

WaterStrategyMan
EVK1-CT-2001-00098

DELIVERABLE 10

REPORT ON MODELS, TOOLS AND DSS FOR WATER MANAGEMENT



Prepared by
Progea S.r.l.

January 2003

Contents

1. INTRODUCTION	3
2. DECISION SUPPORT SYSTEMS, TOOLS AND MODELS.....	5
2.1. MIKE BASIN	5
2.2. BASINS	18
2.3. DSS FOR WATER RESOURCES PLANNING BASED ON ENVIRONMENTAL BALANCE.....	31
2.4. A SPATIAL DECISION SUPPORT SYSTEM FOR THE EVALUATION OF WATER DEMAND AND SUPPLY MANAGEMENT SCHEMES	35
2.5. INTEGRATED QUANTITY AND QUALITY MODEL (IQQM).....	48
2.6. ENSIS.....	53
2.7. REALM	58
2.8. MULINO.....	64
2.9. RIBASIM	69
2.10. WEAP	74
2.11. WATERWARE.....	80
2.12. AQUATOOL.....	86
2.13. IRAS	91
3. METHODOLOGIES.....	102
3.1. AN ECONOMIC MODEL FOR WATER ALLOCATION IN NORTH EASTERN SPAIN	102
3.2. DEVELOPMENT AND EVALUATION OF MULTIPLE-OBJECTIVE DECISION-MAKING METHODS FOR WATERSHED MANAGEMENT PLANNING.....	102
4. CONCLUSIONS.....	105

1. Introduction

This document is the Deliverable No.10 of the Water Strategy Man Project (WSM) (EVK1-CT-2001-00098) and concerns models, tools and DSS for water management. This report is one of the outcomes of Work Package No.5 that is entitled *Review, testing and adaptation of tools for water resources management* and is part of the Analysis Phase of the project together with WP No.4 *Development of a methodology* and WP No.6 *Data and GIS database*.

The report is a review of available Decision Support Systems and Tools that support Decision Makers to address water resources issues within a framework of analysis, planning and management integrated on multiple aspects such as environmental, socio-economic, administrative and of sustainable development. The majority of the software packages presented has been developed and is currently applied to river basin realities, but the features and approaches they use and the models they embed are general and can fit specific user-defined areas and zones.

The tools reviewed in this Deliverable No.10 are the following:

Mike Basin, by the Danish Hydraulic Institute (DHI)

Basins, by the U.S.- Environmental Protection Agency

Dss for Water Resources Planning Based on Environmental Balance, developed within a project funded by the Italian Cooperation with Egypt

A Spatial Decision Support System for The Evaluation of Water Demand And Supply Management Schemes, by the Technical University of Athens

Iqqm, by the New South Wales Department of Land & Water Conservation, with collaborative assistance from the Queensland Department of Natural Resources (QDNR).

Ensis, by the Norwegian Institute for Water Research (NIWA) and the the Norwegian Institute for Air Research (NILU)

Realm, by the Victoria University Of Technology and the Department of Natural Resources and Environment, in The State of Victoria, Australia

Mulino, main objective of the related European Mulino Project

Ribasim, by Delft Hydraulics

Weap, by the Stockholm Environment Institute's Boston Center at the Tellus Institute

Waterware, main objective of the European research program Eureka-EU487

Aquatool, by the Universidad Politecnica de Valencia, Spain

Iras, by the Civil and Environmental Engineering Department of Cornell University and the Resources Planning Associates Inc of Ithaca, New York State

In the chapter of *Methodologies*, some criteria, approaches and procedures for water allocation, water quality monitoring and analysis are shortly presented. Their descriptions are cited from the respective articles and papers.

The present document has been compiled by Progea S.r.l, with the contribution of the following Project Partners:

- NTUA (Greece)
- Ruhr University of Bochum (Germany)
- Office Internationale De l'Eau (France)
- The Hebrew University of Jerusalem (Israel)
- The Water Development Department and Aeoliki Ltd. (Cyprus)
- INSULA (Spain)
- The University of Porto (Portugal)

2. Decision Support Systems, Tools and Models

2.1. Mike Basin

In terms of actual DSSs, one may consider MIKE BASIN as a first example of a more comprehensive tool. Developed by the Danish Hydraulic Institute (DHI) as a *Versatile Decision Support Tool for Integrated Water Resources Management and Planning*, MIKE-BASIN has been integrated into the ArcView GIS environment. This ensures to maintain the full functionality of the Esri Tool and apply its standard facilities to water resource modelling.

The user is introduced to the main window of Mike Basin's interface by a dialog box where he chooses the simulation options. Mike Basin studies by default the water distribution within the basin but a water quality option and a module for simulating groundwater can be selected as well.

The first step in building a MB project consists of the basin schematisation as a network of nodes and branches. As in large river basins the description of numerous individual demands and features takes a lot of time and efforts, some networks can be simplified according to objectives of the modelling and availability of information. For instance, smaller rivers can be lumped into a single branch upstream an intake point, small irrigation sites scattered in an area can be represented by a single scheme with one intake point and civil and industrial supply can be lumped into one entity. However, MB leaves either the alternative to draw a simplified *schematic* scheme, or to keep the details of a basin.

The *Schematic* network can be drawn on a geographic map showing the hydrography of the area of interest. At first the user digitises manually the main river and his tributaries in terms of a polyline following the trace on the map. Then he places the nodes in the following order: River Nodes, Reservoirs, Hydropower nodes and Water demand nodes. River nodes are placed on the river polyline and are *Simple* or *Catchment* type. The former define confluences, diversions, upstream end of tributaries and the outlet of the river system whilst the latter is the outlet of an upstream catchment area. These areas are depicted hatched in green colour in the specific *Runoff* layer. A Simple or Catchment node can assume the further feature of *Offtake Node* when it is connected to demand nodes. Reservoir nodes are placed on top of river nodes whereas Hydropower nodes are placed out of it. Water demand nodes are placed at last and represent irrigation sites and water supply systems conveying water to cities or industries.

