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CLIMATE CHANGE AND DECISION SUPPORT SYSTEMS FOR WATER RESOURCE MANAGEMENT IN LARGE RESERVOIRS

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Abstract

The issue of water resources management requires more and more approaches in which multiple skills and capacities are nested together (Integrated water resources management process), especially when critical situations are taken into account, such as climate change scenarios. The various disciplines involved can be climatology, meteorology, hydrology, ecology, environmental science, agricultural science, water resources engineering, socioeconomics, law and public policy. In this context, Decision Support Systems (DSS), applied to the management of water resources, play an essential role since they must allow the different stakeholders and competencies involved to summarize results and produce decisions on a common and shared basis. The RIVER software is a DSS for water resource allocation and management which portraits the hydraulic situation in the catchment area with a simple intuitive "node-arc" sketch, at the same time uses simulation algorithms to allow the user to take into consideration many different scenarios of water use according to the principle of "priority-balanced" criteria shared by all stakeholders involved. The case study for the Montedoglio reservoir in the Tiber River Basin, highlights how these principles can be applied for a proactive management of critical scenarios in periods of drought due to climate change hypothesis. In particular, time series of hydrological flow, modulated with drought and climate trends, have been simulated and, as output of the system, indications for preventive interventions to be planned for a correct use of water for irrigation, civil and environmental use have been obtained.

Key words*: climate change, decision support systems, environment, irrigation, water resource management.*

INTRODUCTION

The management of surface water resources can be studied by means of simulation models to sketch hydrographic network in terms of nodes and arcs in a graph, which are combined with mathematical algorithms to simulate water management. By adopting this method, configurations typical of the majority of the river systems can be described in a more or less synthetic way, but at the same time extremely effective. In literature there are some interesting applications of this methodology, the most relevant are: "Aquarius" (Diaz et al., 1997), "REALM" (Resource Allocation Model, AA.VV., 2001) and "wargi" (Water Resources system optimization aided by Graphical Interface, Sechi and Sulis, 2009).

In this bibliographic context, the River software, used in this study, has been developed and expanded by the authors (Pierleoni et al., 2008) in order to operate in a territorial scope of the river basin, in the presence of a multiple use of water resources, with the aim of representing an instrument to support the decisions that are often also subject to territorial and administrative constraints.

The main features of River can be identified as follows:

- weekly time-step simulation of the time series, with the possibility to work at a monthly scale;
- Adoption of an algorithm for the management of water resources under deficit conditions that uses a policy called "primary balance";
- Possibility of using hydrological input data in the form of time series, the year type or both;
- Extremely flexible data output for reservoirs, generic use and control of the flow in both a graphical and numerical way, with a particular

attention to the use of the model in terms of management in the short term together with probabilistic assessments.

MATERIALS AND METHODS

The algorithm that manages the distribution of water from the reservoir node is certainly one of the features that characterize this mathematical model the most, in this particular case study, for the upper valley of the Tiber River. In fact, in this basin, there is the artificial reservoir of Montedoglio (maximum available volume 142.5 Mm^3). The hydrological study of the reservoir dates back to the '60s, so the management of the reservoir must take into account the changing needs of users and the new hydrological framework, also according to the hypothesis of climate change.

The algorithm is based on an equation of balance between the available volume present in the reservoir and the total need required by the various user nodes which should be supplied from the reservoir. The distribution and number of uses can be easily changed by editing the topology of the network, allowing the use the model both during management of existing works, and in the programming phase of the works of adduction to be built.

The balance equation is centered on the calculation of the Total Available Volume (TAV) in the reservoir node (S) and the Total Required Volume (TRV) of the user nodes, resulting in a ratio for the generic time step i

$$\alpha_{rid}(i) = \frac{TAV_S(i)}{TRV(i)}$$

The parameter α is the management index, as it returns the ratio by which the requests FA of the n users managed must be reduced, therefore defining the actual Available Volume

$$AV(i) = \alpha_{rid}(i) \cdot \sum_{j=1}^{n} FA_j^*(i)$$

The issue of managing the water needs during periods of deficits can be studied in terms of optimization between the various users (Georgiou et al., 2006), or though the simulation of hypothetical scenarios (Strzepek et al., 1989). In this model, the logic of optimization has been made more flexible in terms of operational management, to obtain an instrument that can be adapted to the political and economic issues related to the various uses and in the territorial features.

