development and recognize integrated, dynamic, interactive, multi-scale and multi-sectorial approach as the best management option. Irrigation management is based on the interaction of agronomic and engineering parameters at different scales aiming at a balance between water demand and water supply. Mitigation options are analysed scaling up the agronomic practices and water saving strategies while scaling down the engineering solutions for a more efficient water supply. Two examples of implementation of the activities are presented: the first is related to the development of the regional GIS-based irrigation management system and the second to the real-time monitoring of water availability and irrigation water requirements in the Consortia "Bonifica della Capitanata".

Key words: Drought mitigation, Geographical Information System (GIS), irrigation water management, scaling, web-based real time irrigation scheduling, Apulia region.

RESUME – *"Stratégies et instruments modernes pour l'économie d'eau et l'atténuation de la sécheresse dans le sud de l'Italie". Ce travail est axé sur les stratégies et les instruments modernes qui sont utilisés dans la région des Pouilles (Italie du sud) pour économiser l'eau et atténuer la sécheresse. Les programmes opérationnels visant à l'amélioration de la gestion de la terre et de l'eau englobent les principes du développement durable et identifient l'approche intégrée, dynamique, interactive, multi-échelle et multisectorielle comme étant la meilleure option de gestion. La gestion de l'irrigation se base sur l'interaction des paramètres agronomiques et d'ingénierie à différentes échelles dans le but d'atteindre un équilibre entre la demande et l'offre de l'eau. Les options d'atténuation sont analysées en agrandissant à l'échelle supérieure les pratiques agronomiques et les stratégies liées à l'économie de l'eau et en réduisant l'échelle pour les solutions d'ingénierie en vue d' un apport hydrique plus efficient. Deux exemples d'implémentation des activités sont donnés : le premier est lié au développement du système de gestion de l'irrigation axé sur le GIS (Système d'Information Géographique) et le deuxième au monitorage en temps réel de la disponibilité de l'eau et des besoins en eau d'irrigation auprès du "Consorzio di Bonifica della Capitanata".*

Mots-clés : *Atténuation de la sécheresse, Système d'Information Géographique (GIS), gestion de l'eau d'irrigation, changement d'échelle, pilotage de l'irrigation en temps réel axé sur le web, région des Pouilles.*

Introduction

Many areas of the Mediterranean are exposed frequently to the extreme climatic conditions causing serious damages to land and water ecosystems and loss of production potential. During the last twenty years, long dry periods had occurred in the Eastern Mediterranean basin in 1989-1990, Tunisia suffered severe drought from 1987 to 1989 and in 2000-2001, Western Iberian basins and Morocco faced the worst drought in 1991-1995 (Demuth and Stahl, 2001), Southern Italy and some other Northern Mediterranean regions had serious water problems in 1993 and, then, in 2001 and 2002 (Hamdy and Trisorio Liuzzi, 2004). Again, in the recent years, several areas of the Mediterranean (from Spain to Greece and from Italy to Tunisia) faced grave water shortage problems. In the EU, one of the most widespread droughts occurred in 2003 when about 100 million people and one-third of territory were affected. The cost to the European economy was estimated to € 8.7 billion while total cost of droughts in the EU over the past thirty years amounts to € 100 billion (EC, 2007).

The above mentioned events have increased political, environmental and social concerns of the fragility of natural resources and imposed necessity for the creation of large regional and inter-regional strategies for mitigation of natural temporary imbalance of water resources. During the last decade, these new strategies comprehend many issues as networking of scientists and researchers, priority settings and allocation of necessary funding, inter-regional and inter-country technology transfer, institutional capacity building and strengthening, human resources development, etc. (Demuth amd Stahl, 2001). Among others, these strategies invoke for application of modern technological tools (e.g. Geographical Information Systems – GIS, remote sensing, global positioning systems – GPS, Decision Support Systems – DSS, models, etc.) especially for monitoring and forecasting of natural events and mitigation measures. In this paper are presented some of the modern strategies, measures and tools applied in Apulia region (Southern Italy) for water saving and drought mitigation in irrigation sector.

