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WSUDC: A prototype Decision Support Tool for water supply systems management under drought conditions

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SUMMARY – In order to implement an integrated approach for drought management, appropriate decision support tools are needed both in planning and operation stages. The paper presents WSUDC (Water System management Under Drought Conditions), a prototype software consisting of several modules for the reconstruction of streamflow series either in gauged or ungauged basins, the assessment of water volumes that can be diverted from a river section with fixed return period, the computation of water balance for reservoirs and diversions, the simulation of complex multipurpose water supply systems and the analysis of risk of water shortages. An application to an Italian case-study including several reservoirs and competing uses is discussed.

Key words: Decision Support System, drought, water management.

RESUME – *"WSUDC : Un prototype de software d'aide à la décision pour la gestion des systèmes d'alimentation en eau en conditions de sécheresse". Afin de mettre en pratique une approche proactive pour la gestion de la sécheresse, il faut utiliser des instruments appropriés d'aide à la décision soit pour la phase de planification soit pour la phase d'exploitation. L'article présente WSUDC (Water System management Under Drought Conditions), le prototype d'un software qui se compose de huit modules pour évaluer les séries de débits d'une rivière et la disponibilité en eau des barrages, pour calculer le bilan hydrologique pour les réservoirs et pour les barrages, pour simuler des systèmes complexes de distribution de d'eau pour plusieurs usages et pour étudier le risque des pénuries d'eau. Dans cette recherche on examine un étude de cas italien avec plusieurs réservoirs et plusieurs usages conflictuels de l'eau.*

Mots-clés : *Système d'Aide à la Décision, sécheresse, gestion de l'eau.*

Introduction

A Decision Support System (DSS) can be defined as a tool that allows decision makers to combine personal judgment with computer support, in a user-machine interface, to produce meaningful information for support in a decision making process (Simonovic, 1996). In particular, focusing more on the architectural structure rather than in the activities supported, in general terms a DSS consists of three subsystems, the modeling subsystem, the database subsystem and the user interface subsystem, strongly interconnected with each other and sharing common datasets.

Decision Support Systems can play a key role within an integrated approach to water resources management especially for water systems supplying conflicting uses and located in drought-prone areas (Rossi *et al.*, 2007). Several general water management oriented software are available (Labadie *et al.*, 1995; Andreu *et al.* 1996; Díaz *et al.*, 1997; Cancelliere *et al.*, 2003) and application to many case studies have shown that the adoption of DSSs can reveal very useful for strategic planning or for management and operational control of water supply systems. Despite the current efforts to address through existing DSSs a broad class of problems, very few examples exists of DSS specifically oriented to evaluate the risk of water shortages due to drought in complex water supply systems. Furthermore often existing DSS do not conform with the peculiar objectives of water systems located in drought-prone areas such as making decisions related to choice of short or long term mitigation measures to face possible drought conditions. In the present paper a prototype DSS named WSUDC (Water System management Under Drought Conditions) is discussed. WSUDC has been developed within the Italian national project AQUATEC supported by the Italian Ministry for University and Research which had the main aim to study an innovative approach for improving planning and management of water resources under the requisites deriving from European and Italian legislation framework providing tools to cope with permanent water scarcity and drought problems. The general objective of WSUDC is not to directly resolve water uses conflicts but help stakeholders in gaining a better understanding of the existing problems, formalizing common performance objectives, developing and evaluating possible alternatives, providing confidence in solution and a common ground for discussions and further negotiations. In particular, the software enables to perform the following tasks:

(i) evaluation of hydrological inputs for water supply systems according to the methodology proposed by Cutore *et al.,* 2007;

(ii) estimation of demand-resource water balance;

(iii) drought risk assessment in water supply systems according to the methodology proposed by Nicolosi *et al.* (2007).

WSUDC structure and computational modules

From a conceptual point of view WSUDC is divided into three main components: computational modules to carry out specific DSS tasks, a common system database and a specifically developed graphical user interface. A functional scheme of WSUDC depicting the connections among the different computational modules is reported in Fig. 1.