This was achieved by adopting, during deficit periods, an allocation rule called "priority-balanced." In this, the term "priority" means that it is necessary to set priorities among the various uses served, while with the term "balanced" we mean that it deviates from the strict logic of distributing the resource starting from the higher priorities, or putting first the most economically advantageous uses, but each use is reduced by a certain amount, which varies from use to use, from the latest one in order of priority, recalculating the water budget until $\alpha_{rid} > 1$ (Beauty et al., 2004).

This procedure, basically allows the user to distribute the deficit between many different uses, according to different tolerance levels that can be properly studied and commonly shared among water managers or production activities.

The model can simulate and manage river deficits with an input represented by hydrological time series of average flow rate (weekly or monthly). Obviously, this input can be represented by series of real or simulated time series based on assumptions like climate changes, allowing a quick comparison between the results of various simulations.

In this study management scenarios have been simulated using as input, time series containing the climatic forcing. In particular, an increase in the average temperature expected in 60 years by about 0.75 °C, a linear trend for rainfalls (-8% and -3%), a cyclic variation (15 years) for the winter and fall period and a linear trend (3%-10%) for the spring and summer seasons have been adopted. Such hypotheses on rains and temperatures have been used in a Model Hydrological Lumped continuous type, called MILC, which allows to simulate the continuous rainfall-runoff (Brocca et al., 2008), producing the flow rates to be used as inputs to the simulation model River.

RESULTS AND DISCUSSIONS

The topological scheme of the system on which they develop simulations (Figure 1) takes into account all the uses currently foreseen in the plans, together with the monitoring of releases in the river in order to verify compliance with the objectives of environmental protection in the Tiber River.

