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Etat de l'agriculture en Méditerranée : Ressources en eau : développement et gestion dans les pays méditerranéens

Bari : CIHEAM
Cahiers Options Méditerranéennes; n. 1(1)

1993
pages 198-212

INFORMATION SYSTEMS FOR WATER RESOURCES PLANNING AND MANAGEMENT: APPLICATIONS TO IRRIGATION

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Summary

This paper reviews some aspects of information systems, mainly systems analysis in water resources planning and management. After a short overview on methodologies and techniques, several examples of their application to agricultural are presented water management. These case studies include irrigation scheduling simulation models and decision support systems (DSS) designed to help farmers optimize decisions on when and how much to irrigate, as well as planners and managers to orient decisions on allocation and deliveries according farm strategies. Case studies also cover the use of DSS for design of surface irrigation systems and for improved management of canal irrigation systems. Examples make evident the usefulness of information systems, but also the need of appropriate institutional solutions for implementation and for communication between medellers and users.

Resumé

Cette communication fait la révision de quelques aspects des systèmes d'information, en particulier l'analyse des systèmes, pour la planification et gestion des ressources en eau . Ainsi, après un aperçu sur les méthodes et techniques utilisées, sont donnés quelques exemples d'application en irrigation. Des études de cas concernent des modèles de simulation de la conduite des arrosages et des systèmes de support à la décision (DSS) pour

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appuyer les irrigants à decider sur l'opportunité et les volumes des irrigations, aussi bien que les projectistes et gestionnaires à orienter leurs décisions sur les allocations et les fournissements d'eau selon la perspective des producteurs. D'autres études de cas concernent les DSS pour le project de systèmes d'irrigation de surface et pour l'amélioration de la gestion de systèmes gravitaires collectifs. Les exemples montrent l'utilité potentiel de l'analyse de systèmes en même temps qu'ils font découvrir le besoin de solutions institutionnelles appropriées pour leur implementation pratique et, aussi, la necessité d'améliorer la communication entre les analystes et les utilisateurs.

INTRODUCTION

Information systems are methodologies aiming at supporting decisions. Two main type of information systems are used in water resources planning and management: geographical information systems (GIS) and systems analysis. Geographical information systems are powerful database systems which combine data banks, spatial data processing, thematic mapping and graphic/geometric data processors. GIS are essential support of information for decision making and are often associated with systems analysis for building decision support tools.

Systems analysis is a broad methodology of using models for solving engineering and management problems by decomposing them into inderdependent processes of different nature. Modellers represent the processes involved and theirs inter-relationships according the nature of processes - physical, economical, social, ecological - and objectives to be attained - planning, design, management, operation.

In systems analysis there are two main group of agents, the modellers and the users. Among users we may have designers, managers, operators and other decision makers. The interfaces between these two main group of agents can do not be very clear but distinction can be made in a simple manner, like discussed by Loucks (1992): modellers must accept that decisions may not be influenced by model results, while decision makers should not blame on the models if their judgement has not been the best.

Systems analysis require a strong interaction among modelers and decision makers. The statement of the problem must be clear, objectives be well defined and information maximized. To do so the users have to be involved with the conceptual development of the models and not only be the clients for a final product, while modellers can not be left alone, without any feedback about theirs outcomes.

Main advances in systems analysis methodologies come from research but no similar progress is visible on its use by decision makers despite developments in computational facilities and users friendly interfaces. Therefore the gap between research and practice may be increasing. Challenges have to be faced by both analysts and users (Loucks, 1992) and new efforts have to be done for filling the gap between research and practice. This is particularly true in irrigation and agricultural water resources planning and management.

AN OVERVIEW ON SYSTEMS ANALYSIS

Systems analysis can be applied to a very large number of problems in irrigation and agricultural water management. These comprise on-farm decisions, project operation and management, water resource planning and allocation, water quality management, environmental impacts assessment. In any case an optimal solution is searched but the optimal result can be expressed in particular forms or satisfying specific requisits. Very recent review papers by Loucks (1992), Yeh (1992), Goulter (1992), Simonovic (1992), Uber et al (1992) and Orlob (1992) give a complete information on systems analysis methods and their application in water resources.