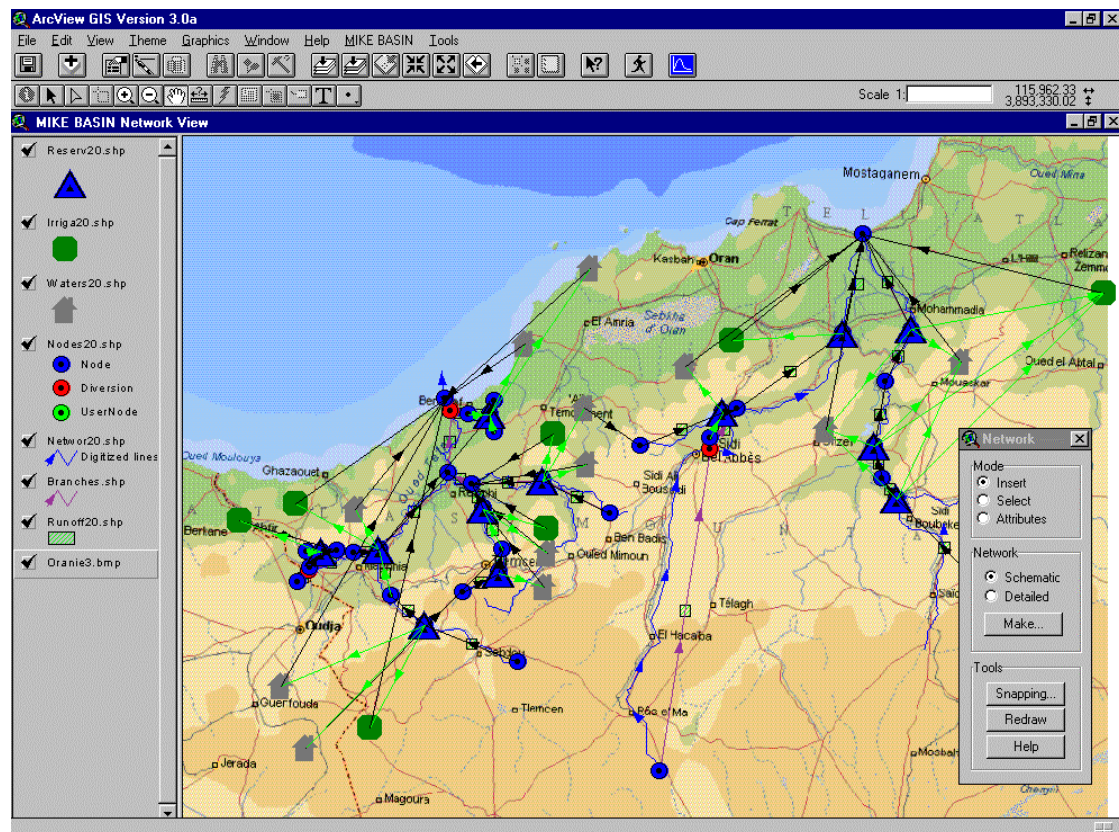


Fig. 1 An example of Basin Schematisation in the Network View of MB

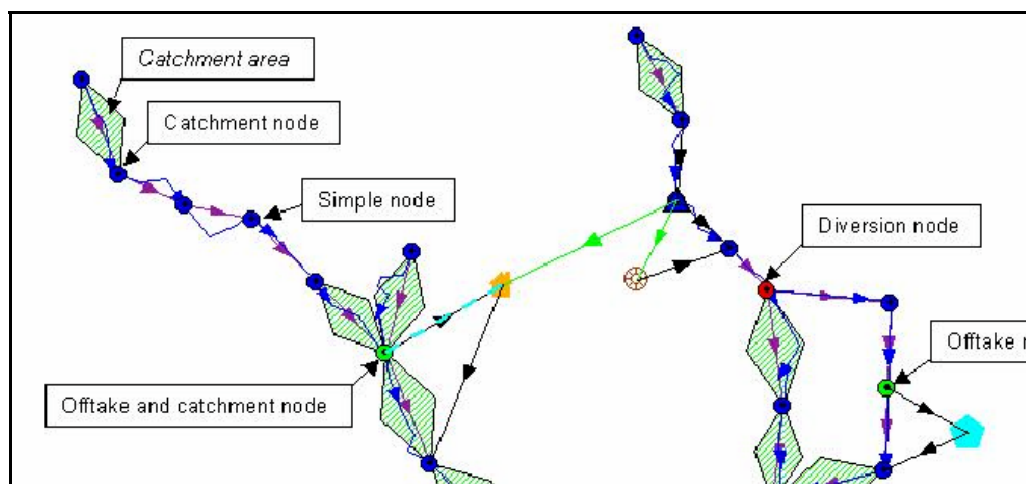


Fig. 2 Definition of Catchment areas and Offtake nodes

MB has an Access database but data for each network element is easily edited or viewed from the *Network View*. MB is set to *Attribute Mode* and pop-up menus specific to each kind of node open at the right-click on the node itself. Through these menus the user is provided with proper dialog boxes where he can specify properties and time-series. For instance, the catchment area's box concerns the area in square kilometres and the definition of the runoff time series.

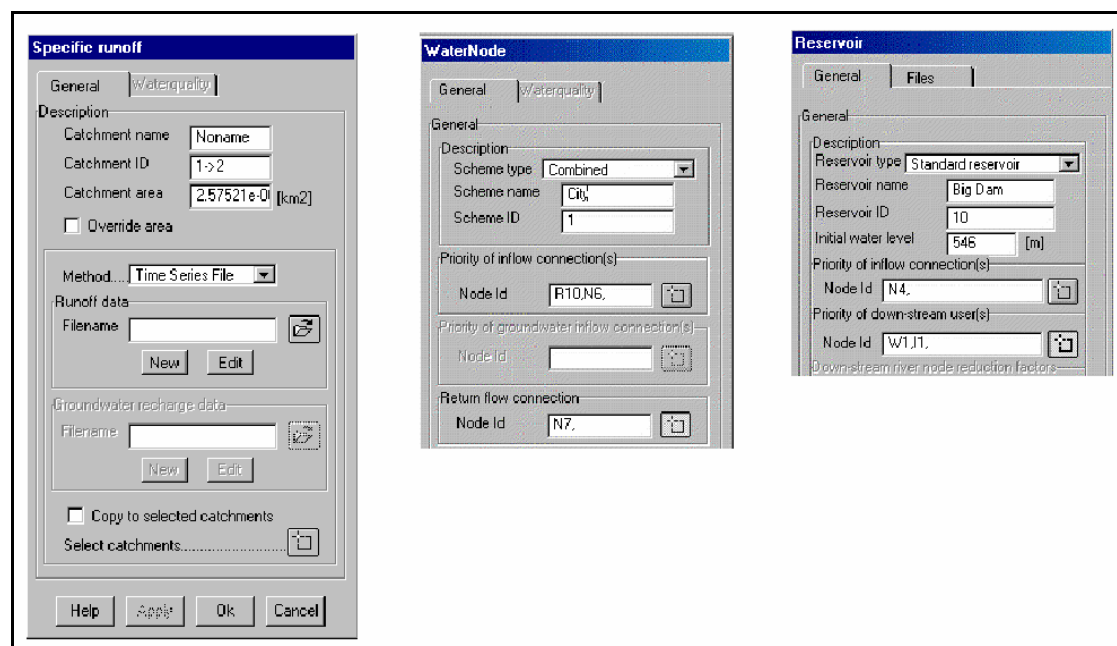


Fig. 3 Dialog boxes for data editing concerning Catchments nodes, Water Supply System nodes and Reservoir nodes

Time Series may have been previously prepared in text files. In this case it is possible to browse them directly from the dialog boxes. Otherwise, time series can be edited launching the Time Series Edit tool (TSedit). This tool's interface has two different panels. On the right there is a small Excel-type worksheet where numbers are filled for each time step. The table can also be created in Excel and then imported with a *copy and paste* operation. On the left there is the plot of the corresponding edited time-series.

When the user edits the attributes of a generic Demand Node in the relevant boxes, he browses and specifies the files with the water demands and the return flows data of the node. Besides, he has to define the water sources supplying water to the node and the *sink nodes* receiving his *return flows*. The definition of the nodes connected to the demand node is performed with the mouse on the network map by dragging a little square around each selected water source, namely River or Reservoir nodes, and each sink node that is usually River Node type. As a consequence of the dragging, the Identifier number of the selected source or sink node appears automatically in the property box of the demand node.

The same operation is done when editing the properties of the offtake nodes, which are River nodes with the assigned role of water source. The user specifies the demand nodes served by the generic offtake node but he has to be careful that these connections are consistent with the ones previously defined from the demand node boxes. In fact in MB each connection between a user node and a source node must be consistently defined in the property boxes of both of them. This means that whenever a user is specified for a source node, the same node must be specified for that user. The *Check Topology* tool is

responsible to sweep the network connections and validate the basin schematisation before starting the simulation.

If the MB's user connects an offtake node to multiple water demanding users, the order he follows in selecting them by dragging the square is significant: it represents the sequence in which connected user nodes will be feed and their water demands fulfilled. Each demand node will receive the minimum between its entire water demand and the water available at the offtake node after upstream user nodes have been fulfilled. On the other hand, if a demand node receives water from more than a source node, the order of the source identifiers listed in the property box stands for the sequence in which extractions are requested from the connected supply nodes. The first node in the list will supply the entire demand (if available) before the second node is considered. This second node will supply the remaining demand (if any after the first node has supplied 'its' water), and so on for the subsequent supply nodes. This is the *Local Priority* principle of MB and it is at the basis of the allocation algorithm of MB. It is named *local* because once we have an offtake and multiple nodes connected to it, the closest nodes are assigned a higher priority than those placed at longer distance. The priority approach is useful in water shortage conditions when conflicts arise among different activities in the basin, all requesting a full coverage of their water needs. Local priorities are applied only to demand nodes served by surface water whereas if groundwater is considered in the system, all users they feed have the same priority and receive water in the same proportion of their water demands.

MB has another principle for managing water distribution, namely *Global Priority Rules*. This option can be selected together with the simulation options in the first window of MB's interface and consists of a set of rules affecting any node in the network that is involved in the water allocation process. Multiple rules can be defined with a priority rank given to each. With the Global Priority algorithm any distribution of water is governed by rules only, so implying some restrictions to the basin schematisation:

- Diversion nodes are not allowed and they must be replaced by a virtual user, to which an extraction rule with the same extraction volume is attached
- Return flow from water users must be to a node on the river immediately downstream to the extraction node

Global Priority Rules concern extractions, minimum flows, reservoir storage and reservoir target levels. Hereunder a table shows the rule types, their purpose, nodes and data affected.

Table 1 Global Priority Rules of Mike Basins

Type	Purpose	Specification Required
Extraction	Enforces a water user (water supply, irrigation, hydropower) to receive enough water to cover its demand as given in that user's input time series	Upstream node on river as water source and downstream user node
Minimum flow	Enforces minimum flow at nodes	Relevant node on river (no downstream node), time series of flow requirement
Reservoir storage	Enforces storage in reservoirs up to flood control level	Relevant reservoir node (no downstream node, no time series)
Reservoir target level	Enforces water level in reservoir	Relevant reservoir node (no downstream node), time series of target level
Specified extraction	Enforces a water user to receive enough water to cover its demand as given in a separate time series (overriding input time series)	Upstream node on river and downstream user node, time series of demand

The global rules are edited in dedicated dialog boxes and summarised in the *MB Rules Window* where they are listed and information about involved nodes and time series is reported. Here the rules can be selected and edited again. When selected, the corresponding nodes they affect are highlighted on the map.