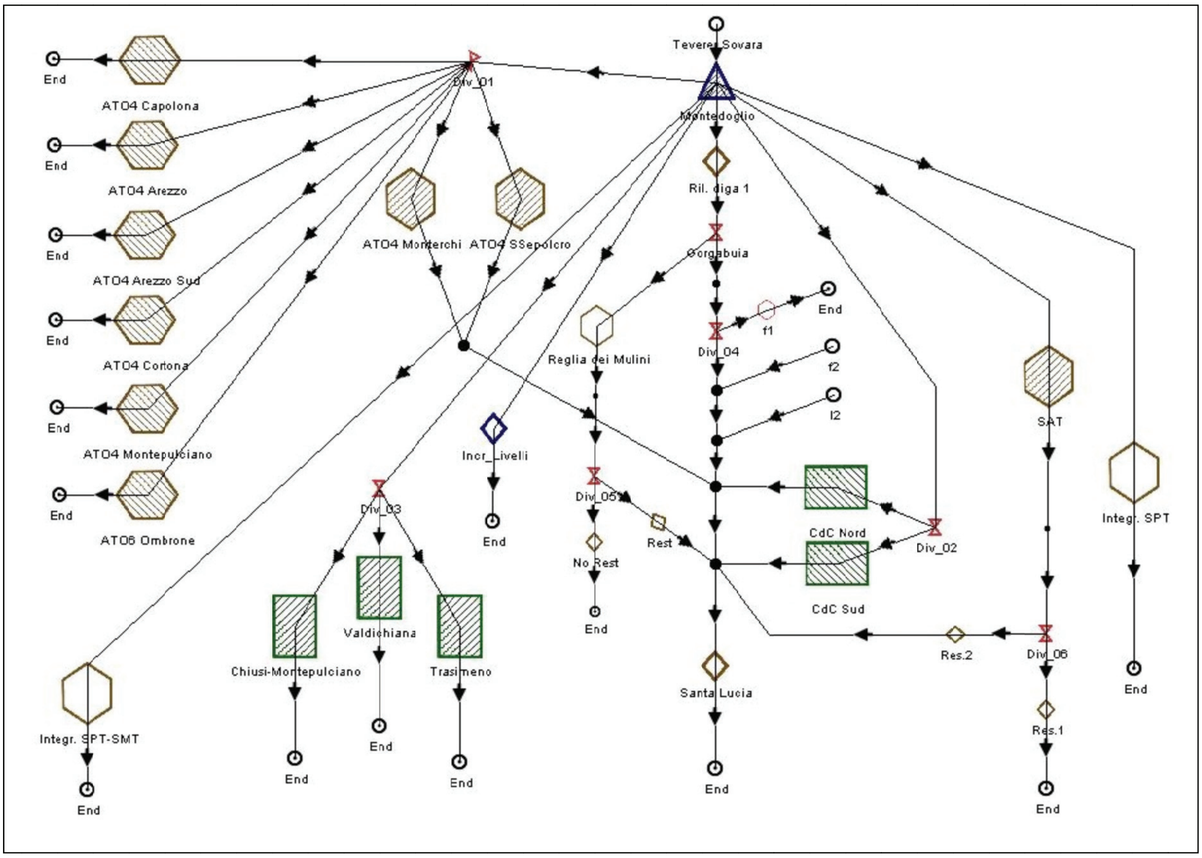

Figure 1. Flow network in the case of study

So, downstream of the Montedoglio reservoir (triangular node) there are two sets of uses, each one of them with two types of uses: the Western bloc, with drinking water uses (hexagonal nodes) and irrigation (rectangular nodes) that are served by a network of pipes that end out of the basin of the Tiber River and the Eastern bloc, with the same types of uses but in a smaller number, that fall in the basin of the Tiber River. Finally, along the natural river bed of the Tiber, there are flow control points (diamond nodes), by which is possible to enforce / monitor releases from the reservoir for environmental purposes.

From the point of view of the operation of the model the prioritization provides a marked uniformity for all drinking uses, regardless of their location, then an equal value of percentage reduction of the needs in conditions of deficit. Irrigation uses, instead, higher priority is given to the uses of the Eastern bloc and the node named Trasimeno, which are in areas with the greatest problems and even more advanced state of completion of the irrigation distribution networks with respect to other nodes in the Western bloc.

The hydrological input to the reservoir node takes into account the climatic forcing described above, which translated in terms of incoming volumes determines the situation represented in Figure 2. In particular, during the sixty years period indicated there might be a pattern with a recurring period of about 15 years, with a decreasing trend in both maximum values and minimum values, which is about -15% in the period.

With respect to this hydrological input the needs required by the various uses are presented in Table 1 and Table 2. In particular, since the hydrological input is represented by a time series of 61 years generated on the basis of climate trends, it appears logical to simulate the water resources management plan taking into account the future demand, according to two time horizons 2023 and 2040 that are identified by the planning policies for irrigation and domestic use.