Apulia region: Description of the area and recent drougths

The Apulia region is situated in South-eastern Italy covering a surface area of 19,361 km^2. Most of territory is characterized by the semi-arid Mediterranean climatic conditions with annual precipitation between 400 and 700 mm occurring predominantly during the winter season. Frequently, the summers are dry, almost without any rainfall for several months, and with the maximum temperatures going up to 40°C. The region is not able to satisfy its water demand and chronic shortage of water is attenuated by a significant water transfer from the surrounding regions, in particular, from Basilicata and Campania where precipitations are much more higher and the overall availability of water resources is satisfactory.

In the Apulia region, the agricultural land represents more than 70% of the total surface area. Most of agricultural production is based on irrigation although water availability is very limited and highly depends on the water inflow from the surrounding regions and water extraction from groundwater aquifers. Six land reclamation and irrigation consortia are located in the region and they are responsible for water distribution in agricultural sector and operation and maintenance of dams and hydraulic structures situated in their territory (Fig. 1). The consortia cover about 90% of the whole region. Surface area equipped with the consortia water distribution networks is extended over 236,012 ha. It is estimated that effective irrigated area is significantly greater and reaches about 352,732 ha since most farmers use water extracted from private wells located at their farms. In fact, only one-third of overall agricultural water demand of 789.65 million m^3 per year is satisfied by with water delivered by the consortia while two-thirds (about 550,000 m^3 per year) relied on the abstraction of groundwater (INEA, 1999). This huge and uncontrolled withdrawal of groundwater causes periodically an excessive drop of groundwater table and intrusion of the saltwater in the aquifers.

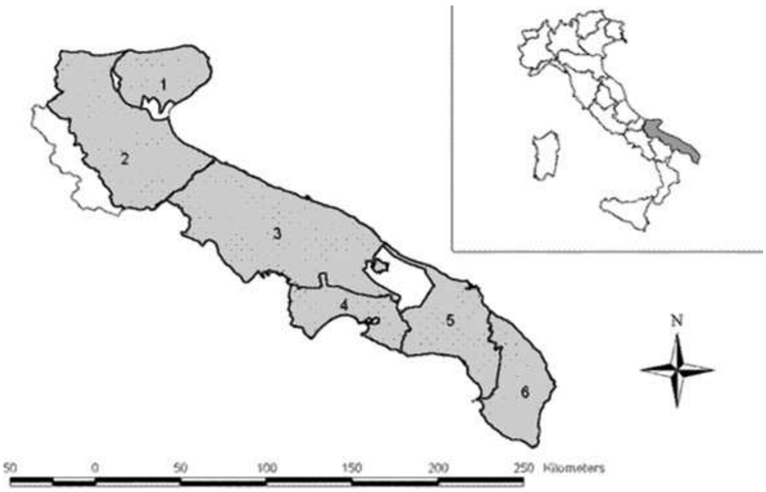

Fig. 1. Apulia region and administrative boundaries of irrigation consortia (1 - Gargano; 2 - Capitanata; 3 - Terre d'Apulia; 4 - Stornara e Tara; 5 - Arneo; 6 - Ugento e Li Foggi).

Recent analysis of the trend of the mean temporal variation of weather variables in the Apulia region throughout four decades, from 1951-1960 to 1981-1990, has demonstrated a significant decrease of annual precipitation, in the range of 22.5%, which corresponds to an average yearly amount of about 167 mm (Todorovic, 2007). The analysis of temperature data indicated a slight decrease in maximum air temperature and a minor increase in minimum air temperature, both in the range of 0.5°C over four decades. Such a variation of air temperature has provoked, in average, a decrease of evapotranspiration of about 57 mm/year, which is equivalent to 5.4%. The overall results of this analysis have shown that water deficit in the region has increased over four decades, on annual basis, in average, by 110 mm. As a consequence many areas with crops which are not usually irrigated (e.g. olive-trees, wheat, etc.) have been converted to irrigated agriculture. In fact, thirty years ago, olive-trees have not been irrigated at all in the region. Nowadays, they are irrigated in an area of about 15,000 ha. The change of climatic conditions and increase of water deficit have produced serious consequences also on water quality and overall environmental conditions in the region increasing the risks of erosion and desertification processes.

