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WARGI: Water Resources System Optimisation aided by Graphical Interface

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Abstract

An optimization tool for water resources system planning and management, named WARGI, is proposed in the paper. The optimization tool utilizes a graphical interface to allow the user a friendly data-input phase and to visualize output results. It is easy for the user to modify system configuration and related data to perform sensitivity analysis and to process data uncertainty using scenario optimization. WARGI allows to start from the physical system to reach the optimal solution having the possibility to control all the intermediate phases, easily to update system configuration and to consider different optimizers. The graphical interface WARGI prevent obsolescence of optimizer codes exploiting the standard input format MPS. An application of WARGI to a real system is also described.

1 Introduction

Modeling tools for water resources planning and management (WRPM) optimization have been developed since the early '60 [9] using standard optimization tools. Much has been written and proposed in these years to reach the economic efficiency and the optimal water allocation in complex system using different algorithmic approaches [8],[17]. At this time most of the easier water system configuration has been generally realized and; nevertheless, the increasing needs of an adequate, efficient and sustainable use of water is a crucial world-wide problem. As WRPM needs to consider different physical components, planning and operation rules, related models grow up to very large dimensions.

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Moreover, a significantly extended time horizon must be considered in order to adequately represent hydrological input and demands. Recently very efficient computer codes for general purpose mathematical programming are available supporting up to thousand of variables and constraints. A crucial factor treating large dimension problems with these efficient general-purpose algorithms is becoming the availability of efficient computer graphical interfaces designed to facilitate the use of models and database in a decision support system (DSS) context to help end-users to evaluate the best choice in a friendly-to-use way.
The main features of the proposed WRPM optimization tool, named WARGI, are:

- Friendly to use in input phase and in processing output results.
- Prevent obsolescence of the optimizer exploiting the standard input format in optimization codes.
- Easy to modify system configuration and related data to perform sensitivity analysis and to process data uncertainty.

"Prevent obsolescence" and "easy updating" are strictly connected aspects. To prevent the risk of an early useless, the tool has been assembled as transparent boxes collection, composed by independent modules, in such a way each module can be easily managed.
The main boxes inside the graphical interface are:

- System elements characterization.
- Connections topology and transfer constraints.
- Links to hydrological data and demand requirements files.
- Time period definition and scenario settlement.
- Planning and management rules definition.
- Benefits and costs attribution.
- Call to optimizers.
- Output processing.

WARGI allows to start from physical system to reach the optimal solution having the possibility to control all the intermediate phases, easily to update system configuration and to consider different system optimizer using standard data-input format.

2 Water resource systems optimization

A mathematical model for WRPM involves a large number of variables and constraints in order to represent adequately several aspects of the problem.
Considerable progress have been made in optimization by methodological point of view and improvement in computational performances are made day by day producing very efficient computer codes. These last few years great effort has been made in reducing gap between mathematical methodology and real world applications in WRPM coming from different scientific communities in spite of seldom interactions in the past [13] [6]. WRPM tools have been recently produced [1] [3], containing representation, simulation and optimization software with the aim to be friendly for users but strictly linked to their resolutive tools.

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On the other hand, in the field of optimization, improvements in mathematical programming methodologies are not generally referred to a specific application but exploit special algebraic structures of models. In this contest great progress have been made in computational efficiency of resolutive technique of linear programming problems. New polynomial time algorithms alternative to simplex methods have been developed as interior point methods, network oriented codes with complicating constraints, new graph structures, etc.[14] [2] [7]. By implementation point of view, advanced codes in mathematical programming allow to adopt the more suitable performance of the package depending on the structure of the matrix constraints: sparse matrix, graph structure like node-arc incidence matrix, bounds, block diagonal matrix, tridiagonal matrix, etc., each of them coming from particular physical, economical, technical constraints.
Inside the scientific community the necessity to adopt a standard format for data arose in order to allow comparisons among different approaches to verify efficiency of algorithms and codes as in a wide variety of test problems [4] as in a wide variety of real world applications.
Recently the MPS format has been adopted as standard data format and used by almost all optimization software developers [5] [14] [16].
In such way, as showed in previous papers, the possibility to compare different "general purpose" linear programming codes in WRPM gave rise to specialized tools exploiting end users experience. This approach seems adequate to problem complexity and to the generally huge size of the model leading to good strategies of choice.
In other words a first level interface oriented to MPS standard format should allow to take advantage of the progress in optimization methodology and codes efficiency in implementing water resources optimization.
A second level interface oriented to end-user allows to perform an advanced optimization even if the user is not familiar with mathematical programming techniques.
WARGI tool adds features of first and second level interface: user can exploits his scientific knowledge and experience to perform a wide experimentation in different optimizer tools performing scenarios analysis and sensitivity backtracking or can follows standard suggestions and, in case, tuning some system parameters.

