A software for optimal reservoirs management in Sardinia (Italy) - GhOST

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Abstract

Recent dry seasons in Sardinia have shown the inadequacy of water system management methodologies not based on mathematical models and statistical forecast. In fact management decisions based on experience alone and not on rational rules are unable to solve users' conflicts. This work presents the results of a study by Hydrocontrol on the Tirso river basin in Sardinia. The study was aimed at elaborating a management model for the Cantoniera Tirso reservoir (GhOST - Gestione Ottimale Sistema Tirso - 1995), which will be the main reservoir supplying the area of Oristano. The management methodology developed will be able to check the consequences of drought by providing the right apportionment of water among the different users and an optimal distribution of resources.

1 Introduction

The increase in water requirements in recent years has shown the inadequacy of the present management structures of water systems that are often insufficient to meet demands.
The aim of this work has been to develop a management model that can be applied to a pluriennial regulation multiple use reservoir system, with particular reference to the *Cantoniera* reservoir on the *Tirso* river in Sardinia.
It has thus been possible to give an indication of the maximum extension of the *Basso Tirso* (that will receive 80% of the available volume) that can be irrigated when the *Cantoniera-Tirso* reservoir (745 Mm^3 capacity) becomes operative in 1996. The maximum irrigation water volume was obtained by imposing a series of management rules (reduction thresholds on the basis of winter runoff and stored volumes, number of admitted deficit years) in order to produce only deficits "programmed" with a fixed frequency.
The developed simulation software receives its input from a more extended

study[1] on the location of the area, the collection, reconstruction and organization of the data and the generation of synthetic series, with the aim of preparing a valid database for the simulation of a system of reservoirs based both on historical and synthetic series.

2 Study area and database organisation

The located study catchment basin was the *Tirso* river at the *Nuraghe Pranu Antoniu* weir slightly downstream from where the *Rio Flumineddu* and the *Tirso* river join (subtended area: 2952.8 km^2) (Fig. 1). The location was chosen because the weir and the *Cantoniera* dam will be hydraulically connected by a pumping station to send the excess water from *Flumineddu* to the *Cantoniera* reservoir in emergency situations.
The hydraulic scheme of the system (Fig. 2) includes 15 reservoirs, 4 potable water demand centres, 2 industrial water demand centres and 2 irrigation water demand centres.
The storage capacity of small potable use reservoirs upstream from the branches *Tirso* and *Taloro* (*Sos Canales, Govossai, Torrei, Olai*) has been neglected; moreover two reservoirs belonging to the scheme (*S. Chiara d'Ula, Busachi*) will be submerged by the *Tirso a Cantoniera*.
Therefore the reservoirs considered for regulation are the following:
- on the *Tirso*: *Terramala* (planned), *Cantoniera, Nuraghe Pranu Antoniu*;
- on the tributary *Taloro*: *Gusana, Cucchinadorza, Benzone*;
- on the tributary *Flumineddu*: *Araxisi a S'Allusia, Imbessu a Nuraghe Casteddu, Misturadroxiu a Sa Serrada Manna* (all planned).

Data collection included recording of pluviometric and hydrometric stations, the data needed to process the hydrological balance at the reservoirs, the data referred to the historical outflows from the dams for potable, irrigation and industrial uses and those referred to the forecast of future needs.
The data organisation of the considered historical period (1922-1992) was referred to the reconstruction of the natural runoff at the dams, the homogeneity analysis of pluviometric data, and the calculation of maximum evapotranspiration at a guide station in the study reservoir.
The aim of the data processing was to reach a database that should allow the reconstruction of natural runoffs at the damming sections. Moreover, a cartographic plan of the study area was prepared by a GIS.

3 Simulation of the reservoir system in the historical period

3.1 Definition of simulation scenarios

Three time reference horizons that made up the scenarios for the regulation study were determined for the system simulation:
- short term: referring to the situation of the water scheme at the time the *Cantoniera* dam becomes operative;
- medium term: referring to the time the *Terramala* dam becomes operative;
- long term: referring to the time the *Flumineddu* reservoirs become operative.