Additional evidences of the climatic changes and overall worsening of climatic conditions not only in the Apulia region but also in the other regions of Southern Italy (and especially in Basilicata, Sicily, Campania and Sardinia) have come from serious droughts in 2001 and in the first part of 2002 consisting of persistent lower-than-average precipitation and higher-than-average air temperatures. This has resulted in drying up of streams and long-term water deficit in accumulations (Fig. 2) which caused alarming situation in water supply not only for agriculture but also for many urban zones. Further consequences were excessive groundwater exploitation and drop of groundwater level, degradation of surface and groundwater quality, compromising conditions of aquatic ecosystems, etc. According to this alarming situation, in many areas of Southern Italy, Italian Government has declared the state of emergency regarding the drought and scarcity of water resources.

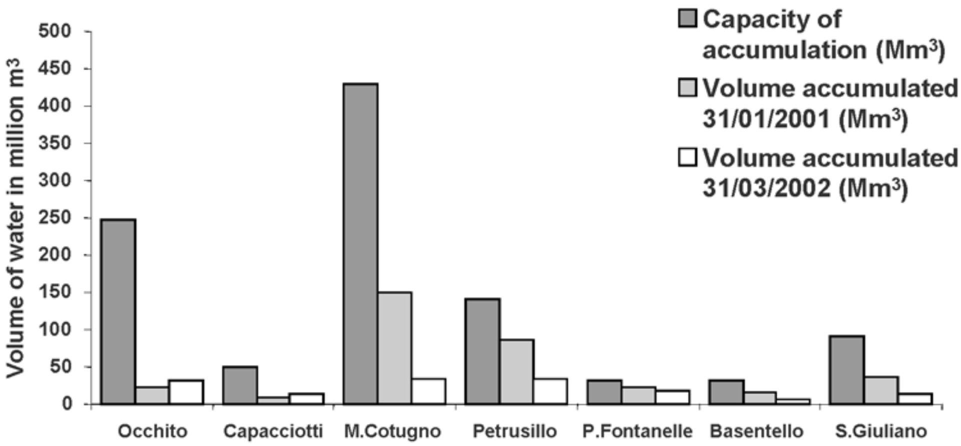

Fig. 2. Example of hydrological drought in Southern Italy in 2001 and 2002: Capacity of some most important dams and effective water accumulated on 31/01/2001 and 31/03/2002.

Priority actions for land and water management and mitigation of water scarcity and drought

The on-going Program for improving land and water management and combating negative impacts of water scarcity and drought has been lasting for several years and represents a continuation of the already achieved results in the modernization of agricultural systems in the past and, especially, in the last decade during the realization of the Operative National Programs 1994-1999 and 2000-2006. The last Program considered fully the EC Water Framework Directive 2000/60 and includes a series of long-term concerted activities going on at different scales (from national and inter-regional to local level) and covering both supply and demand side of water balance. Among others, these activities include the following priority actions regarding the irrigated agriculture:

(i) Assessment of the actual state of irrigation sector including identification of the equipped areas and those effectively irrigated, the state of infrastructures and water distribution systems, etc.

(ii) Agro-ecological characterization of the territory and economic analysis of applied irrigation practices in order to asses their profitability.

(iii) Analysis of availability of water resources and ways of their use in irrigated agriculture with a particular emphasis on reuse of treated wastewater.

(iv) Setup of a permanent monitoring system on the use of water in irrigated agriculture.

(v) Setup of the irrigation management system for the creation of irrigation scenarios and estimation of corresponding irrigation requirements.

(vi) Setup of modern information web-based tools for estimation of crop water requirements and irrigation scheduling, etc.