3 WARGI Scenario Optimization

As extensively described in some previous papers [10] water resources decision problems with a multiperiod or multistage feature are typically characterized by a level of uncertainty on the value to be assigned to crucial parameters. On the other hand any possible value assigned to them can invalidate the results of the study. When the statistical information about data estimation are not enough to support a stochastic model, scenario analysis approach can be adopted modeling WRPM under uncertainty in order to rich a robust decision policy minimizing the risk of wrong decision.

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One of the main goal in WRPM study is to reach a configuration that should guarantee an adequate level of reliability of water supply and provide management criteria to be adopted by the Water Authorities.
In WRPM uncertainty is mainly referred to cost-benefits or demands-supplies parameters. This is a typical problem in which the level of uncertainty cannot be represented by a probabilistic rule. Alternatively, uncertainty on input data can be represented by a set of version of synthetic series (scenarios) derived from historical data.
We can represent this procedure with a graph structure, the scenarios tree, in which each node represents a point in time where a decision can be made. The scenarios tree is the structure of the set of scenarios along the planning horizon, generated from the user defined strategies. Each root-to-leaf path represents a scenario that is one possible realization of the unknown parameter.
In real systems the graph "explodes" in dimension with the increasing of the possible configurations number.
This approach leads to a huge multi-period model composed by a small number of versions of subproblems, each referred to each scenario, that correspond to the available information level until the moment to take the planning decision. In this context it becomes crucial to have the possibility to adopt the best state-of-the-art mathematical programming code, as WARGI can do.
Studying the scenarios optimal solution, one may be able to discover similarities and trends and to model a decision support system quantifying the risk of planning operations. Moreover each scenario can be weighted in order to represents the "importance" assigned to the running configuration.
The minimizing of the difference between the decision policy waited cost and the solution optimum under each scenario gives the "robustness" required to the method, which leads to a "barycentric" solution, which respects different possible weighted scenarios.
Scenarios can be generated by time-cluster aggregation with different temporal lags using several techniques AR models, Neural Nets approach or Monte Carlo generation.

4 Physical system formalization

Following the physical-system formalization adopted in previous works [11] [12] and recently used in the WARSYP Project [15], the water resources system can be viewed as a physical network where nodes and arcs are as follows:

- *Reservoir nodes*: these represent surface water resources with storage capacity. In these nodes losses by evaporation can be considered.
- *Demand nodes*: as for irrigation, civil, industrial among others. They can be consumptive or non-totally consumptive water demand nodes.
- *Hydroelectric nodes*: they are non consumptive nodes associated to hydroelectric units .
- *Confluence nodes*: such as river confluence, withdraw connections for demands satisfaction, etc.

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- *Aquifer nodes:* these nodes represent groundwater resources with storage capacity.
- *Natural stream arcs*: these represent the natural runoff along rivers or river beds.
- *Conveyance work arcs*: these are artificial channels as ditches, pipes, etc.
- W*ater pumping facility arcs*: these are arcs with a pumping plant.
- *Emergency transfers arcs*: these arcs allow transfers of water to face shortage.
- *Recharge facility arcs*: these allow direct injection of surface water from a connection node into an aquifer.

Some of the operational management issues to consider in the problem can be easily modeled using graph structures as the following:

- Priorities in the stored water level of reservoirs:
- Priorities in demand satisfaction of demand nodes.
- Penalty on shortage and emergency transfers.
- Water quality aspects related to storage conditions.

The planning issues refer to the design of the physical system as dimensions associated to future works: reservoirs capacities, pipes dimensions, irrigation areas, etc. Other planning aspects are related to unit consumptive use demands, irrigation technologies and agricultural assessments.

5 WARGI graphical interface

The interface has been developed and tested within an HP-Unix and PC-Linux environment. The various software components have been coded in C++ and TCL-TK graphic language.

The WARGY graphical interface provides the possibility to insert the basic system configuration components and connections between them. As shown in Figure 1, the main window presents an empty canvas and the program window is composed of several parts as described below:

Title - The name of the current graph (*NoName* if the graph is new and has not been saved).