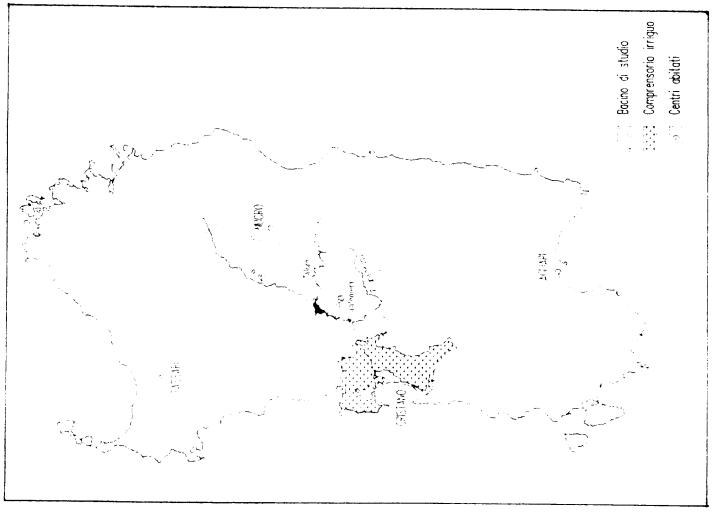

Figure 1 - Study catchment basin

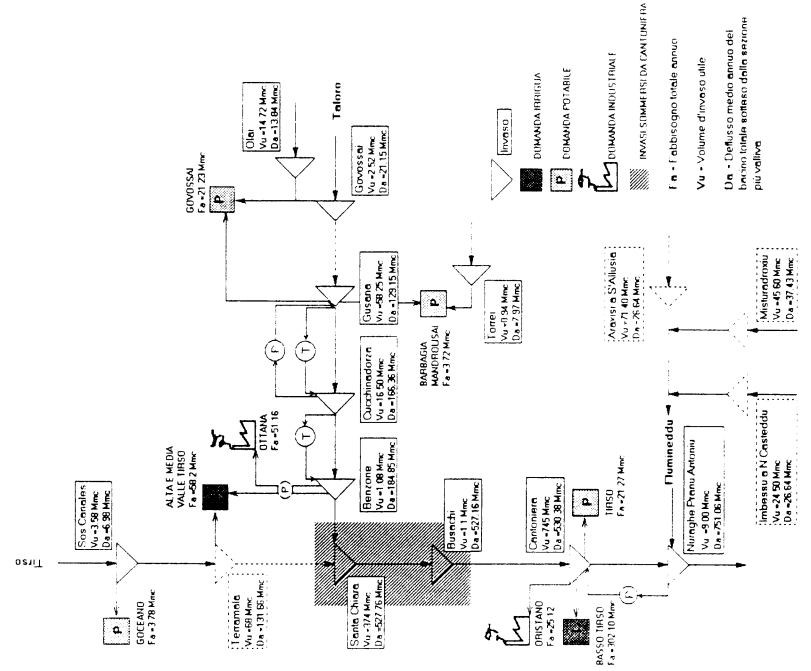

Figure 2 - Hydraulic scheme of the system

When in conflict, the different user requirements were dealt with according to the following priority: domestic, hydroelectric, industrial and irrigation.
The *Gusana* and *Cucchinadorza* reservoirs have been considered one reservoir (the *Taloro* node) and their capacities added, irrespectively therefore of the resource exchanges due to the presence of a reversible type hydroelectric plant.
For the irrigation requirement of the *Basso Tirso*, the maximum "tolerable" deficit was defined by the cultures in the study area and assumed at a 25÷30% reduction of the total requirement.
Simulation of the behaviour of the reservoir system in the chosen period was carried out by applying the balance equation to the different reservoirs from upstream to downstream at a monthly pace, once the management rules have been fixed.
The number of programmed substantial (deficit greater than 15%) irrigation deficit years admissible on the total number of simulated years was established a priori. Depending on the criticity of the simulated period, a figure of 15÷20% deficit years was considered acceptable.
A value of "first attempt annual average irrigation demand" and, for the *Cantoniera* reservoir, a variable "initial reservoir volume" depending on the chosen simulation period, were established as initial inputs.

3.2 Determination and calibration of the management rules

The following two management methods are hypothesised:

- one is defined the "rule on the winter runoff", and is based on the control of the runoff volume in the *Cantoniera* section in the winter semester. Two thresholds are established on the winter runoff, that vary according to the period of simulation. These thresholds are chosen considering the winter semester runoff sequence. A programmed reduction of the distributed volume that equals the tolerable maximum deficit (25%), of between 0 and 25% or null is imposed depending on whether the level is below the minimum threshold, between the two thresholds or above the maximum threshold;
- the other method is defined the "mixed rule", and applies a further reduction in case the stored volume at the end of March at the *Cantoniera* reservoir is lower than the pre-established threshold. The threshold value varies between periods and was calibrated by trial and error with successive simulations in such a way that the further reduction (5%) should intervene for very few years and that the total reduction should not exceed the maximum tolerable deficit.