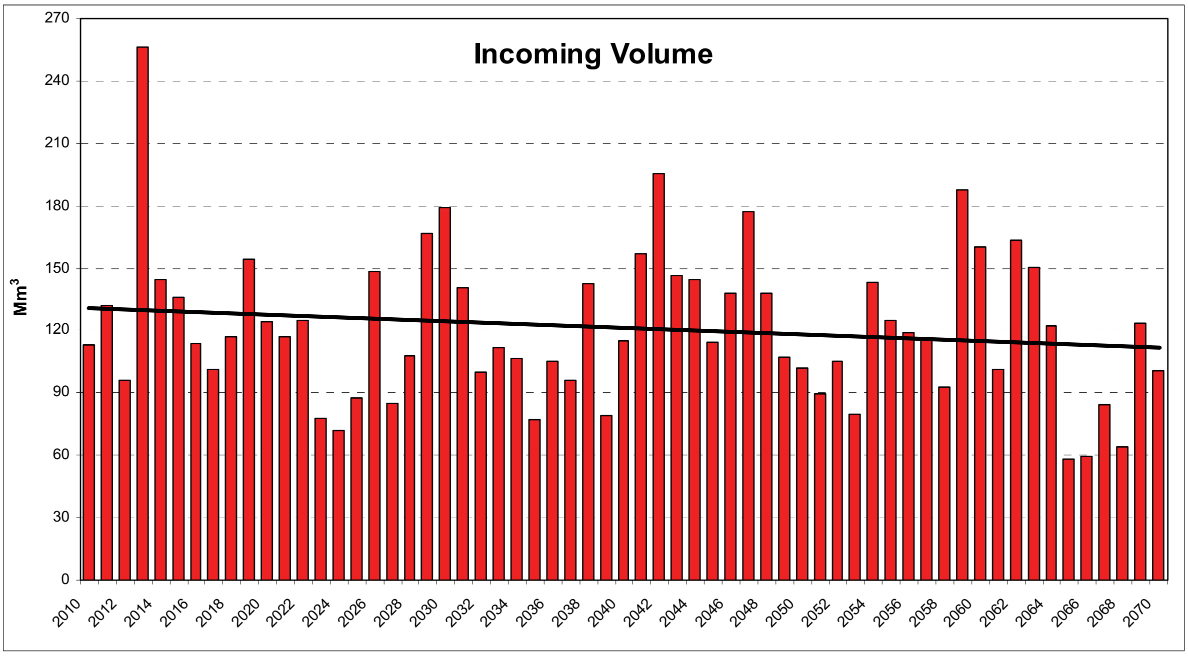

Figure 2. Water volume incoming in Montedoglio Reservoir

Table 1. Irrigation demand foreseen for 2023 and 2040

Years		**2023**			**2040**	
	Area		Vol.	Area		Vol.
Node	Ha	m^3/ha	Mm^3/y	Ha	m^3/ha	Mm^3/y
Valdichiana	36965	1800	66.54	36965	1800	66.54
Trasimeno	12471	2100	26.19	16047	2100	33.70
Chiusi Montepulciano	833	1800	1.50	833	1800	1.50
CdC sud	3615	1800	6.51	3615	1800	6.51
CdC nord	5661	1900	10.76	5661	1900	10.76
Total	59545		111.49	63121		119.00

Table 2. Domestic demand foreseen for 2023 and 2040

Years	**2023**	**2040**
	Vol.	Vol.
node	Mm^3/y	Mm^3/y
ATO4 Capolona	1.45	1.56
ATO4 Arezzo	13.79	14.84
ATO4 Arezzo sud	7.79	8.39
ATO4 Cortona	2.9	3.13
ATO4 Montepulciano	3.67	3.95
ATO4 Monterchi	0.33	0.36
ATO4 S. Sepolcro	1.27	1.37
ATO6 Ombrone	6.3	6.78
SAT	9.63	9.97
SPT	1.57	1.57
SPT.SMT	1.57	1.57
Total	50.27	53.49

For the irrigation uses the increase in demand in the two horizons is more pronounced and yet only involves the Trasimeno node, while for domestic use the modest increase depends on all uses equally.

Simulations are run at a weekly time step, so the annual needs must be distributed over the 52 weeks in a typical year. For domestic use that distribution is almost uniform, with a slight increase in the weeks between the 27 and 35 (Figure 3). In the case of crops instead, the demand is distributed in a restricted period between weeks 22 and 43, according to a law of use which reproduces the most unfavorable trend (Figure 4).

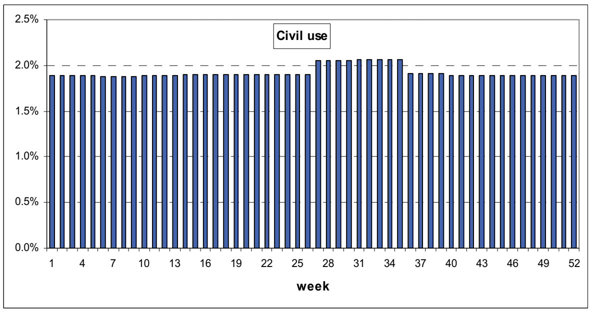

Figure 3. Typical year for domestic use

The first result to be examined in the simulation concerns the behavior of the reservoir in regard to the increasing demand for water for various uses, together with the trend for the hydrological input.

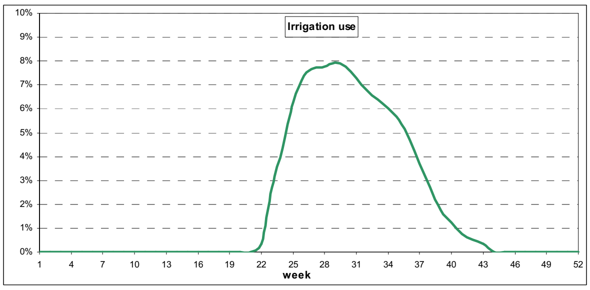

Figure 4. Typical year for irrigation use

There is always a heavy water demand from the Montedoglio reservoir (Figure 5) with evident oscillations in the volume, and consequently in the levels, even in rather short periods of time, with a relative irrelevance of climate trends that still influences the trend of the volume stored.