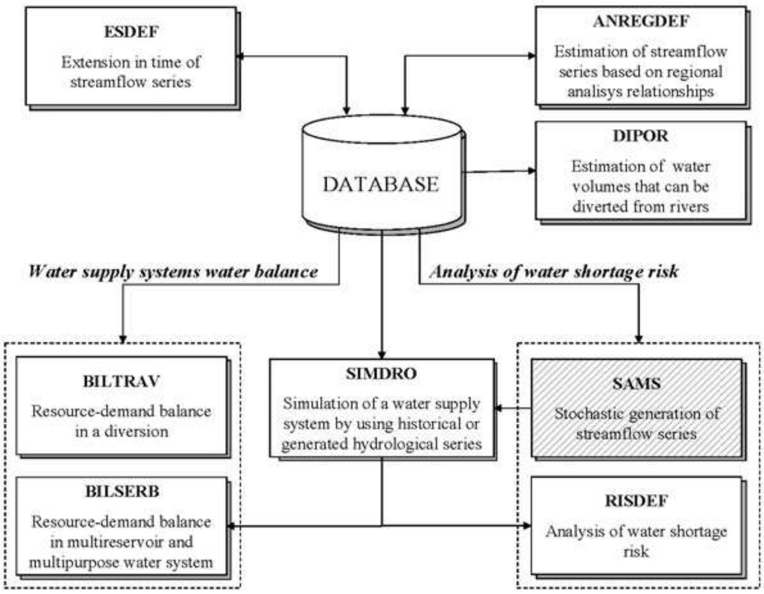

Fig. 1. Structure of WSUDC.

More specifically, WSUDC comprises seven specifically developed computational modules, in addition to an existing module SAMS for synthetic data generation (Sveinsson *et al.*, 2003), namely:

ESDEF, at site precipitation-streamflow modelling based on multiple linear or non-linear regression and/or neural networks for the extension of historical time series of streamflow at river sections;

ANREGDEF, regional precipitation-streamflow modelling based on non-linear regression and/or neural networks for the reconstruction of streamflow time series at river sections without observations;

DIPOR, estimation of water volumes that can be potentially diverted from a river section corresponding to fixed return periods, based on daily flow duration curves;

BILTRAV, evaluation of water resources-demands balance for a single river diversion;

SIMDRO, simulation of complex water supply systems taking into account the implementation both of long and short term drought mitigation measures using historical and stochastically generated data through the external module SAMS;

BILSERB, analysis of results of the module SIMDRO oriented to drafting the water balance for the different components of a complex water supply system;

RISDEF, analysis of results of the module SIMDRO oriented to the assessment of the risk of water shortages due to drought through performance indices and graphs representing frequencies and severity of water shortages;

WSUDC requires as input basic hydrometeorologic data (i.e. monthly historic streamflow, precipitation and temperature series), geomorphologic data of the basin under study (i.e. area, mean elevation, percentage of pervious basin area, slope of the main stream), information about present and estimated water demands, technical and management information about diversions and reservoirs (i.e. flow-duration curves for diversions, surface-storage curves for reservoirs, operating rules, etc.).

Some innovative features of WSUDC in respect to other existing DSSs include:

(i) the possibility to reconstruct long streamflow series for all the basins upstream water plants in order to evaluate resource-demand balance corresponding to several occurrence probability of streamflows;

(ii) the simulation of complex water supply systems under drought conditions addressing explicitly the risk of water shortages through the use of dedicated operating rules and target storages imposing rationing for not prioritary water uses;

(iii) the representation of results oriented to support decision makers with user- friendly probabilistic information about the risk of shortages due to drought in correspondence of the implementation of different mitigation measures for complex systems.

Current version of WSUDC is a prototype in Italian language. The modules are written in several languages (FORTRAN, Visual Basic and MATLAB) and the graphic interface runs in MATLAB environment.

Application to a complex water supply system in a drought-prone area

The Agri-Sinni multipurpose water system supplies several water uses located in the Southern part of Italy involving three administrative regions (Basilicata, Apulia and Calabria) historically suffering water scarcity problems recently worsened by frequent drought events. The decision making process related to the allocation of the water resources available for the Agri-Sinni water supply system is particularly complex. The water system is strongly interconnected (4 reservoirs, 4 diversions, 9 points of demands), supplies different water uses (municipal, irrigation, industrial located in three administrative regions) in addition to ecological constraints. As a consequence water conflicts among stakeholders are very likely especially during drought conditions. In order to solve conflicts, a joint institution between Apulia and Basilicata regions (Coordination Committee) is responsible for the allocation of water resources among the different regions and uses.

Due to its complex nature, the system represents an ideal candidate to test the ability of WSUDC to evaluate the effectiveness of structural and non-structural mitigation measures in reducing risk of shortages due to drought. First, the module ANREGDEF of WSUDC has been used in order to augment the available dataset. In particular the streamflow series corresponding to eight river sections of interest have been estimated by developing a relationship among the available series of streamflows (obtained in correspondence of the reservoirs and reconstructed through water balance) and some meteorological and geomorphologic characteristics of the upstream basins. Such relationships have then been adopted for the sections of interest lacking data. Multiple regressions and Neural networks techniques have been applied and linear and non-linear multiple regressions models have been adopted, computed at monthly scale grouping data for three-months periods, namely:

$$D(t) = f(P(t), T(t), D(t-1)) \qquad D(t) = (P(t), T(t), H, perm, L, D(t-1)) \tag{1}$$

with *D(t)* streamflow at a given section, *P(t)* areal precipitation on the basin upstream the section of interest, *T(t)* mean temperature of the basin upstream the section of interest, *H* mean altitude of the basin, *perm* percentage of pervious area of the basin, *L* main stream length, *t* time step (month).