A part of this program is actually under development at national and inter-regional scale by the governmental agencies while the rest is under implementation for some more specific areas by regional and local institutions, universities and local management agencies. The activities presented in this work refer to CIHEAM–IAM Bari Institute experiences and cover different scales of implementation (from field to irrigation district and region) of the program aiming at better management of land and water resources and water saving and drought mitigation in Southern Italy.

Regional GIS-based irrigation management system

The operational functions of the irrigation management system are based on the interaction of engineering and agronomic parameters at different scales from field to farm, irrigation sector, district and watershed as it is illustrated in Fig. 3. At each specific scale, agronomic and engineering aspect of irrigation water management are compared by means of water demand and water supply aiming at a balance of resources. Then, a set of mitigation strategies is analysed scaling up the agronomic practices and water saving options and scaling down the engineering solutions for a more efficient water supply.

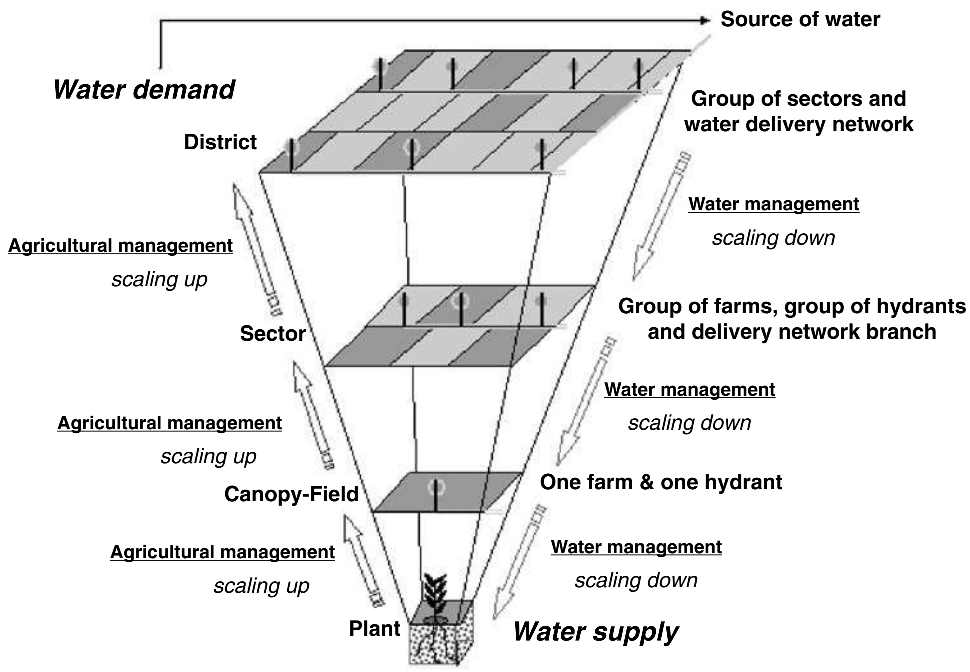

Fig. 3. Interaction of engineering and agronomic parameters at different scales of an irrigation water management system.

The system is performed in a customized version of ArcView GIS on the grid cells with size varying from 250x250 m, in the case of relatively smaller areas (i.e. municipality, irrigation districts etc.), to 500x500 m, in the case of irrigation consortia, and 1x1 km when the whole region is taken into consideration (Todorovic and Steduto, 2003). The variable cell size was accepted in order to distinguish between the planning and management at smaller areas when more detailed information is necessary and the applications over the larger areas (i.e. province or region) when the data can be more generalized. Actually, the major efforts are focussed on the realization of GIS-databases for specific irrigation districts embracing all relevant information from field to district scale. In such a way, the user of the system can define the area of interest (i.e. the scale of application) and choose to proceed with: (a) the spatially referenced queries, (b) the calculation of irrigation requirements and identification of areas with water deficit (i.e. irrigation module), and (c) a link to crop productivity model.