Menu Bar - The menu bar for selecting various options and tasks.

Scroll Bars - Permit scrolling the canvas in order to use a canvas larger than the size visible on the screen.

Status Bar - multi-function bar providing information on graphical objects and also acts as a guide during graph construction.

The tool palette is a small window containing a set of graphical objects needed for creating graphs. In order to open the tool palette, the user has to call the **View** menu and select **Tool Palette**. The tool palette window will open and can be dragged into a suitable position on the screen.

The tool palette is composed of a number of buttons, each representing a graphical object or an action that can be performed on the palette or a graphical object placed on the canvas. The main objects that can be inserted in the window are:

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- Reservoirs;
- Civil demands,
- Industrial demands;
- Irrigation demands;
- Hydroelectric Power stations;
- Confluence nodes;
- Conveyance structures
- Natural streams.
- Aquifers

Two buttons on the tool palette have an effect on the tool palette itself. The **? button** toggles the text description on the right of the button icons. The text description is useful for new users who are not familiar with the symbols used for creating graphs. The **OK button** is used to close the tool palette once graph creation is complete.

Placing nodes on the canvas is a two step process. Firstly, the user must have the tool palette open. This will give the user access to the various node types that can be used.

The first step to placing a node on the canvas is to **select the node** you wish to

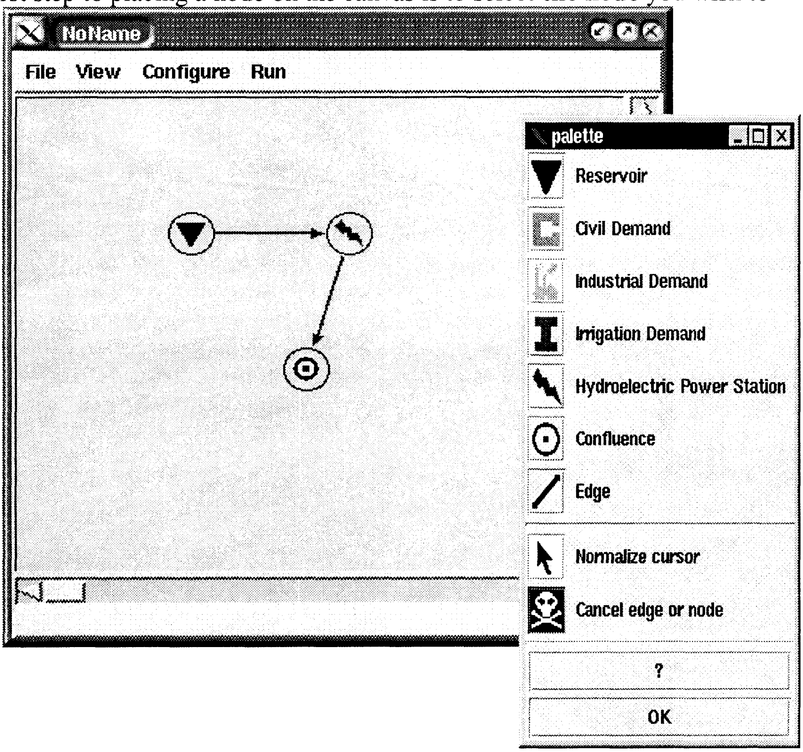

Figure 1: Main window and palette of WARGI.

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place from the tool palette. This is done by clicking on the icon representing the node in the tool palette using the left mouse button. The selected node type will be highlighted. The second step is actually **placing the node** on the canvas. Simply moving the mouse over the canvas to the point in which the user wishes to place the node and press the left mouse button.
Once the node has been placed on the canvas the user may proceed to inserting the data associated with the node or continuing the graph-creating process.
Placing arcs is slightly similar to placing nodes and requires 3 steps using the mouse.
Using the tool palette it is possible to delete graphical objects from the canvas, selecting the **Cancel Edge or Node** from the tool palette.
Once the graph has been completed or a new node or arc has been placed on the canvas it is necessary to insert the data related to the object. This is done through a template window which is accessible by clicking on the graphical object using the right mouse button. The template window is different for each type of object placed on the canvas.
In Figure 2 the input windows for reservoir objects is shown.
Some sections of the template windows can be accessible in the case of project optimization, others in operational optimization