Analysis of results, based on indices such as mean error (*ME*), round mean square error (*RMSE*) and coefficient of determination (R^2), showed that a linear multiple regression model based on hydrologic similitude among basins is preferable. Using the above mentioned model, streamflow series have been reconstructed for all the eight sections of interest for the period 1963-2005.

Five different simulations of the system have been carried out by means of the module SIMDRO. Two simulations, namely simulation 0 and simulation 1, are representative of the present configuration of the system (hydraulic plants in operation and current water demands with an improved operation rule in simulation 1) whereas simulation 2, 3 and 4 consider the system in its future configuration (new diversions and increased municipal water demands).

Simulation 2 includes improved operation rules based on the use of carryover storage capacity of Montecotugno reservoir and the safeguard of the priority of municipal demand satisfaction through the assignment of monthly target storages in reservoirs. Simulations 3 and 4 include the implementation of long term and short term measures to reduce the vulnerability to drought of the system. In particular simulation 3 includes water reuse of treated waste waters, recovery of water excess from irrigated lands to be devoted to agricultural demands, and use of pumping from surface and groundwater marginal resources during emergencies. Simulation 4 includes, besides the long term reuse of treated wastewaters, also the temporary re-allocation of water normally devoted to hydropower generation of Cogliandrino reservoir.

Results of SIMDRO have been analyzed through the module RISDEF. In Fig. 2, examples of outputs from the modules are shown. In particular, from the two plots at the bottom, it can be inferred that adopting mitigation measures against drought (Sim_3) reduces the risk of water shortage due to drought with reference to irrigation uses since the probability of occurrence of severe water shortages (expressed as a percentage of the total monthly demand) is reduced.

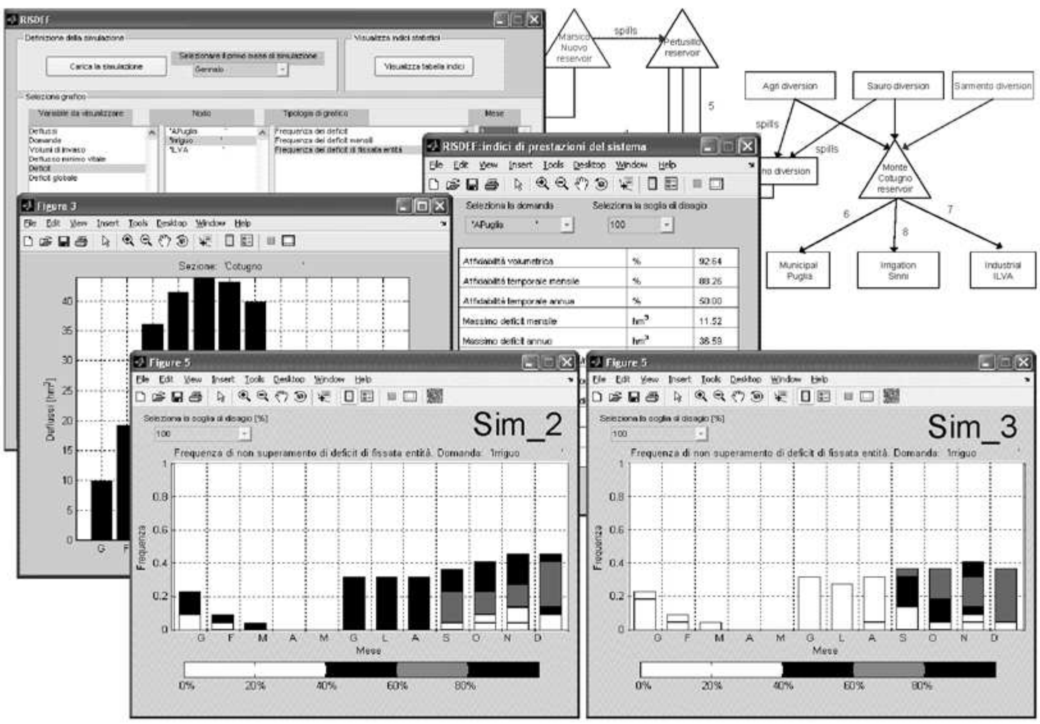

Fig. 2. Examples of output from module RISDEF and comparison of the probability of water shortages of given entity between Sim_2 (no mitigation measures) and Sim_3 (with mitigation measures)

Conclusion

Planning and operation of water supply systems can effectively improve through the application of advanced tools, especially when facing drought conditions. Such tools should be easy to use and flexible to accommodate changes in the environment and in the decision making approach. The integration of several mathematical models within an user friendly DSS such as WSUDC can effectively support decision makers in helping the evaluation of the reduction of water shortage risk due to drought, consequent to the implementation of different mitigation measures. The use of tables and simple graphs can improve the understanding of the water problems affecting a complex water supply system contributing on building a common shared vision among stakeholders.

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