The development of the spatially referenced queries is related to the identification of the areas which satisfied requested climatic conditions (temperature, precipitation, evapotranspiration and climatic water deficit), soil characteristics (soil classes and soil properties), topography (elevation, slope and aspect), land use (agricultural or other land classes, irrigated and non-irrigated land, etc.). These queries can rely on a specific theme and/or they can be related to several themes contemporaneously (i.e. multi-thematic queries). The GIS software is completely customized for the single-theme queries where a non-expert user can follow the pre-defined procedures for exploring the spatial databases. Nevertheless, a more expert user is required in the case of multi-thematic queries when a more complex elaboration is needed.

The most of operational functions of the irrigation module are based on the FAO CROPWAT software for irrigation planning and management (FAO, 1992) and they are explained in details in Todorovic and Steduto (2003). The flowchart of the procedure for the estimation of irrigation requirements and identification of water deficit areas is given in Fig. 4. The reference evapotranspiration is calculated from the temperature data by using the Hargreaves formula (Hargreaves and Samani, 1985). Then, crop evapotranspiration is estimated using the single crop coefficient approach (FAO, 1998). The user of the system can choose between the already existing crop coefficient (Kc) values available in the database or can insert new values through a dialog box. The effective rainfall can be calculated as a fraction of the average rainfall or the rainfall of certain probability of occurrence corresponding to more dry or wet years. Therewith, the net irrigation requirements (NIR) are calculated as a simple difference between the crop evapotranspiration and effective rainfall. Moreover, if necessary, the leaching requirements can be taken into consideration. Finally, the gross irrigation requirements (GIR) can be estimated as the ratio between NIR and irrigation efficiency (IRRc) provided that the application efficiency of irrigation method is known. Accordingly, the total amount of water necessary for irrigation of an area can be calculated summing up the values of GIR for each cell or field.

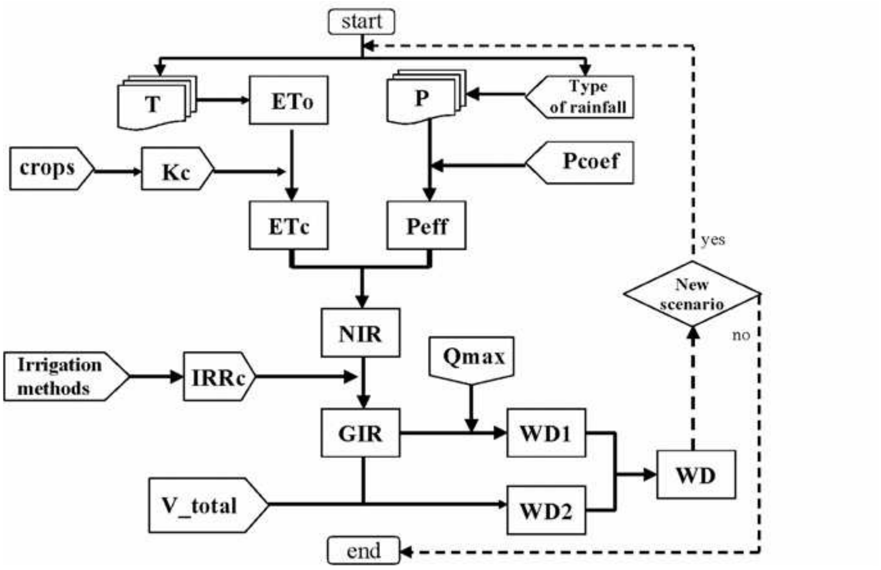

Fig 4. Flowchart of the calculation procedure for the estimation of irrigation requirements and identification of water deficit areas (Source: Todorovic and Steduto, 2003) .

The regional irrigation management system employs the results of the estimate of gross irrigation requirements and the global assessment strategy for the identification of the water deficit areas by using two main constraints for water distribution during an irrigation season:

(i) limited maximum flow rate of water distribution system allowing for the satisfactory operation pressures at the outlets (Q_{max} - WD1), and

(ii) conditions of drought and limited total volume of water available for irrigation ($V_{\_Total}$ - WD2).