Linear programming (LP) is one of most widely used techniques for managerial purposes in water resources (Yeh, 1992), including linearization or quasilinearization procedures when dealing with non linear equations. This optimization technique is common in agriculture when the objective function is expressed in monetarian terms. A recent example is given by Prato and Ma (1991) for evaluating impacts of agriculture on water quality. Linear programming is also common to optimize pipe distribution networks (Goulter, 1992).

Techniques derived from linear programming like dynamic programming and non linear programming are also common, with both deterministic and stochastic approaches. As for LP, they are particularly useful for water resources management, namely for water allocation purposes and for reservoir management (Simonovic, 1992). Several other formulations of mathematical optimization models have been developed in the last decade to responde to complex systems or multi-objective and multi-criteria problems. They are applied in particular to optimize water allocations and to evaluate water quality strategies and alternatives (Uber et al, 1992; Orlob, 1992; Kindler, 1992).

The use of simulation models also developed enormously to support decisions. These models cover a great variety of situations and approaches (Loucks, 1992). A simulation model can be utilized alone creating alternative solutions or scenarios which help the user to make a decision. This is typically the case for irrigation scheduling (Stockle, 1991; Pereira et al, 1992). Or the model can generate state variables which allow the best operation decisions, as it happens with canal models (Burt and Gartrell, 1991, Clemmens et al, 1991).

More recently, several models are embedded in a frame programme making it possible an holistic approach considering the interaction of different processes. This is tipically used for design and management (Ait Kadi et al, 1990, Zagona and Strzepek, 1991) of irrigation systems. The present literature is rich of similar examples in many areas interesting irrigation and agricultural water resources management. At present, decision support systems (DSS) become more widely used because they combine, in a holistic and interactive approach, simulation and/or design models, optimization models, data bases and/or geographical information systems embedded in a friendly and graphical user interface. This facilitates the use of models and should increase the interaction and communication between analysts and users (Loucks, 1992).

Exemples of DSS in irrigation and agricultural water management are growing, both for design (Bralts et al, 1990; Garcia et al, 1990) and management at farm (Hoogenboom et al, 1991; Wilmer et al, 1991) and project level (Ait Kadi et al, 1990; Zagona and Strzepek, 1991).

EXAMPLES OF APPLICATION IN IRRIGATION

Decision levels and planning scales

For irrigation and agricultural water management, three levels of decision must be considered (Pereira, 1987):

a)_ The farm level. Farmers decide on crops, cropping systems, irrigation methods and irrigation management practices. These decisions combine to define the on-farm water management. Results of the irrigation projects depend upon the appropriateness of such decisions. Nevertheless, farmers decisions and O-FWM practices are influenced by decisions and criteria from the upper levels.

b)_ The irrigation project level. Decision belongs to the operation, maintenance and management (OM&M) authorities. The OM&M decisions, in particular the delivery scheduling, affect and introduce restrictions to the on-farm water management decisions. Thus they should be oriented to provide the adequate conditions that enable the best irrigation and farming practices. Decisions should also make effective the water resources policies and the involvement of farmers in the management process.

c)_ The basin level. Decisions are related to the country or regional water resources policies and influence agriculture through water allocation and water quality criteria. Representatives of the farmers and of irrigation associations should be involved in the process of water resources policy making and for solving intersectorial conflicts.

Exemples are given bellow relative to the first two levels of decision. These examples concern case studies of research being developed. For the third level of decision, the river basin or region, it is our understanding that problems of institutional nature prevail on the technical ones (Pereira 1987; Pereira 1991). A large number of tools to support corresponding decisions are reviewed in Loucks (1992), Simonovic (1992) and Uber et al (1992), just to quote some of most recent papers.