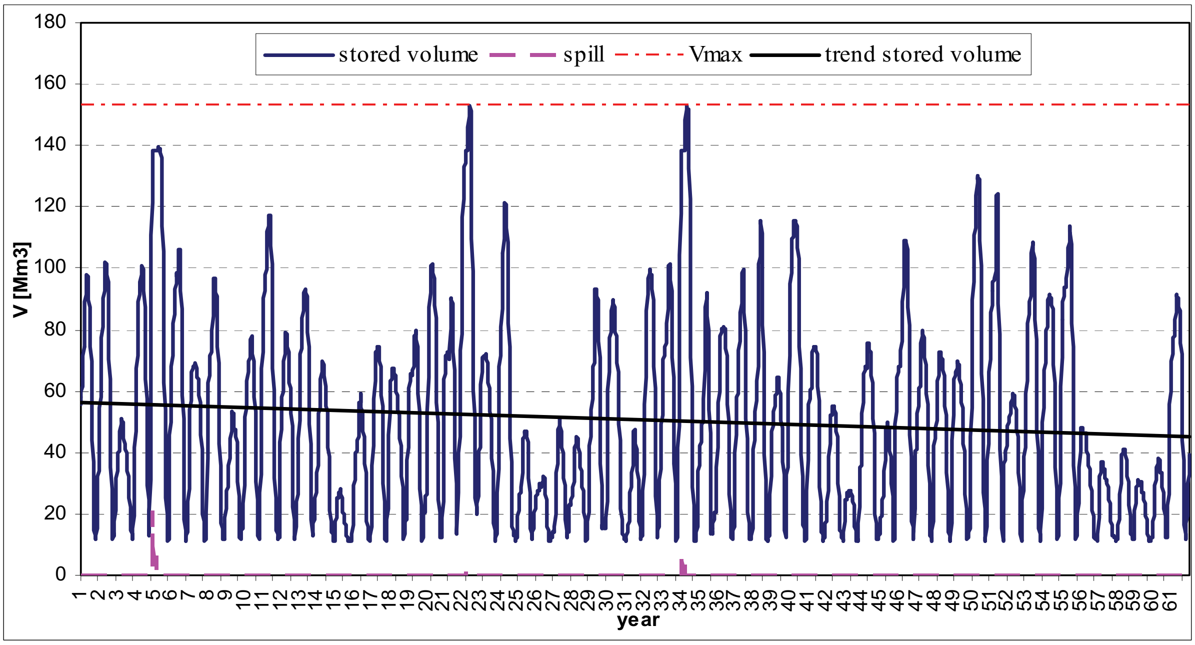

Figure 5. Trend of the volumes, in the simulated time series (2040), for the Montedoglio reservoir

The trend of the available volumes for the various uses, as well as the relative deficits, can be analyzed in terms of time series of weekly data, in order to better understand the frequency in relation to seasonal periods, or it can be cumulated in annual values, or even analyzed in terms of weekly or yearly extreme values. In any case, the approach investigated more in-depth the links between the uses and the reservoir, showing in a graph the trend of the annual deficit per use as a function of the reservoir volume in one week, which can be freely chosen. Figure 6 shows an example of this representation for one irrigation node, taking as a reference the volume stored in Montedoglio, for example, at the 22th week. As can be seen, there are many years with a deficit, as could be expected given the lower priority of irrigation use and especially the high-stress situation of the Montedoglio reservoir; however, the most interesting point is that once a critical deficit threshold has been set (e.g. 10%), it is possible to read the value of the reservoir volume at the 22th week (approx. 120 Mm^3) below which it is probable that this threshold is exceeded, with increases in the deficit more or less linear with the decrease in the available volume at the 22th week.

This result can be used both in the planning of stages for evaluating the degree to which the various uses suffer in the overall context of the network with the hypothetical priorities assigned, and in the management stage as a decision support system, especially in possible negative trend due to climate change.