Both constraints are presented schematically in Fig. 5 where the irrigation water demand (i.e. gross irrigation requirements) over an irrigation season is plotted on the 10-days basis. In fact, an area is depicted as water deficit zone when irrigation water demand is greater than the maximum flow rate of water distribution system (Qmax) corresponding usually to the periods of peak crop evapotranspiration. Similarly and especially under conditions of water scarcity and drought, an area may be treated as water deficit zone when total available water is lower than gross irrigation requirements.

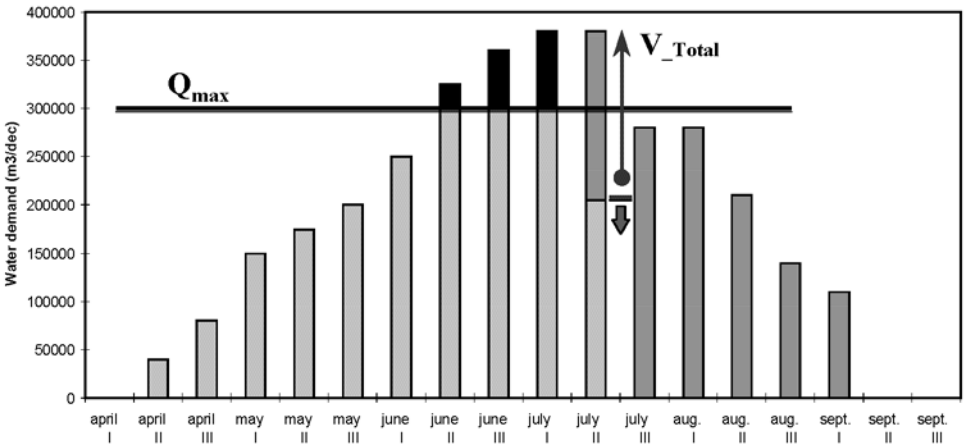

Fig 5. Application of the global assessment strategy for identification of water deficit areas (Qmax - maximum flow rate of water distribution network permitting satisfactory working pressure at the outlets; V_Total - total volume of water available for irrigation over an irrigation season).

Both constraints are highly related not only to the total availability of water for irrigation and the performances of water delivery network but also to the climatic conditions and designed cropping pattern and agronomic practices in the area of interest. Two water distribution constraints can be used either both together or separately and for different time periods (from 10 days to the whole irrigation season). Moreover, the system permits the comparison of different irrigation scenarios at various scales where the whole set or only few input parameters should be modified. The overall results of a simulation are presented in GIS as maps demonstrating the whole area under consideration with water deficit and surplus zones and administrative boundaries of irrigation district/consortia. Furthermore, for each specific scenario, can be displayed the maps showing the magnitude of failure of the system and regarding the difference between water demand and water supply volumes.

The last component of the irrigation management system is the crop productivity model which uses spatially referenced GIS database for extract of input information and display of modeling results. This mechanistic model consists of crop-growth and water balance module and runs on the grid cells or simulation units each described by the homogeneous climate, soil and crop characteristics. The model can generate a spatially referenced daily input weather data files and can run at different time-scales from daily to 10-days and monthly. This model had been used also for agro-ecological characterization of the region and estimate of land productivity attitude and it is described in details by Steduto and Todorovic (2001). Nowadays, the main efforts are directed towards the integration of an engineering routine based on COPAM model for performance analysis and optimization of the pressurized irrigation systems (Lamaddalena, 1997; Lamaddalena and Sagardoy, 2000).

Internet-based support for local irrigation managers and farmers

The Consortium of "Bonifica della Capitanata" is the most important Consortia in the Apulia region by means of both irrigated area and crop water requirements. The surface area covered by the Consortia water distribution network is about 140,378 ha and about 90% of it (126,000 ha) is effectively under functioning. The irrigated land is slightly smaller and it is estimated to about 121,266 ha (27.5% of total area). However, only 45% of irrigated land is supplied by water through the Consortia water distribution network, while the rest, although located within the Consortia, is irrigated directly by the farmers using the private wells (INEA, 2001).