Priority	Rule Type	Node 1:		Node 2:		Time Series File
		ID	Name	ID	Name	
1	ReservoirTargetLevelRule	R5	Ord River Dam			minlevelrule.dfs0
2	MinimumFlowRule	N12	Control Node			downstreamflowtarget.dfs0
3	ExtractionRule	R5	Ord River Dam	H1	Ord River Dam Hydr	
4	ExtractionRule	N3		I1	Current Irrigation	
5	ExtractionRule	N10		I5	Weaber Plain	
6	ExtractionRule	N9		I2	West Bank	
7	ExtractionRule	N3		I2	West Bank	
8	ExtractionRule	N6		I3	Mantina	
9	ExtractionRule	N13		I3	Mantina	
10	ExtractionRule	N14		I4	Carlton	
11	ReservoirTargetLevelRule	R5	Ord River Dam			ordreservoirtargetlevel.dfs0
12	ReservoirStorageRule	R5	Ord River Dam			

Fig. 4 The MB Rules Windows summarising the global rules

Simulation and models

Once the river basin schematisation has been completed, the data have been entered and the rules defined, some parameters characterising the simulation must be specified. The simulation window asks for the starting and ending dates of the simulation period and to choose between a monthly or daily time step. Some options related to the result presentation can be selected as well: some results views can open automatically when simulation is terminated or output can be visualised for only a specific sub-set of nodes. Then the simulation is launched with the ok button at the bottom of the window.

Water Quantity

As said above, MB simulates water quantity, water quality and groundwater. As far as water quantity is concerned, the calculation of water flows and their distribution in the Basin is performed on the basis of the Local or Global Rules. The runoff data used by the allocation algorithm are specified for each catchment node in text files associated to the nodes themselves in their property boxes. However, MB integrates a rainfall-runoff (RR) module that allows the computation of the runoff time series given the initial conditions, a set of necessary parameters and time series of evaporation and precipitation. The user is asked for this kind of information in *the Rainfall-Runoff Modelling dialog box* that is accessed from the generic catchment node box. In the same box he can choose among three different rainfall-runoff models that are part of another DHI software package named Mike 11. The models are NAM, SMAP and UHM.

The NAM is a conceptual model originally developed by the Department of Hydrodynamics and Water Resources at the Technical University of Denmark. It simulates the rainfall-runoff processes occurring at the catchment scale and calculates in particular surface-overland flows, interflows and baseflows as a function of the soil moisture content, surface storage and accumulation and melting of snow. It is lumped type, so it treats each catchment as a single unit whose variables assume average weighted values for the entire area. The NAM parameters are estimated through proper calibrations against time series of physical data observations.

The input requirements of NAM are moderate and consist of 1) basic meteorological data, such as rainfall and evapotranspiration 2) some additional data of temperature and radiation used by the snow modelling 3) observed discharge data at the catchment outlet, to be compared with the model output for validation and calibration purposes 4) water used for irrigation and 5) pumping rates from aquifers. The time scale of meteorological data is different for each kind of time series: for rainfall it depends on the time scale of the catchment response but usually daily values are sufficient, potential evapotranspiration can be provided as monthly values while temperature as daily mean values.

NAM comprises the following modules:

- Basic modelling module
- Extended Groundwater module
- Snow module
- Irrigation module

The basic module of NAM simulates the overland flows, infiltration and aquifer recharge, interflows in the root zone and the base flow in aquifers. Moisture intercepted by vegetation and cropped areas as well as accumulated in depressions is conceived as a surface storage whose outflows are due to evapotranspiration and infiltration. The water amount exceeding the *surface storage capacity* generates the surface land flows feeding streams. The soil layer below the surface is schematised as the *root zone storage* receiving water for infiltration and losing water for roots transpiration, interflows and deeper infiltration recharging the aquifers.

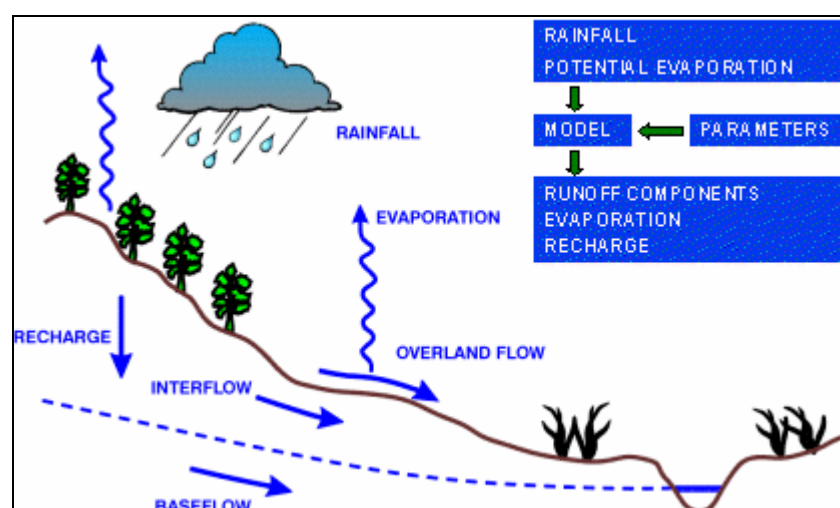


Fig. 5 The schematic of natural phenomenon for the NAM model

The Extended Groundwater module of NAM describes the water balance of the *Groundwater Storage* by considering recharge, capillary flux, net groundwater abstractions and base flow. *Groundwater storage* is described as a lower storage with usually has a slow responding component of the base flow and an upper storage providing a faster response. They are studied both as linear reservoir. The capillary flux of water from the groundwater to the root zone is a function of the depth of the water table below the ground surface and the moisture content of the root zone. This module of NAM also considers the possible drainage of water to or from neighbouring catchments due to local geology and geomorphology. The amount of recharging water feeding near catchments

or coming from them is calculated as a proportion of the total recharge multiplied by the ratio of groundwater catchment area over topographical catchment area.

The Snow module of NAM addresses the snowmelt component of runoff that is significant in mountainous areas mostly, where precipitation is retained in terms of accumulating snow during cold periods and appears as snowmelt in warmer ones. The general approach of the module is distributed type and consists in dividing the catchment area in many *altitude zones* and studying the contribution to the total runoff of each one individually. This reflects the fact that in mountainous areas snow cover, precipitation, evapotranspiration, temperature and radiation vary remarkably within a catchment and the use of separate data and coefficients improve the results of the simulated snow melting process. The Snow module uses a mean daily temperature approach to compute the melting rate coefficient but seasonal variations of it can be accounted in order to consider seasonal variations of incoming short wave radiation and of albedo of the snow surface.

The irrigation module of NAM takes into account the weight of large agricultural areas in the global water balance of the catchment. They affect the runoff distribution in terms of local water abstractions, from aquifers and rivers, and of increased local infiltration and groundwater recharge on the other side. Increased evapotranspiration and possible external water transfers for irrigation too have not negligible influence on catchment hydrology. The conceptual approach is to define each large irrigation site as a sub-catchment described by its own individual parameters such as irrigation losses to evaporation, seepage and overland flows. Monthly Crop coefficients to consider the proper evapotranspiration and stage of growth are used as well.

The Unit Hydrograph Module (UHM) is a hydrological model of the Mike 11 package and simulates the runoff from a single storm event using unit hydrograph methodology. The total rainfall less the amount that infiltrates in the root zone gives the volume of precipitation, which generates the land-flows. Infiltration is calculated through either fixed initial value followed by a constant loss rate, a loss rate proportional to the rainfall intensity (Rational Method), or determined by the Soil Conservation Service curve number method.

The third model of Mike 11 included in the Rainfall-runoff module of Mike Basins is SMAP. It is a hydrological model simulating the runoff of the generic catchment area by accounting for moisture storage in the root zone and in aquifers. These two kinds of storage are schematised as linear reservoirs, as it is within the NAM model. The model works on a monthly basis and updates the storage of both the reservoirs at each time step on the basis of the calculated terms of the balance such as surface runoff, groundwater recharge, evaporation and base flows. Input data required by SMAP concern precipitation, evaporation, some specific parameters and the monthly mean discharge at the control outlet point of the basin, which is used for calibration purposes. Using monthly data, SMAP can be used in place of NAM when daily data are not available.

Water Quality

The *water quality module* of Mike Basins simulates transport and degradation of significant substances affecting water quality issues in reservoirs and rivers. The substances modelled are: the total organic matter expressed as Biological Oxygen Demand, Ammonia, Nitrates, Dissolved Oxygen, Chemical Oxygen Demand, Total Phosphorus and E. Coli bacteria. The user is enabled to add a further substance of interest for case-specific analysis.

Solute transport is modelled as purely advective and dispersion is not taken into account. This assumption is reasonable in rivers without much turbulence and if degradation time is less than residence time.

Transport and degradation processes are simulated in River branches, Reservoirs and Groundwater, assuming perfect mixing conditions. Re-aeration phenomenon taking place where river water overflows weirs is considered also.

The differential equations used for both rivers and reservoirs are integrated over the time step length and give steady state solutions. Transport in groundwater is modelled as conservative. Any possible decay in the root zone is to be considered by the user when preparing the time series of mass flows featuring the water recharge.

Mike Basins supports the definition of pollutant loads both at point and non-point sources. Point sources are associated with water supplies which discharge into rivers a total pollutant load proportional to the return flows outgoing them. As water supplies are usually connected to waste water treatment plants whose effluents finally get the rivers, Mike Basins allows to describe concentrations entering river nodes as a function of the treatment type used within the plants. The user can specify his own concentrations and add new treatment methods or choose from a table of pre-defined common ones. This kind of information is accessed in the property box of water supply nodes.