The latter method leads to a more rational management. As a matter of fact even if the number of total deficit years increases, though the single further reduction is not substantial, a greater volume is accumulated. In some cases this allows a greater yearly average irrigation demand; it also affords a better way of coping with more critical drought events than available in the historical series.
The optimal value of the yearly average volume irrigation supply was determined by iterative simulations until we obtained a stored volume for the end of the irrigation season (September) that was sufficient to meet the *Tirso* potable requirement for the next four months and the irrigation season

requirement for the autumn cultures, in the hypothesis of a dry autumn.
As an example Table 1 shows the results of the simulations of the 1979-80/1991-92 period (historical series of the last 13 dry years) that were carried out according to the mixed management procedure.
The scenario considered to assess the resources available at the moment *Cantoniera* becomes operative, as a function of which the new irrigation districts are to be supplied, included the reservoirs of *Terramala* and *Pranu Antoniu* and the runoffs of the residual basin of *Flumineddu*. In fact failing to consider these, the greater water availability could induce the users to supply a greater extension than can possibly be irrigated. The time reference period is 1979-80/1991-92, since it is more precautionary in defining the maximum extension of the irrigation areas.

4 Simulation of the reservoir system with synthetic series

From an examination of the series of rainfall and runoffs it has been possible to point out that the time series is non-stationary and therefore that a deeper analysis is necessary to explain phenomena that have led to the sharp reduction in average runoff recorded after 1975. The generation of synthetic series of runoffs to the study reservoirs is based on a simplified modelling of the hydrological phenomenon (Monte Carlo generation); the reference historical series relates to the last twenty years of measured runoffs, a more precautionary period in this respect.
The simulations of the reservoir system have been carried out considering 36 periods of 100 years each.
The management rule imposed was that the a priori potable requirement should be totally met. The simulation input values were those obtained from a simulation based on the historical series of the 1979-80/1991-92 period.
In the first simulation carried out, the average yearly irrigation demand was considered 192 Mm^3. This value was obtained by optimising the irrigation demand in the simulation with the historical series taken as reference. This first simulation recorded several deficit years, far beyond the limits fixed with the simulations based on the historical series. Another three simulations were then made with a decreasing irrigation demand value (185, 180, 175 Mm^3) in order to analyse the behaviour of *Cantoniera* for different extension hypotheses of the irrigation areas.
The simulation results are reported as isodeficit curves for different irrigation demands (e.g. in Figures 3÷4). With these graphs it will be possible to deduce useful indications on the maximum extension of the irrigation area of the *Basso Tirso*, which can be supplied with the resources available after the *Cantoniera* becomes operative; it may also be possible to guide reservoir management decisions during operation.

5 The software produced

The regulation study of the *Tirso a Cantoniera* reservoir was carried out with a

	Schema idrico	n° anni di deficit consistenti	Regola mista			Domanda irrigua media
			Soglie ottimali sui deflussi invernali (Mm^3)		Soglia sul volume invasato	
			max	min	(Mm^3)	(Mm^3)
D1	Senza Terramala Senza P. Antoniu e i deflussi del Flumineddu	1 su 6	195	35	210	**217**
D2	Senza Terramala Con P. Antoniu e i deflussi del Flumineddu (senza pompaggio)	1 su 6	220	40	210	**233**
D3	Senza Terramala Con P. Antoniu e i deflussi del Flumineddu (con pompaggio)	1 su 6	220	40	210	**241**
D4	Con Terramala Senza P. Antoniu e i deflussi del Flumineddu	1 su 6	155	27	210	**192**
D5	Con Terramala Con P. Antoniu e i deflussi del Flumineddu (senza pompaggio)	1 su 6	175	30	210	**209**
D6	Con Terramala Con P. Antoniu e i deflussi del Flumineddu (con pompaggio)	1 su 6	175	30	210	**218**