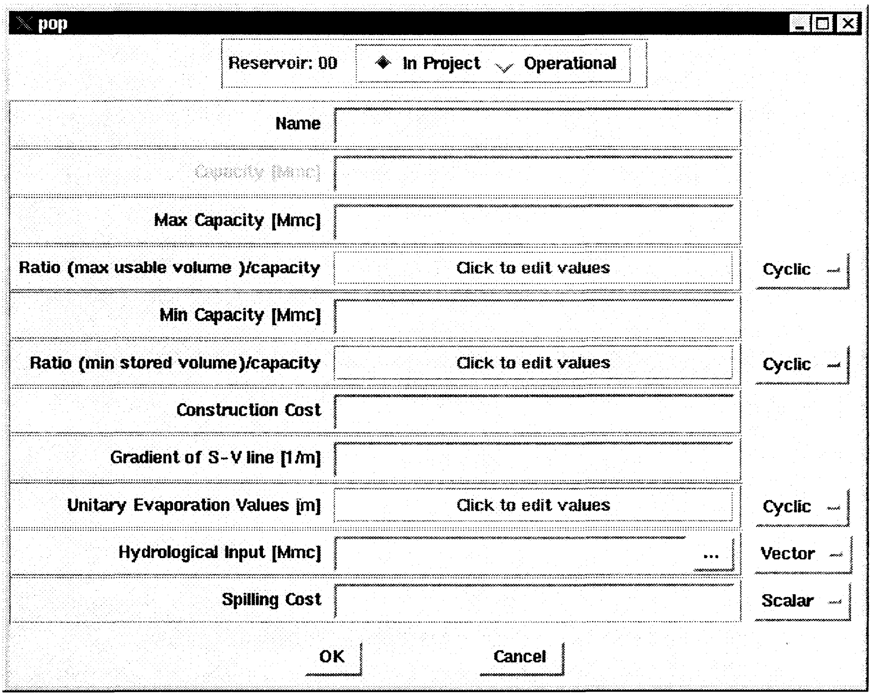

Figure 2: Input windows for reservoir objects.

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Once the graph has been completed and all the necessary data has been inserted, it is possible to generate the necessary MPS file to feed to the solver.
MPS file generation is achieved by selecting **Generate MPS** from the **File** menu. Graphs may be saved and previously saved graphs may be loaded by using the **File** menu. When a graph becomes too large to fit on the currently visible canvas, it may be helpful to scroll and zoom the canvas to have a better understanding and vision of the graph the user is creating. It can be done by selecting **Scrolling** and **Zooming** from the **View** menu.
In order to be able to launch the solver from the Graphical User Interface the user must first set the command line required to launch the solver. This is done from the **Configure** menu by selecting **Solver**. Once the required command has been inserted in the space provided clicking OK will set the command line for launching the solver.
At the end the user can visualize results using **View results** and **Plot results** options from the **View** menu.

6 WARGI application to Flumendosa-Campidano-Cixerri water resource system

The use of WARGI software to a real water system has been tested using, as reference scheme, the Flumendosa-Campidano-Cixerri water sytem (Sardinia-Italy) as provided by the WARSYP Project [15]. Since 1987 the Sardinia-Water-Plan points out the necessity of defining an optimal water works assessment and the urgency to find optimal management rules for the water system. These requirements became more and more urgent in time, as the system managers had to face the serious resource deficits resulting by the drought events of the past decade.
The Flumendosa - Campidano main works were built in the mid '50's and supplies most of Southern Sardinia. The main water supply source of the system is represented by the three reservoirs of Flumineddu, Flumendosa and Mulargia with a total storage capacity of 666.4 millions of cubic meters (Mm^3). The reservoirs are connected by gravity galleries. In the system there are not remarkable aquifers to be considered.
As illustrate in Figure 3, the principal works are the following:
<u>Water supply sources</u>

- Capanna Silicheri dam on the Flumineddu river (3.6 Mm^3);
- Nuraghe Arrubiu dam on the Flumendosa river (316 Mm^3);
- Monte su Rei dam on the Mulargia river (347 Mm^3);
- Sa Forada de S'Acqua dam (1.6 Mm^3);
- Casa Fiume dam on the Fluminimannu river (1.1 Mm^3);
- Simbirizzi dam (33.8 Mm^3);
- Genna is Abis dam on the Cixerri river (30 Mm^3);
- Is Barrocus dam on the Fluminimannu river (14 Mm^3);
- Monastir weir on the Rio Mannu river;

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- Rio Fanaris weir;
- Rio di Monti Nieddu weir;
- Rio di S. Lucia weir;
- Assemini weir.