Non-point sources are catchment areas and irrigation schemes. Time series of solutes can be expressed in terms of concentration or mass flows; these latter as annual mean values later multiplied by monthly rate coefficients. Time series can be user-defined or they can be calculated with the *Non-point Calculator Tool* of Mike Basin. It finds the effective loads for each catchment by overlaying the ArcView themes of land use and population data with the catchment theme. This tool is also used to update loads input when runoff changes or to adjust them for calibration purposes.

Groundwater

The *groundwater module* of Mike Basins can be activated in the first tool's window together with the other simulation modules and the choice of local or global rules approach. This

module consists of a simple physical model of an aquifer that is conceptualised as a linear reservoir exchanging water with water users and surface water bodies. The terms of the water balance comprise pumping, recharge, seepage from rivers and discharge to rivers. The first three are assigned by the Mike Basins user as time series. This kind of information is defined in the property box of network elements such as catchment areas and river branches as groundwater is conceptually linked to them. More in details, the user specifies: 1) seepage loss fraction, to be multiplied by the simulated flow in the stream branch to obtain the water volume lost to aquifer 2) groundwater recharge from the catchment area encompassing the stream as above 3) pumping demand rates, which Mike Basins will try to cover on the basis of groundwater actual availability. Groundwater discharge stands for the water flows at the shallow and deep outlet levels feeding rivers and it is proportional to the water level of the aquifer and also to the its storage because the supplying catchment areas are constant. Being a hydraulic response, discharge is not assigned by the user but computed by the groundwater module.

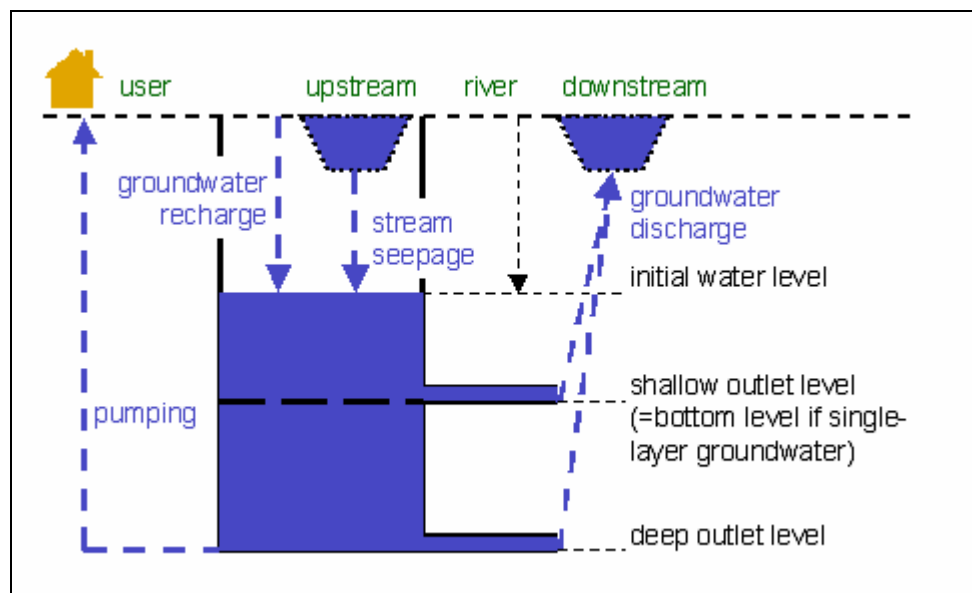


Fig. 6 Aquifer schematisation and exchanged flows

Viewing Results

Simulation results consist of performance of reservoirs and hydropower units, water balance and water quality status at the user nodes and river flows at each river node. Information is displayed in three different formats:

- As time series and related graphs
- Summary HTML tables
- On the geographic layer

The first two modes are entered directly from the map by right clicking on the desired node and choosing *Time Series Result* or *Monthly Table* respectively from the opening pop up menu. As regards the time series, a window of the TSedit opens for the specified node and shows its characteristic two panels. In the panel on the right, output is organised in tabular form with the time dates simulated in rows and the different output items in columns. In the panel on the left plots relevant to data series are visualised in different colours and for the entire simulation horizon. The plotted data series are ticked in the *select item* box.

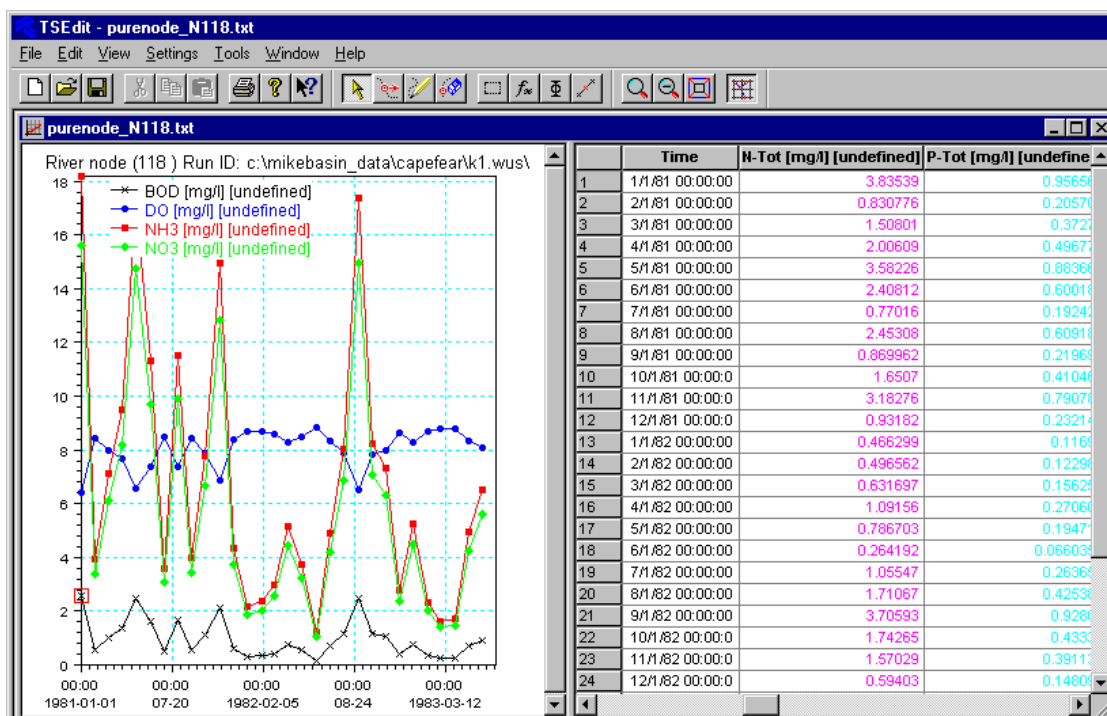



Fig. 7 The TSedit tool displaying results

The HTML tables contain the same output but the presence of *go to* links to the various sections of the file gives the advantage of an easy navigation through it. Links to other HTML files relevant to the neighbouring nodes, actually the upstream and downstream ones, are also provided. The HTML also contains descriptive statistics of data such as minimum, maximum and mean values for each data series.

As a third option, the MB User can see the behaviour of the water resource system through an animated view on the geographic layer. Dimensions and colours of the network elements change at each time step according to the values assumed by output variables. On the left of the map there is a list of legends describing the range of values each kind of output can assume and the associated coloured and sized items. A dedicated bar displays the time steps and the position in time within the simulation horizon.

Results can be saved into a Microsoft Access Database, launched from the main interface with a specific button, so that they are available for future queries. In addition, result reports of Access can be created.

MIKE BASIN



Node:	River node N22
Simulation ID:	wq.run
Simulation description:	

Link(s) to upstream node tables	Link(s) to downstream node tables
Catchment node N5	

[GOTO Net flow to node](#)
[GOTO Observed flow](#)
[GOTO Minimum flow target](#)
[GOTO Inflow from: Catchment node N5](#)
[GOTO Water leaving model area](#)
[GOTO BOD](#)
[GOTO DO](#)
[GOTO NH3](#)
[GOTO NO3](#)
[GOTO P_Tot](#)
[GOTO COD](#)
[GOTO E.coli](#)
[GOTO User-defined](#)
[GOTO Node mass balance](#)

Net flow to node [m³/s] [GOTO TOP OF PAGE](#)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	Min	Max
1998	72.183	43.850	25.541	28.430	58.184	99.960	101.517	410.384	494.218	544.348	354.182	203.100	202.991	25.541	544.348
1999	154.719	78.085	44.776	67.429	85.912	15.179	252.956	363.984	745.940	702.540	435.179	250.191	266.407	15.179	745.940
2000	200.655	118.342	73.682	50.301	163.226	222.254	636.344	682.275	667.750	455.225	249.679	149.773	305.792	50.301	682.275