Table 1 - Results of the simulations of the 1979-80/1991-92 period

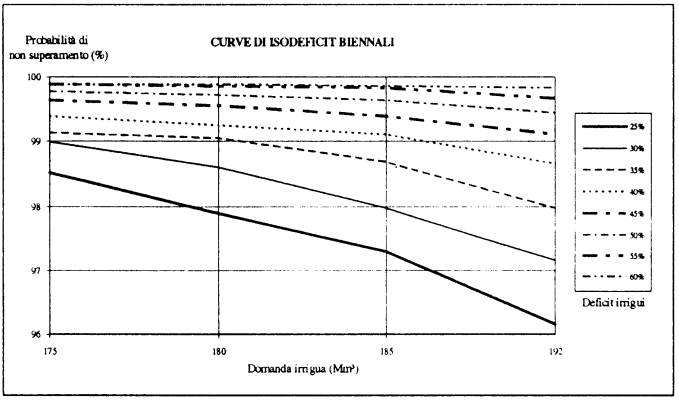

Figure 3

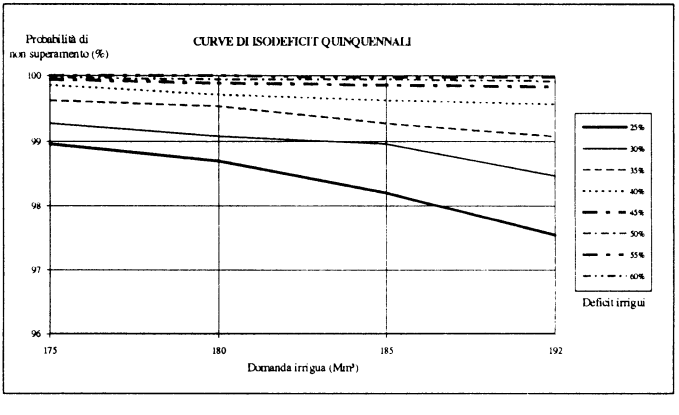

Figure 4

simulation software under Windows written in the programming language Visual Basic 3.0 Professional[2] developed by Hydrocontrol. Our aim has been to create a user-friendly programme. This has been possible thanks to the Windows environment and by enhancing the programme with windows reporting error messages or instructions.

5.1 Description of the programme

After an introductory display to the software showing the position of the Tirso basin (Fig. 5), the hydraulic scheme of the study system appears with the following main menu (Fig. 6):

- General aspects
- Previous simulations
- End of application
- New simulation
- Data update

General aspects

This introduces the user to a hypertext environment where some general aspects are described using the Windows Help technique. The aspects are the simulation scheme, management rules, simulation procedures and a guide to the use of the programme.

New simulation

This activates the initial setting window (Fig. 7) in which the initial simulation variables are defined.

The first selection is whether to base the simulation on *historical* or *synthetic* series. Moreover here the user must state whether or not to include the Terramala reservoir (*Terramala option*), and the Pranu Antoniu reservoir with the Flumineddu runoffs (*Flumineddu option*). The *pumping option*, which includes the Pranu Antoniu pumping facility, is only activated if the Flumineddu runoffs are included.

If historical series are used the simulation period must be entered. The user can accept the entire series of data available (1921-22/1991-92) or select an intermediate period. The "years of substantial deficit" must also be specified as a ratio with the total number of years to simulate.

The next display (Fig. 5) shows the scheme determined by the initial conditions and presents the following options by means of a bar menu:

- Input data: the input data to the simulation can be shown as numerical tables or graphs.
- Management rules: the programme proposes the management rules (Fig. 9).

If the rule based on winter runoffs is to be used, the programme proposes the maximum and minimum thresholds automatically calculated by the programme, as well as the text areas to insert thresholds and reductions imposed to the irrigation demand. If the mixed rule is to be used, besides runoff thresholds, the stored volume threshold and the corresponding irrigation demand reduction must be entered.

The user must then establish the "initial volume" at Cantoniera. A default value of 100 Mm^3 is suggested. This value may be accepted or modified. Moreover, the "yearly average irrigation demand" is introduced as a first attempt to calculate the optimal irrigation demand value. Once the management rules are