Irrigation scheduling simulation

Large number of papers give information on simulation models which could help farmers decisions about when and how much to irrigate. The papers included in Pereira et al (1992) give a perspective on these diversity and explain a large number of models and approaches. As exemple, the model ISAREG is selected (Teixeira and Pereira 1992; Teixeira et al, 1991).

The model ISAREG performs a soil water balance for irrigation in combination with an water-yield routine. Thus irrigation scheduling is evaluated through two parameters, the relative crop evapotranspiration and the relative yield loss.

The programme has a friendly users interface, with Portuguese and English versions, which permit the users:

- to select, introduce, modify or update the data files on crops, soils and meteorological variables (evapotranspiration and effective rainfall);

- to choose the simulation options for (i) fulfilling the crop water requirements (maximal yield), (ii) applying deficit irrigation using a selected irrigation treshold, (iii) irrigating with restricted available depths and at fixed periods; (iv) optimizing the irrigation dates when water supply is limited;

- to repeat calculations with new tresholds or new assumptions for the computational procedures, thus comparing alternative irrigation strategies;

- to make new computations for alternative crops or crop systems, as well as other environmental data.

This simulation model is therefore a tool for selecting alternative strategies for irrigation management, helping the farmer to plan irrigation of several crops in more than one location. Present developments include: the development of a programme to help designing irrigation projects using simulated scenarios of crop patterns and irrigation management rules (programme PROREG); the development of programme to simulate the demand in an irrigation system aiming at improving deliveries and operation; the combination with a geographical information system to make easier the utilization of ISAREG at regional scale.

Decision support systems for irrigation management

The usefulness of DSS for irrigation management is evident: the farmer (or an irrigation system manager if the programme is designed under this perpective) can, in real time, decide and revise decisions on the timeliness and depths of irrigations.

These DSS developed first for center pivots irrigation management (Wilmes et al, 1990) but tend to be applied to diversified conditions. This is the case for an EC project[1] aiming at developing an irrigation management DSS, the HYDRA DSS. Diverse irrigation processes (sprinkling, drip/trickle and surface irrigation) are considered as well as several crops - fruit, vegetable and field crops. The system is expected to be applied by farmers at regional level, integrated or not in collective irrigation systems.

The HYDRA is composed by

- an user's interface, commanding the input and output using a friendly language;

- a knowledge processor, consisting of (i) an interpreter for converting users goals into optimization calls, (ii) a scennario generator to select the computational sequence and models to be utilized, (iii) an optimizer for solving optimization functions, and (iv) a translator which converts the mathematical optimization results into the user language;

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1 The project leader is the University of Trento and associates are CSIC-Murcia, IAM-Bari, Staring Centre-Wageningen, RES, Rothamested, ISA-Lisbon, Bonifica-Roma, HITEC, Athens.

- a models processor commanded by the knowledge processor. Several simulation models can be embedded which are called by a trigger model according the nature of problem to be solved. At present models considered are ISAREG (Teixeira & Pereira, 1992), a real time irrigation scheduling model RELREG derived from ISAREG, the soil water balance and crop growth model SWACRO (Kabat, 1992), and sub - models derived from this one, including a salinity model;

- a data processor composed by a data base management system commanding several information systems relative to agro-meteorological data, soils, crops and other spatial data like thematic geographical information systems.

Building this HYDRA DSS is a very challenging activity requiring a strong multidisciplinar approach, which justifies the involvement of institutions of several countries.

It is expected that HYDRA be accessible to farmers under different hardware configurations like personnal computers or videotex. This DSS should enable farmers to optimize planning of irrigation strategies and to decide irrigations in real time. The simulation capabilities together with the thematic and spatial database would allow managers and planners to optimize deliveries and water allocation. Uses of DSS are comparable to those of simulation models but optimization capabilities, multiple choice of models, and enlarged capacities of databases give to DSS a wider application and improved accuracy.

As for using simulation models, a problem subsist: the implementation in field practice. This require not only the models be adequately validated but that appropriate institutional arrangements be built, involving farmers and extension officers in a strong cooperation.