Fig. 8 An HTML table for a river node

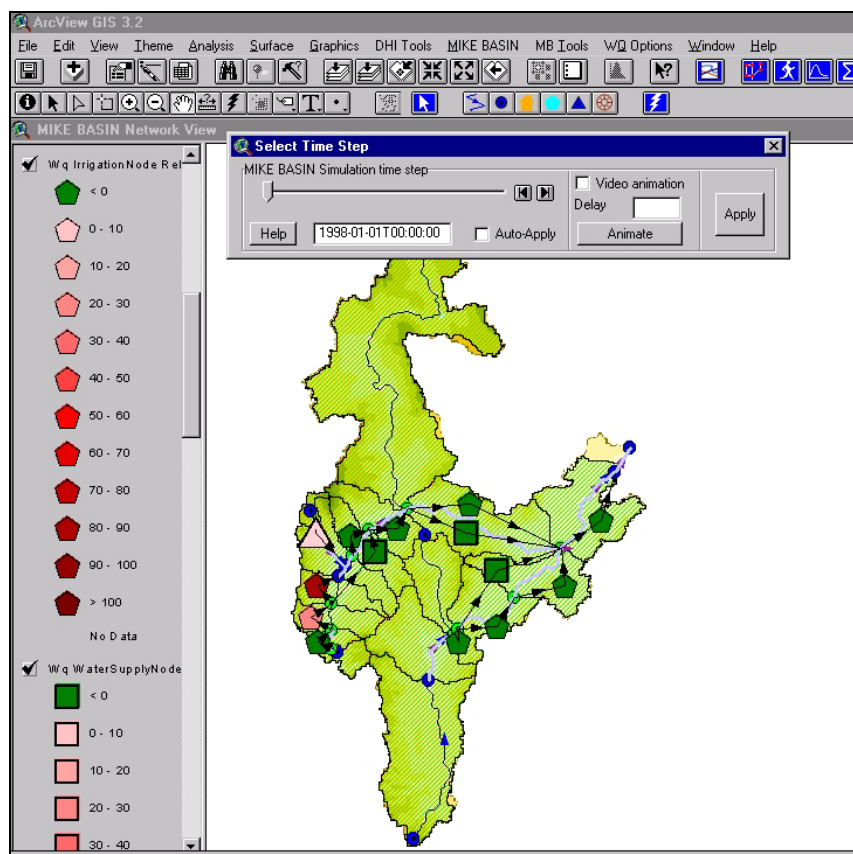


Fig. 9 The Animated View displaying simulation results

Adaptability to the Water Strategy Man Project

According to the developer MIKE BASIN should facilitate sustainable management of surface and groundwater resources and water quality. Unfortunately the system concentrate on the physical and optimisation aspects of water resources, without taking into account socio-economical impacts and impact analysis techniques, such as for instance the PSIR (Pressure/State/Impact/Response) approach proposed by the Organisation for Economic Co-operation and Development (OECD), or the DPSIR approach (Driving forces, Pressures, State, Impacts and Responses) promulgated by the European Environment Agency (EEA) linking policy objectives to information and analysis in the context of management implementation.

2.2. Basins

Another example of available DSS in Water Resources is the Better Assessment Science Integrating point and Non point Sources – BASINS, developed by the U.S.-Environmental Protection Agency.

After the first release in 1996 and the upgrade in 1998, Basins is now at its third version, dated June 2001. It has been originally conceived to meet the needs of Local, Regional and State environmental and pollution control agencies to perform ecological and water quality studies at a watershed scale.

Objectives

- To facilitate examination of environmental information;
- To support analysis of environmental systems;
- To provide an integrated and modelling framework for examining point and non-point source management alternatives;

Although the package addresses primarily the analysis of pollutants' maximum daily loads from point and non-point sources, it has been also applied to other issues: wet weather combined sewer overflows, storm water management, drinking water source protection, urban and rural land use evaluations, animal feeding operations and habitat management practices.

Components

Basins comprises a set of interrelated components that are integrated within the Esri's ArcView Gis environment. They are:

- Gis
- National environmental databases;
- Assessment tools addressing both large- and small-scale analysis;
- Watershed Delineation tools;
- Watershed Characterisation Reports;
- Utilities for importing, organising, evaluating data;
- Utilities for classifying elevation, land use, soils, and water quality data;
- A suite of models concerning in-stream water quality and pollutants' loads and their transport;

- A scenario generator tool;

The use of ArcView makes the Basins architecture to be open and flexible in that each agency or generic user can develop and customise his own utilities to better address specific needs and different kinds of application. These utilities are loaded in the system as extensions of ArcView, to be added to those already present or made available by Esri. Moreover, all customised components of Basins version 3.0 such as model interfaces, data management utilities and watershed assessment tools, have been developed as own Basins extensions so as to allow the user to load the only extensions they will use within their water basin project as Basins components. On the other hand this also helps the developers to maintain and upgrade the package as they concentrate on individual extensions rather than on the entire system.

Gis

The BASINS GIS, which is driven by the ArcView 3.1 or 3.2 environment, provides built-in additional procedures for data query, spatial analysis, and map generation. These custom BASINS procedures allow a user to visualise, explore and query the available data, and perform individualised and targeted watershed-based analyses.

Database

The databases included in Basins provide cartographic, environmental and water quality information, which have been selected on the basis of national availability and relevance to environmental analysis. Basins users can also import additional locally derived data in order to support the most appropriate and accurate analysis.

Base Cartographic Data concern:

- hydrographic boundaries associated with major U.S. river basins,
- a network of the major highways
- populated and urbanised area
- administrative boundaries

Environmental data comprises of background and monitoring information. The former describe the watershed in terms of soil characteristics, land use coverage, and the stream hydrography whilst the latter primarily concern water quality data.

More in detail, Environmental Background Data consist of:

- delineation of the Eco-regions defined by the U.S. EPA and of the study areas;
- Soils information;
- Results of the wastewater control;
- stream networks;
- drainage networks;
- Digital Elevation Model;
- Land Use and Land Cover;
- National Inventory of Dams and associated information;

Environmental Monitoring Data concern:

- historical water quality data for physical and chemical parameters and bacteria registered at monitoring stations;
- observed data at monitoring stations;
- freshwater and coastal sediments and amount of nutrients;
- locations with advisories for fishing;
- inventory of surface water gauging station data;
- Weather Station Sites;
- location of public water supplies, their intakes, and sources of surface water supply;
- location and extent of shellfish areas;

The fourth kind of data store in the Basins databases is the Point Source/Loading Data that include information on locations and type of facilities generating and discharging pollutant loads:

- Industrial Facilities Discharge Sites;
- Toxic Release Inventory Sites and Pollutant Release Data;
- Location of transfer, storage, and disposal facilities for solid and hazardous waste;
- Location and characteristics of mining sites;

Environmental Assessment Tools

The Assessment Tools *TARGET*, *ASSESS*, and *DATA MINING* constitute three of the useful extensions of Basins. They allow the user to perform regional assessments of in-stream water quality conditions, identify point source discharges at a watershed scale and access and review summary data at a site-specific scale.

Target works at the macro-level of regions and areas with many watersheds. It investigates the monitoring data concerning concentrations of pollutant and parameters or the permitted discharges and it ranks the various watersheds based on evaluation parameters, thresholds and monitoring time periods selected by the user. The results of the analysis are displayed in three different views:

- a geographic layer displaying the average monitoring value computed for each watershed;
- a bar chart that shows the distribution of watersheds with respect to the number of stations exceeding the selected threshold value.
- a bar chart that summarises the distribution of watersheds with respect to the average monitoring values.

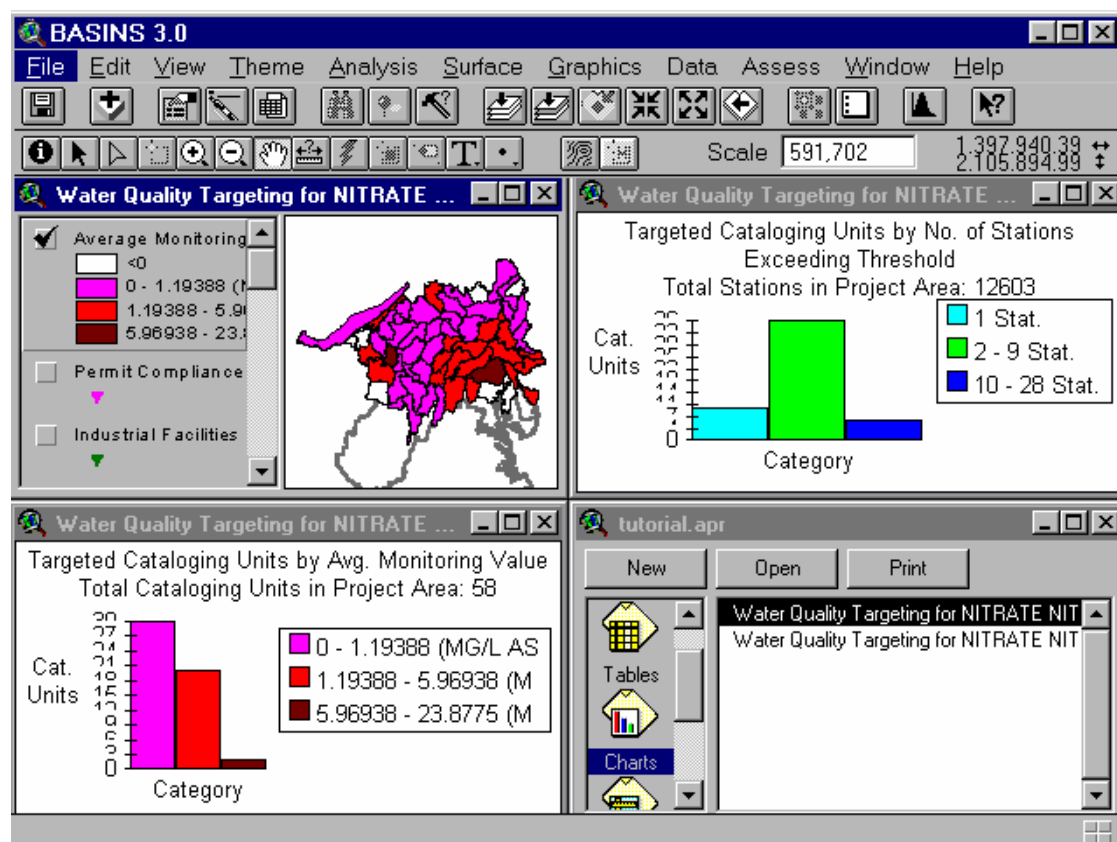


Fig. 10 The Target tool of Basins

Assess works on an individual watershed or a group of watersheds, which may have been identified as areas of concern in a previous Target analysis performed on a regional scale. Analogously to Target, this tool examines the monitoring data on the basis of specified time periods and thresholds parameters but in this case it evaluates each monitoring station separately and provides a comparative view of the water quality condition at each station. The Assess's results are summarised in the following views:

- a geographic layer displaying water quality stations ranked according to the average monitoring value for the selected time period and selected water quality parameter;
- a bar chart displaying the distribution of the stations based on the monitoring value;

The Assess tool can be used for various purposes such as evaluation of stream conditions, establishment of relationships between in-stream water quality conditions and potential sources and causes, evaluation of monitoring programs.

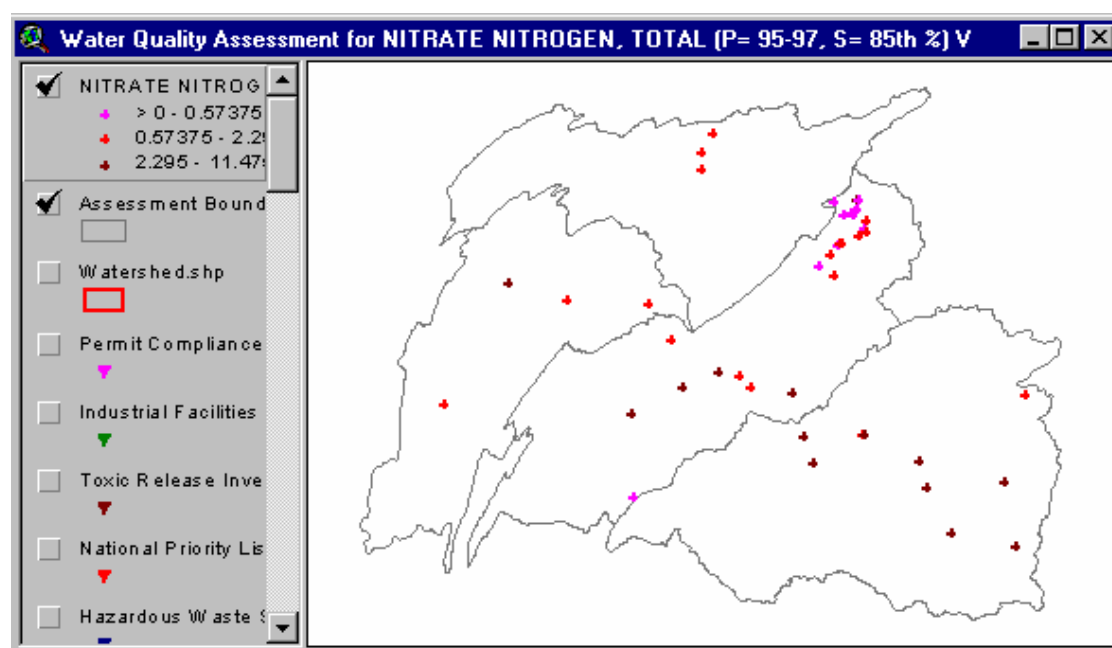


Fig. 11 The Assess tool of Basins

The third assessment tool is Data Mining. It allows the user to select one or more stations on the geographical layer by dragging a box with the mouse around the stations or around the area of interest and to retrieve and visualise the corresponding data in dedicated tables. The possible elements to be selected are stations monitoring water quality and bacteria and the locations of facilities having received permits to discharge waste water in surface water bodies.

The relational data tables and views displayed by Data Mining are:

- Station Table with the codes of the selected stations
- Parameter Table with the list of pollutants or bacteria
- Data Tables (one table for each time series available).
- The geographical Data Mining layer

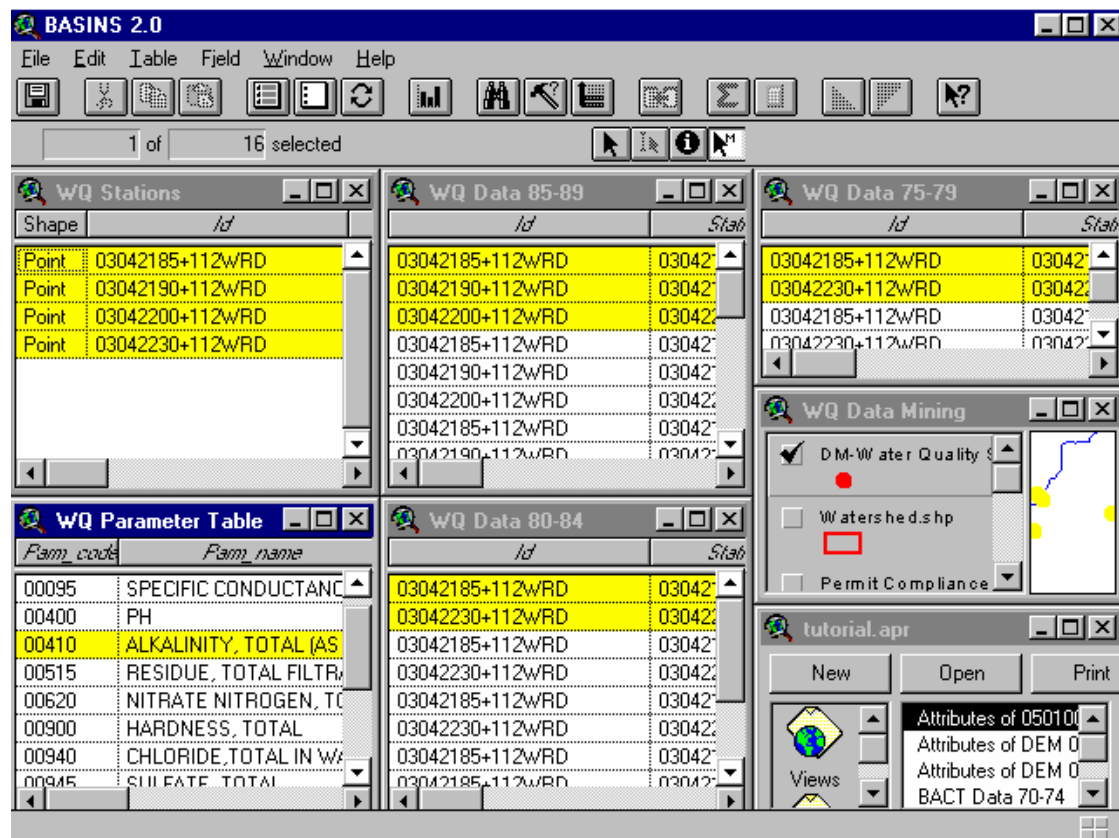


Fig. 12 The Data Mining of Basins

Watershed Delineation tool

The delineation feature guides the dss user to divide a watershed into one or more subwatersheds. The boundary of a sub-basin is drawn directly on the Gis layer as a set of segments through a point-and-click process. Watershed modelling and analysis can be performed on a single delineated watershed or multiple watersheds by using the Basins' HSPF or SWAT models and the Watershed Characterisation Report tools.