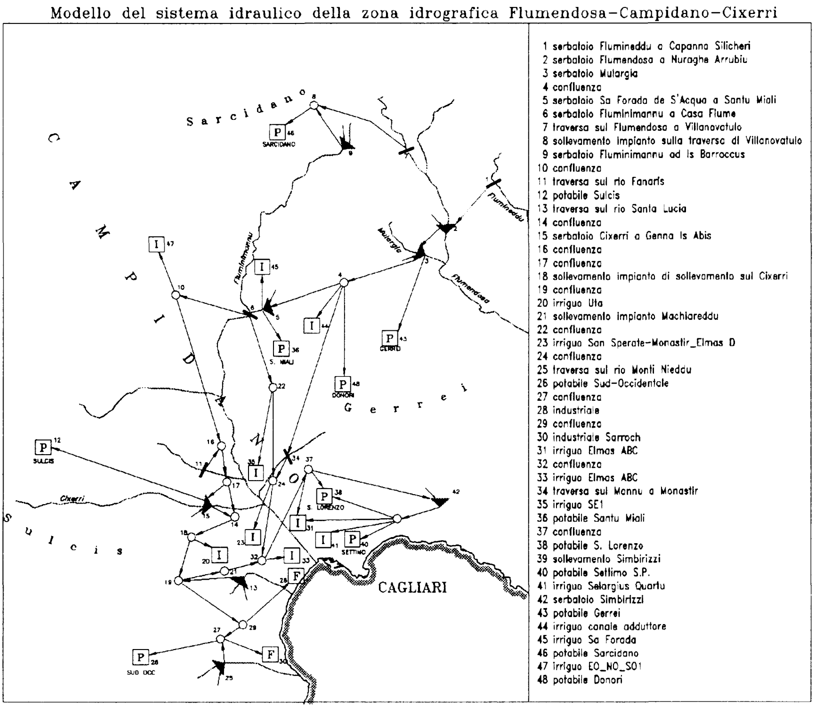

Figure 3: The Flumendosa-Campidano-Cixerri water system.

<u>Water diversion and communication galleries</u>
- Flumineddu - Flumendosa communication gallery (6,890 m, 13 m^3/s);
- Flumendosa - Mulargia communication gallery (5,917 m, 95 m^3/s);
- Uvini - Sarais diversion gallery (9,920 m, 52 m^3/s).

<u>Main water supply and distribution network</u>
- Main supply canal (20 Km, 54 m^3/s);
- East - West distribution canal (10.7 Km, max. 30 m^3/s);
- North-West distribution canal (21.6 Km, max. 7 m^3/s);
- South - West distribution canal (25.8 Km, max. 11 m^3/s);
- South - East distribution canal (54.3 Km, max. 11 m^3/s);

<u>Hydroelectric power stations</u>
- Uvini power station (13 MW)
- Santu Miali station (25 MW)

<u>Irrigation distribution network</u>
- The irrigated district is about 70.000 gross hectares

<u>Pumping stations</u>

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- Flumendosa (4 x 3,000 l/s pumps, head 23 m);
- Simbirizzi Main (6 x 1,300 l/s pumps, head 40 m);
- Pumping station no.1 for the supplementary aqueduct of the City of Cagliari (4 x 475 l/s pumps, head 40 m);
- Pumping station no.2 for the supplementary aqueduct of the City of Cagliari (4 x 550 l/s pumps, head 40 m);
- Opera Nazionale Combattenti (6 x 340 l/s pumps, head 45 m);
- Cixerri (4 x 1,000 l/s pumps, head 47 m);
- Sulcis (5 x 121 l/s pumps, head 270 m);
- Macchiareddu (4 x 670 l/s pumps, head 70 m);
- Monti Nieddu (4 x 120 l/s pumps, head 25 m);
- Assemini (6 x 245 l/s pumps, head 35 m);
- Sestu (5 x 240 l/s pumps, head 15 m).