Figure 5 - Software introductory display

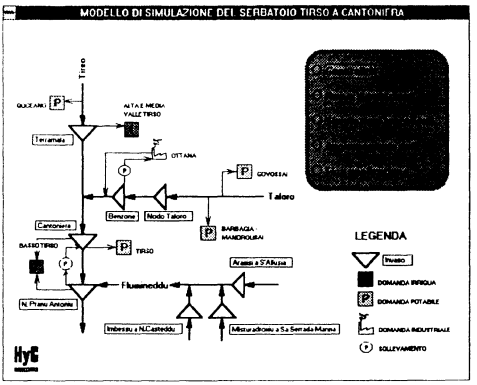

Figure 6 - Hydraulic scheme and main menu

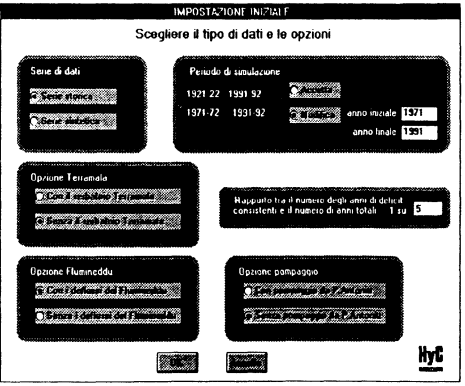

Figure 7 - Initial settings

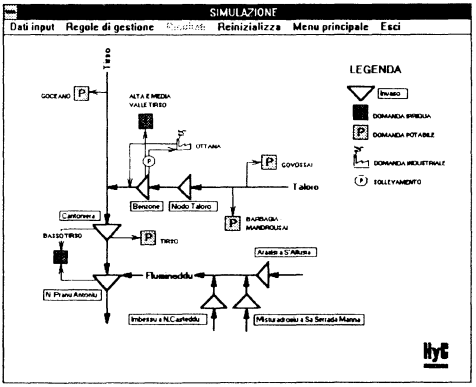

Figure 8 - Bar menu and simulation scheme

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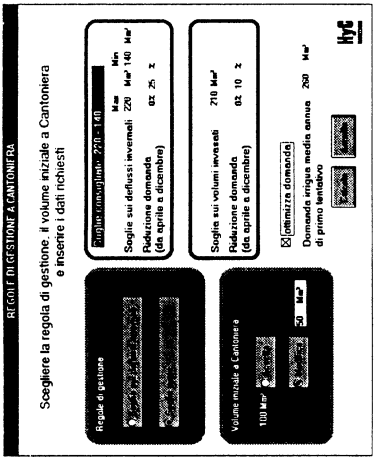

Figure 9 - Setting the management rules

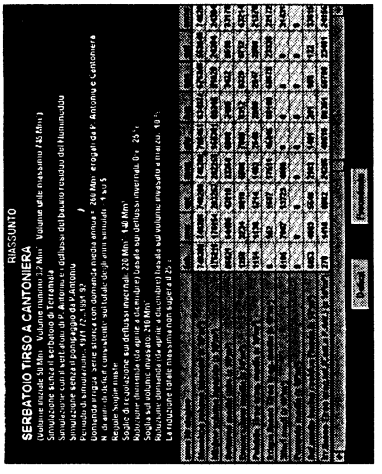

Figure 10 - Results - Summary table

Figure 11 - Results: graphical example of historical series

Figure 12 - Results: graphical example of synthetic series

defined, the CALCULATE key activates the simulation routine.

- Results: this item is activated only after a simulation has been performed. It is possible to display the results as complete tables, as summary tables (Fig. 10) that give a number of simulation statistics, and as graphs (Fig. 11). In this case by pressing the ANIMATED key, it is possible to scroll the selected diagram along the years of the simulation period.
- Reinitialisation: it is possible to reinitialise the system and perform a new simulation without exiting the application.
- Main menu: returns to the initial window (Fig. 6).
- Exit: exits the presented simulation software.

If the user wishes to simulate with the synthetic series, once the simulation scheme has been selected, the programme shows a window from which the initial data can be entered. The output of the results is graphical (Fig. 12) and is represented by the irrigation deficit probability density histogram and by the probability histogram of not exceeding the irrigation deficits.

Previous simulations

It is possible to view the results of previously saved simulations. When a file is selected, the initial data and adopted management rules are shown. Thus the user can better identify the simulation and decide whether to view the results or not.

Data update

It is possible to add new input data into the programme (e.g. a new year) or modify the data already entered. The programme has error messages to warn the user of any incorrect entry of data or characters.

6 Conclusions

The management model has afforded the following results:

- a pluriennial regulation has been obtained at *Cantoniera* in order to optimise the distribution of irrigation water and determine the maximum extension of the served irrigation area (*Basso Tirso*);
- the managing authorities are offered an easy tool in order to assess, at the beginning of each irrigation season, the volumes to be destined to agriculture as a function of the winter runoffs and the reservoir levels.

Acknowledgements

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References

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2. Microsoft *Visual Basic 3.0 Professional* handbooks.