Watershed Characterisation Reports

This Basins tool assists the user to create customised maps and tables to summarise the overall condition of the study area. BASINS version 3.0 generates six different types of watershed reports:

- Point Source Inventory Report, providing a summary of loading discharge facilities in a given watershed. It is useful to a rapid identification of point sources, an evaluation of their proximity to major streams and the assessment of the magnitude and severity of point source contributions.
- Water Quality Summary Report, providing statistical summaries of the mean and selected percentiles of water quality data observed at the monitoring stations during a given time period.
- Toxic Air Emission Report, that is a summary of estimated releases of toxic pollutants in the air at the facilities included in the USEPA Toxic Release Inventory (TRI)
- Land use Distribution Report, in both table and map layout formats
- State Soil Characteristics Report, providing a summary of the spatial variability of soil parameters such as water table depth, bedrock depth, soil erodibility, available water capacity, permeability, bulk density, pH, organic matter content, soil liquid limit, soil plasticity, and percent silt and clay content
- Watershed Topographic Report, providing an elevation map of the study area and the graph of hypsometric curve showing the cumulative percentage of the total area under a particular elevation

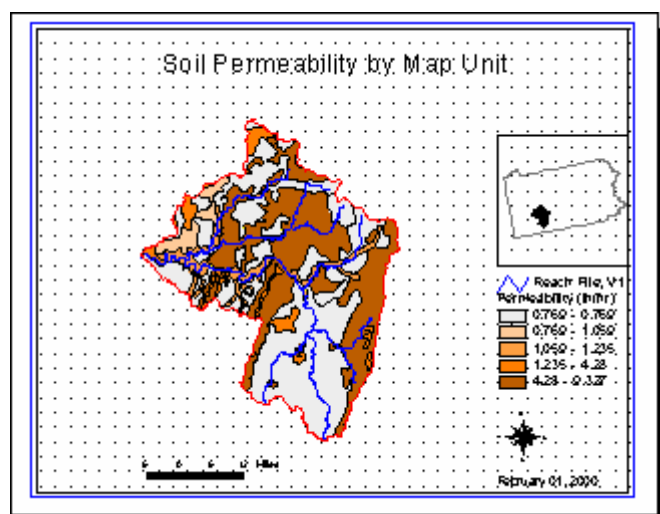


Fig. 13 An example of Soil Characteristics Report

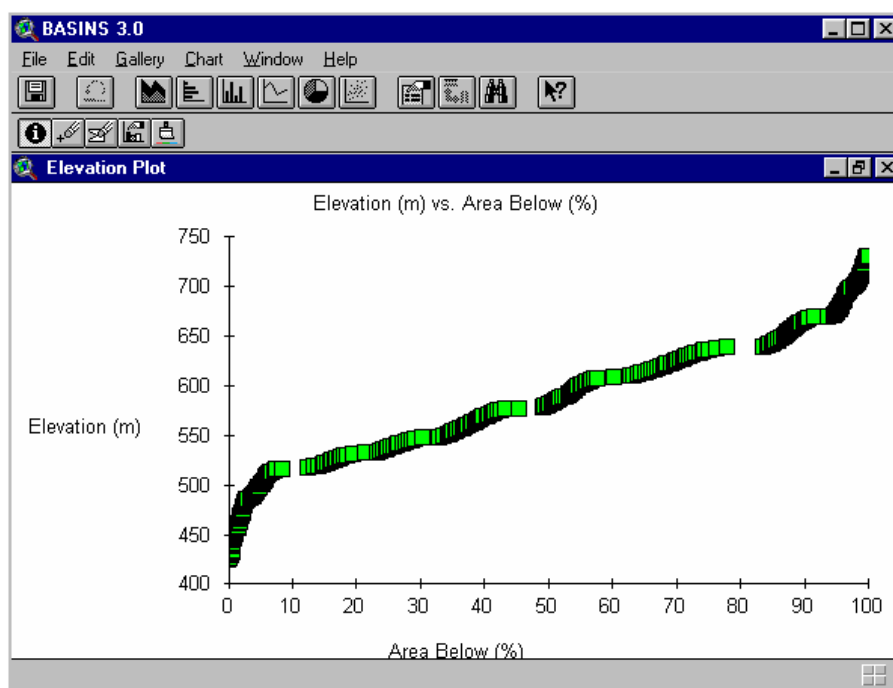


Fig. 14 The Hypsometric Curve of the Watershed Topographic Report

Basins Utilities

Basins has four utilities to reclassify, overlay, and update data. The *Land Use, Soils Class and Overlay* function is used to prepare data input for the SWAT and HSPF models. These models use combinations of land use and soils themes to determine the area and the distribution of hydrologic response units of each land-soil category simulated. The *Land Use Reclassification* utility is used to change land use classifications within an existing data set. Reclassification allows the user to update land use data or simply to change them so as to evaluate alternatives of water quality impacts based on changes to land use over time. Land Use Reclassification simplifies the non point source modelling as well, by grouping detailed land use classes with similar characteristics into broad categories. The *Water Quality Observation Data Management* supports the user to manipulate and add the time-series of water quality data observed at monitoring stations as well as to add, delete and relocate stations. The fourth basin utility is *DEM Reclassification*. It is used to display large amounts of spatially distributed information in suitable detail by modifying default colours and the range of values.

Models used in Basins

The models used in the Basins package are Pollutant Load (PLOAD), Soil and Water Assessment Tool (SWAT), Windows Hydrological Simulation Program-Fortran

(WinHSPF) and Enhanced Stream Water Quality Model (QUAL2). Hereunder is a short description of each model.

Pload is an ArcView GIS Tool that calculates non point pollutant loads at the watershed scale on an annual average basis. It requires pre-processed GIS data and tabular input data. GIS data consist of watersheds boundary and land-use coverage in the ESRI Arc/Info coverage or ArcView shape files format. Tabular input concern pollutant loading rates and percentage of imperviousness for urban and rural land use types. Tables can be easily created and imported from Excel files or database tables. The Basins user is guided by a number of windows to define or choose the information needed by the model, to run the calculation of the annual pollutant loads and to analyse the results.

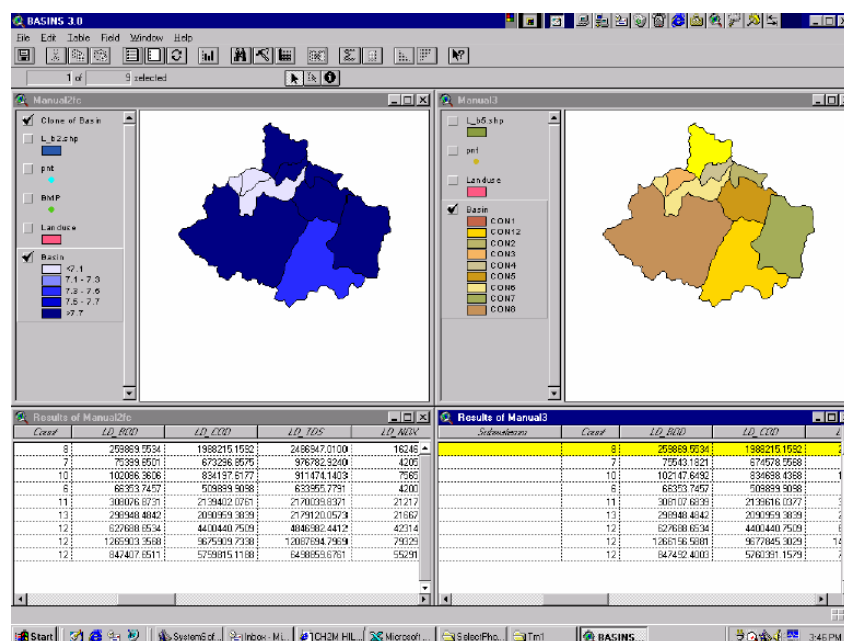


Fig. 15 A comparison of two calculations with the View Sessions

The results can be displayed on maps, together with the corresponding tables of values, and according to two different spatial aggregation: the user can visualise the pollutant loads by watershed, expressed in lb/year, or per unit of watershed area, expressed in lb/acre-year. Besides, a *View Sessions* option allows to view concurrently up to three different outputs, resulting from three different sessions of calculation, so as to compare various situations.

The Soil and Water Assessment Tool, SWAT, is a watershed, scale model developed by the Agricultural Research Service of the US Department of Agriculture. It is physically based and simulates hydrology, pesticide and nutrient cycling, bacteria transport, erosion and sediment transport with a daily time step. It is particularly suitable to predict effects of land use management as well as climatic and vegetative changes on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time (up to a hundred years). As

SWAT describes physical processes associated with water, it requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. Besides, Swat include five databases concerning specific pollutant generation from agricultural practices and municipalities:

- land cover-plant growth, containing information about ideal conditions of and impact of some stresses on plant growth
- tillage information useful to simulate the redistribution of nutrients and pesticide that occurs in a tillage operation
- pesticides
- fertilisers and the related content of nutrients
- urban landscape classification and attributes such as the fraction of urban land area that is impervious and connected to a drainage system, wash-off coefficients or nutrient concentrations in the solids

The Windows Hydrological Simulation Program Fortran is a program originally developed by Hydrocomp Inc. and the U.S. Geological Survey under the name of *HSPF* and it has been recently enhanced with a windows-based graphical user interface within Basins. It simulates non-point source runoff and pollutant loads at the watershed scale, it combines them with point source contributions and performs flow and water quality routing at determined river reaches. In addition, it includes a simplified snow melt algorithm based on a degree-day approach and the ability to model land-to-land transfers. Data required by HSPF comprise meteorologic records of precipitation, estimates of potential evapotranspiration, air temperature, wind, solar radiation, humidity and cloud cover.

The Enhanced Stream Water Quality Model (QUAL2) is a stream water quality model suitable for dendritic river systems. A network of headwater points, reaches and junctions schematises the stream. Reaches are defined as stretch where the physical, chemical and biological parameters can be assumed constant. Furthermore, each reach is divided into a number of computational elements each one characterised by a hydrologic balance in terms of stream flows, a heat balance in terms of temperature and a mass balance in terms of concentration. The latter also includes processes such as transformation of nutrients, algal production, benthic and carbonaceous demand, atmospheric reaeration and their relations with the dissolved oxygen balance. QUAL2 can simulate up to 15 water quality parameters among which DO, BOD, temperature, Chlorophyll Alpha, coliforms and the cycles of phosphorus and nitrogen. The kind of data required by the model concerns hydrologic flows, water quality parameters and climatological information. This latter comprises monitored values of air temperature, atmospheric pressure, wind velocity, net solar radiation and cloud cover, all data involved in simulation of algae and temperature.