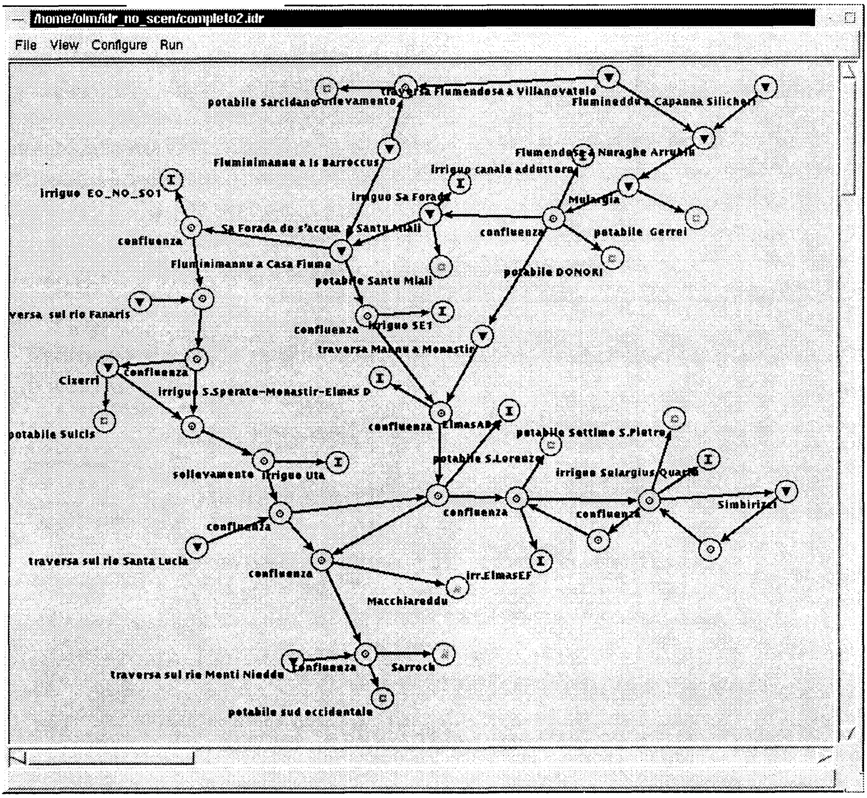

Figure 4: The input window for Flumendosa-Campidano-Cixerri water system.

<u>Water plants for drinking purposes</u>

Simbirizzi potabilisation plant (c. 5,040 m^3/h)

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- Donori potabilisation plant (c. 2,520 m^3/h)

The following is the yearly average distributed volume (mean of the 1992-1994)

- Drinking: 80 Mm^3
- Industrial: 15 Mm^3
- Agricultural: 130 Mm^3

Total: 225 Mm^3

The input window of the examined system is give in Figure 4.

Using WARGI, extensive investigations on water system optimization can be made considering different hydrological and demands scenarios and setting branches and stages of the scenario tree. Optimization results can be shown as in the graph reported in Figure 5 for the optimal flow achieved for Flumendosa and Mulargia reservoirs. WARGI application to Flumendosa-Campidano-Cixerri water system, results and comments are extensively reported in [10].

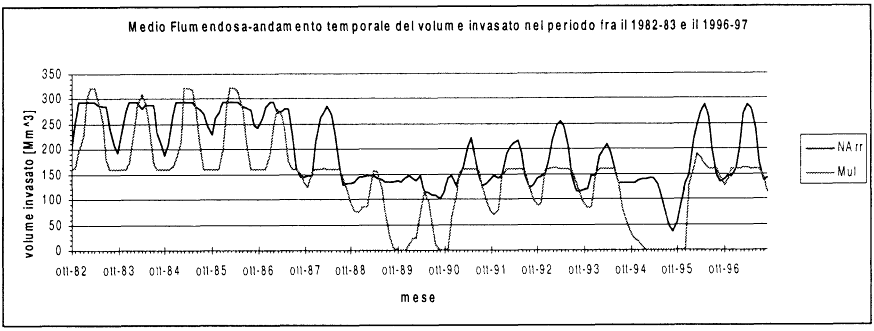

Figure 5: Optimization results.

7 Conclusions

The aim of authors in planning WARGI was to create a tool to help water managers in a DSS context, friendly to use but able to take into account the improvements made in the field of computer science and operation research. The state of the art in Mathematical Programming codes evolves continuously producing algorithms that improve computational efficiency thanks to new methodologies and computer science development. The standard input format allows to insert the best state-of-the-art codes in WARGI.

Several improvements are in progress in WARGI like validation by simulation testing phase, sensitivity analysis, among others.

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