The annual water withdrawal by Consortia is estimated to about 150.5 million m^3. The distribution of water to irrigation fields is estimated to about 86.7% of water withdrawal for irrigation (or 131 million m^3) due to the hydraulic losses of water distribution system and non-authorized water use along the network. This means that the average water supply over irrigated land corresponds to 2440 m^3/ha which in many cases is not enough to satisfy crop water demands. However, total water requirements of the Consortia are much more greater than effective water supply and they are estimated to more than 330 million m^3. In fact, in the Consortia is irrigated almost 70% of herbaceous field crops and more than 50% of vegetables cultivated in the region. Furthermore, about one-third of all vineyards is irrigated, about 22.2% of fruit-crops and 13.2% of olive-trees presented in the area (INEA, 2001).

In order to provide more information to the water managers and farmers in the region, the Consortia has realized and activated on its web site (www.consorzio.fg.it) a set of services aiming at more efficient water use in irrigation sector. These services include:

(i) Real-time and historical data on water availability in four dams (Occhito, San Giusto, San Pietro and Marana Capacciotti) main sources of water for irrigation and managed by Consortia.

(ii) Real-time and historical data about weather parameters over the whole area covered by 13 agro-meteorological stations equipped with electronic data acquisition system.

(iii) Real-time irrigation scheduling service considering climatic and soil characteristics and user-specified crops and irrigation systems technical characteristics.

(iv) Agro-meteorological and phyto-sanitary bulletin with the services related to historical weather data and weather forecasting and eventual risks for the development of plant diseases.

The real-time irrigation scheduling service is of particular importance since it provides essential support to local farmers deciding when to irrigate and how much water to apply. The user of the system enters on the web site indicating approximately on a GIS-based map the area at which his farm is located which permits to the system to identify the closest agro-meteorological station and to use corresponding meteorological data for water balance calculations. Then, the farmers on the local managers insert the information about the crop grown in the area of interest, soil characteristics, and irrigation system choosing between sprinklers, surface and drip irrigation method. In the case of drip irrigation method, the farmers should provide also the data about the distance between the rows, distance between the drippers and discharge of drippers. Finally, the farmers insert the date of the last irrigation and the system calculates soil water content on a daily basis indicating the date of next irrigation and corresponding amount of water to apply. This service uses previously developed database on crop and soil characteristics in the region and weather forecasting information provided by the regional meteorological service and available also on the Consortia web site.

This service together with other Internet-based tools offered by the Consortia has been accomplished step-by-step in several years and, actually, it is very appreciated especially among new generation of farmers who are seeking for the modern tools in order to optimize agricultural production. Certainly, this is also due to widespread use of computers in the last years and Internet services, in general, also in many rural areas of Southern Italy.

Conclusions

The sustainable management of natural resources is the keystone of the modern policies in the Mediterranean Region which acknowledge integrated land and water management strategies, based on a complex and multiple interaction and interdependency among various sectors and land and water subsystems. The implementation of such strategies requires continuous monitoring of resources and many inter-linked variables, development of large geo-referenced databases and multi-disciplinary, multi-scale and multi-participatory decision making processes which inevitable involve the use of modern information technologies and methodologies (Walski *et al*., 2003; EC, 2007).

This work covers two examples of application of the modern management tools which are working at different scales and, consequently, are devoted to two profiles of managers: large-scale decision makers, optimizing the interest of local and regional authorities, and farmers who are particularly taking care about their own income. However, they are both complementary and necessary tools to improve the strategies in the choice of agricultural crops and to schedule irrigation accordingly, deciding which fields (or crops) to irrigate, when and how much. Certainly, both tools contribute in water saving, drought mitigation and an overall progress of land and water management in the region.