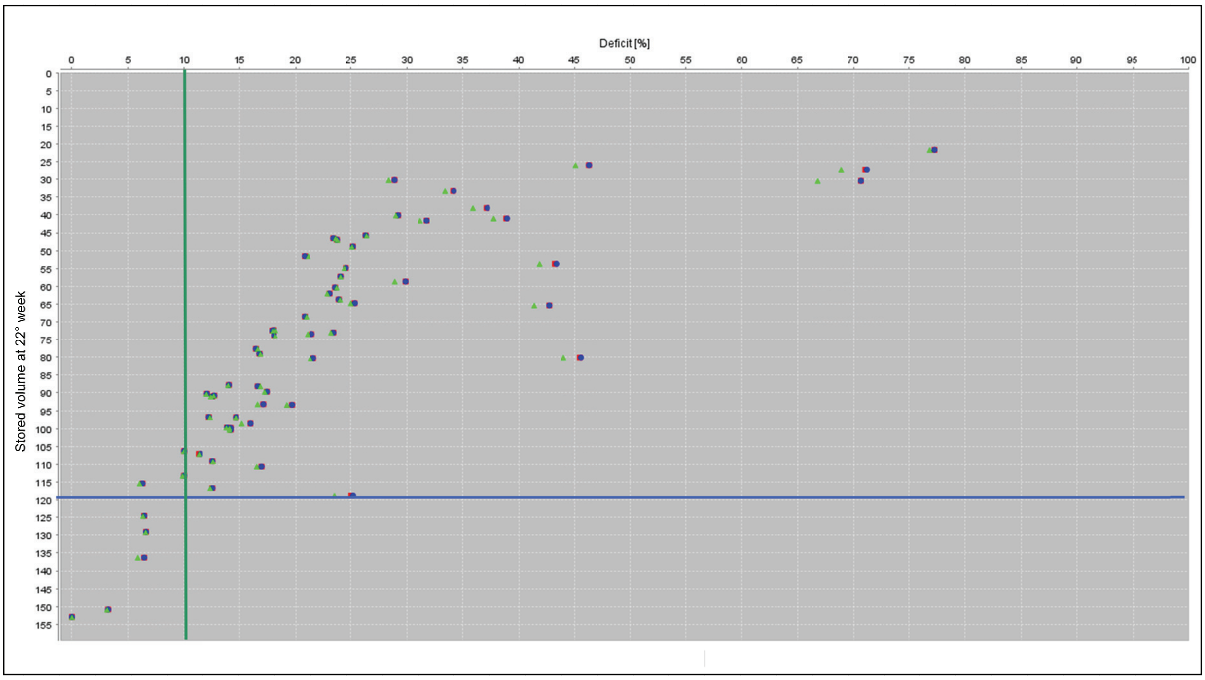

Figure 6. Trend of annual deficits at an irrigation node as a function of the reservoir volumes at the 22th week

CONCLUSIONS

In conclusion, the model developed can be seen as a decision support system to simulate water resource management scenarios that work on historical hydrological data and water needs for multiple uses. The system returns information both on the distribution of the deficit at the weekly scale and on the likelihood that the critical events may occur depending on the availability and management of the volume stored in the reservoir. The simulation algorithm is not strictly related to theories of economic optimization of the exploitation of the resource, but rather aims to facilitate management policies shared among the various users in a spirit of solidarity and tolerance in the redistribution of deficit.

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REFERENCES

Bellezza M., Casadei S., Pierleoni A., Manciola P., 2004. Multipurpose reservoir management and river network modeling. Proceedings of the IASTED International Conference on Environmental Modeling and Simulation, St. Thomas, US, p. 197-201.

Brocca L., Melone F., Moramarco T., Singh V.P., 2008. A continuous rainfall-runoff model as tool for the critical hydrological scenario assessment in natural channels. Headwater to the ocean. Hydrological changes and managements, Taylor & Francis Group, London, UK, p. 175-179.

Diaz G.E., Brown T.C., Sveinsson O., 1997. AQUARIUS: a modeling system for river basin water allocation. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins CO, U.S.

Georgiou P.E., Papamichail D.M., Vougioukas S.G., 2006. Optimal irrigation reservoir operation and simultaneous multi-crop cultivation area selection using simulated annealing. Irrigation and Drainage, 55, p. 129-144.

Pierleoni A., Casadei S., Bellezza M., 2008. A Mathematical Simulation Model for Water Resources Management in Multipurpose Scenarios. In: Ogwu F. J. (Eds.), modelling and Simulation AfricaMS. Gaborone, Botswana, p. 256-262.

Sechi G.M., Sulis A., 2009. Water System Management through a Mixed Optimization-Simulation Approach. Journal of water resources management and planning, ASCE 135(3), p. 160-170.

Strzepek K.M., Garcia L.A., Over T.M., 1989. River Basin Simulation Model. CADSWES, University of Colorado, Boulder, U.S.

AA.VV. REALM, 2001. User’s manual, Victoria University of Technology, Department of Natural Resources and Environment, Australia.