Design of farm surface irrigation systems

The design of surface irrigation is not anymore a task to be left to farmers, like it happen when these systems were traditional. With modern surface irrigation multiple options have to be considered simultaneously: the irrigation process (furrow, level basin or borders); the slope; the length and width of the field units; the irrigation discharge and duration of irrigations; the water supply, like a field ditch with syphons, gated pipes, surge flow equipment, cablegation or other automation devices.

A DSS can be of great interest to help farmers, designers and managers making the best decisions. Thus a DSS for designing farm surface irrigation systems must embed several models or programmes:

- a data base (GIS) including information on field forms and locations, soil hydraulic characteristics, land slopes, the water distribution system and turnout discharges, main crops, water requirements;
- a design model for furrow, border and level basin irrigation, like SIRMOD (USUF, 1989);
- a land leveling design model;
- design models for the on-farm supply systems;
- a programme for computation of the economic impacts of the design solutions;
- a programme for evaluation of alternative solutions based on investment costs, operational costs, irrigation performances and related impacts on yields.

This DSS is being developed for the Mondego area, based in field calibration now under progress. This DSS would provide the support to:

- the selection of the most appropriate surface irrigation method: furrow with continous or surge flow, border or level basin irrigation;
- the required land levelling;
- the definition of the design parameters like furrow length, slope, discharge and irrigation time and, for level basins, the discharge, the length and width of the basin, and the irrigation time;
- the choice of the water supply system, size of conduits and automation devices;
- the computation of irrigation performance parameters, mainly application efficiency and distribution uniformity;
- the investment and operational costs;
- the comparative economic advantage of the irrigation system.

Improvement of irrigation systems management

As reposted earlier, many attempts are being developed and implemented to improve deliveries, operation and management of collective irrigation systems (Ait Kadi et al, 1990; Pereira et al, 1990; Zagona and Strzepek, 1991; Gates et al, 1991). Developments are particularly important for irrigation canal systems, where response time and restrictions to delivery are much greater than in pressurized systems (optimization tools for these systems are dealt in another paper to this Workshop).

For canal systems, objectives of decision suport tools are to help managers deciding deliveries that match demand. This would improve farm irrigation conditions allowing the implementation of more flexible irrigation delivery scheduling, and providing conditions to reduce operational water losses.

Decision support tools for management of irrigation canal systems include several models and processors. Taking as example the case study described by Pereira et al (1990), it can be observed that a system has to include.

- a database concerning the canal conveyance and distribution system including turnouts, the irrigated parcels, the agro-meteorological information, the records of past years irrigation and the records of actual deliveries. A GIS would be required. Information has to be used by the different models;

- a demand model for predicting in advance the outflows at main turnouts in the system in case no restrictions are imposed to users for formulating their own demands. In alternative, if farmers demand is provided enough time in advance, the demand model aggregates the demands at turnouts;

- a delivery model which computes the demand hydrographs and helps to decide priorities of delivery where demand exceeds the capacity of the system;

- a canal simulation model which computes travel times. The hydraulic simulation helps to establish the inflow hydrograph that better satisfy the target deliveries.

Canal irrigation systems management tools can be used not only to improve deliveries but also they may be utilized with remote controlled devices to command regulation structures if remote sensed state variables are available in real time. The data base can also be used with an interface for the irrigators to formulate the demands. Also the database can be use for billing using the information on actual deliveries. More advanced configurations of the systems using optimization processors can be considered as DSS. The advantages of using any kind of these management tools are evident when compared with traditional upstream control systems, where the rigidity of operation and delivery is the basic condition for equity and reliability.

CONCLUSION

The short review above shows a diversity of methodologies and approaches on using information systems to support decisions in water resources planning and management, particularly in irrigation. Applications to on-farm and off-farm irrigation management, as weel as for design of irrigation systems, make evident the potential of such decision support tools, but also two great challenges for making full use of them: reducing the gap between research and irrigation practice and improve institutional arrangements for farmers participation.

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