The tools presented in this work are the results of long-term national and regional strategies for the management and planning of water resources. In fact, the GIS databases have been developing and improving for many years and are still under completion, aiming to comprehend both supply and demand side of water management. In our time, this is an obligatory route for all countries because the use of GIS and spatially referenced databases along with efficient monitoring and forecasting system supports faster and easier exchange and integration of information and interaction of geo-referenced data, models and decision support tools. Equally so, these databases represent a first step towards the Supervisory Control and Data Acquisition (SCADA) systems providing remotely real-time measurement of water level in accumulations and reservoirs and soil water content (or leaf water potential) in the fields and enabling remotely operation of water distribution network elements.

Certainly, nowadays, when water issues are becoming increasingly important, many countries, also on the Southern rim of the Mediterranean, are implementing the modern technologies and integrated water management strategies. Inasmuch the tools are the same, the ways for their implementation may differ from country to country respecting the specific conditions and national policies. Unquestionably and unequivocally, successful implementation of these initiatives lies first and foremost on the responsibility and ability of Governments to design, finance and accomplish national strategies, plans, policies and processes concerning complex interaction and interdependency among various sectors and water and land subsystems.

References

Demuth, S. and K. Stahl (eds.) (2001). ARIDE – Assessment of the Regional Impact of Droughts in Europe. Final report to the European Union. ENV4-CT97-0553. Institute of Hydrology, University of Freiburg, Germany.

EC (2007). *Addressing the challenge of water scarcity and drought in the European Union*. Communication from the European Commission to the European Parliament and the Council, Brussels, *SEC* (2007)993, 15 p.

FAO (1992). *CROPWAT – A computer program for irrigation planning and management*. Food and Agricultural Organization of the United Nations, Irrigation and Drainage Paper 46, 126 p.

FAO (1998). *Crop evapotranspiration. Guidelines for computing crop water requirements*. Food and Agricultural Organization of the United Nations, Irrigation and Drainage Paper 56, 300 p.

Hamdy, A. and Trisorio-Liuzzi, G. (eds.) (2004). Water management for drought mitigation in the Mediterranean. *Options Méditerranéennes, Série B: Studies and Research,* No. 47. CIHEAM-IAMB, Bari, 327 p.

Hargreaves, G.H. and Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. *Applied Engr. Agric*., 1: 96-99.

INEA (1999). *L'agricoltura in Puglia*. Osservatorio Puglia sul mondo rurale e sul sistema agroindustriale, Istituto Nazionale di Economia Agraria, pp. 34, in Italian.

INEA (2001). *Stato dell'irrigazione in Puglia.* Istituto Nazionale di Economia Agraria, pp. 244, in Italian.

Lamaddalena, N. (1997). *Integrated simulation model for design and performance analysis of on-demand pressurized irrigation systems*. PhD Dissertation. Technical Univ. of Lisbon, Portugal.

Lamaddalena, N. and Sagardoy, J.A. (2000). *Performance analysis of on-demand pressurized irrigation systems*. Irrigation and Drainage Paper 59, FAO, Rome.

Steduto, P. and Todorovic, M. (2001). Agro-ecological characterization of the Apulia region: methodology and experience. In: Soil Resources in Southern and Eastern Mediterranean Countries. *Options Méditerranéennes, Series B: Studies and Research*, No. 34: 143-158.

Todorovic, M. and Steduto, P. (2003). A GIS for irrigation management. *Physics and Chemistry of the Earth*, *Special volume "Water for food and environment"*, Elsevier Science Ltd., Oxford, UK, Vol.28, Issues 4-5: 163-174.

Todorovic, M. (2007). Monthly climatic water balance of the Apulia region (Southern Italy): Analysis of historical weather data and the projections for the 21st Century. In: *Proc. of the 3rd International Conference on Climate and Water*. SYKE, Finish Environmental Institute, Helsinki, p. 462-468.

Walski, T.M., Chase, D.V., Savic, D.A., Grayman, W., Beckwith, S., and Koelle, E. (2003). *Advanced Water Distribution Modeling and Management*. Heastad Press, Waterbury, CT, USA, pp. 751.