Scenario generator tool

BASINS includes the program *GenScn*, *GENeration and analysis of model simulation SCeNarios*, that was originally developed by the U.S. Geological Survey. This tool has been integrated within Basins as one of its own extensions and can be directly accessed from the GIS Interface. GenScn primarily serves as a pre and post-processor for both the HSPF and SWAT models, as it allows the user to change their input data and to display output reports in graphical and tabular form. On the other hand, the definition of input data describes a Scenario that will be evaluated through the simulation results and compared with other ones. Therefore GenScn is said to be a Scenario Generator. Moreover this tool is also used to visualise observed time series data, make comparisons with modelled data and perform statistics.

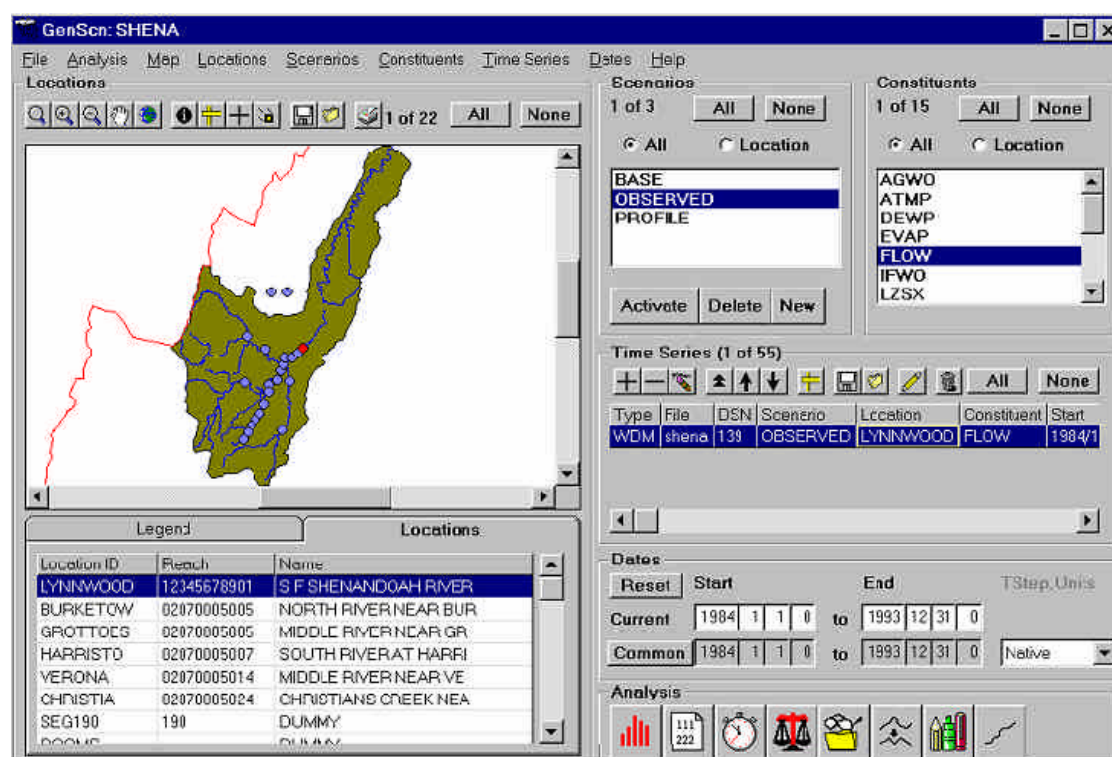


Fig. 16 The main form of GenScn Graphical User Interface

GenScn has a windows-based graphical user interface that was developed in Visual Basic and uses several Fortran functions and routines. The main window of the interface has the following frames:

- a locations frame consisting of 1) a basin's map displaying boundaries and locations to be studied 2) a toolbar containing map manipulation commands 3) a table with a legend and summaries of information found on the map. A location can be selected both by clicking the corresponding spot on the map and by selecting it in the text table. In both cases the text and the spot highlight in a different colour

- a scenarios frame with a list of simulated or monitored scenarios available in the project. Here a preferred scenario for the chosen location can be selected by clicking on it
- a list of items, here *constituents*, such as atmospheric pressure, water flows, dew and evaporation for which observed time-series are available
- the time-series frame, summarising information about the available time-series of selected scenario, constituents and highlighted location.
- the *dates* frame contains information about the range of dates available for the currently selected time series and the default time step
- the *analysis* frame contains a toolbar that links to GenScn's tools generating and editing various types of plots, tables and statistical text reports useful to compare various data series.

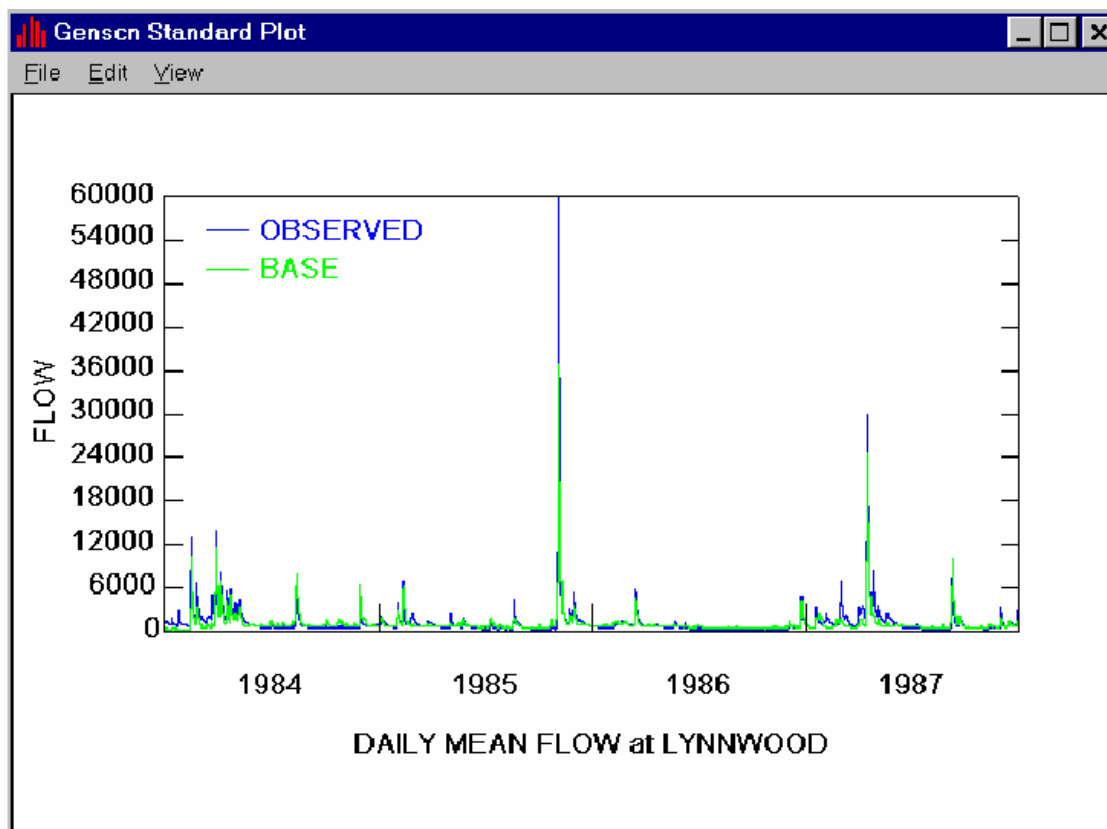


Fig. 17 Comparison of time series of flow item in the selected Lynnwood location

Adaptability to the Water Strategy Man Project

Although *Basins* is more environmentally oriented than *Mike-Basin*, nonetheless, the physical aspects prevail over a comprehensive analysis and assessment of sustainability in the objective of linking policy options to information and analysis in the context of management implementation.

The *GenSen* program allows the management of different scenarios but the definition of scenario is quite different from the one agreed by the water strategy man Methodology group and cited in the WSM Glossary of terms. In *Basins* the word “scenario” refers to a set of data series that are input to the *Basins*’ models and to the relevant outputs. In WSM a scenario has been defined as a group of “developments which can not be directly influenced by the Decision Maker such as Weather, Market Prices etc”. According to this view, the user of the WSM DSS will choose among predefined climatic or economic scenarios that will be a sort of exogenous background to the simulations of water quantity and quality and the computation of multi-sectoral indicators. The variables assuming the data values of time series defining a scenario will be used by models but not be updated at each time step.

2.3. DSS for Water Resources Planning Based on Environmental Balance

More recently a “Decision Support System for Water Resources Planning based on Environmental Balance” project funded by the Italian Cooperation aims at developing a methodological approach to sustainable WR planning (Fig. 18). The project started at the beginning of 1998 with a one-year long inception phase, while the implementation phase of the project ended in August 2001.

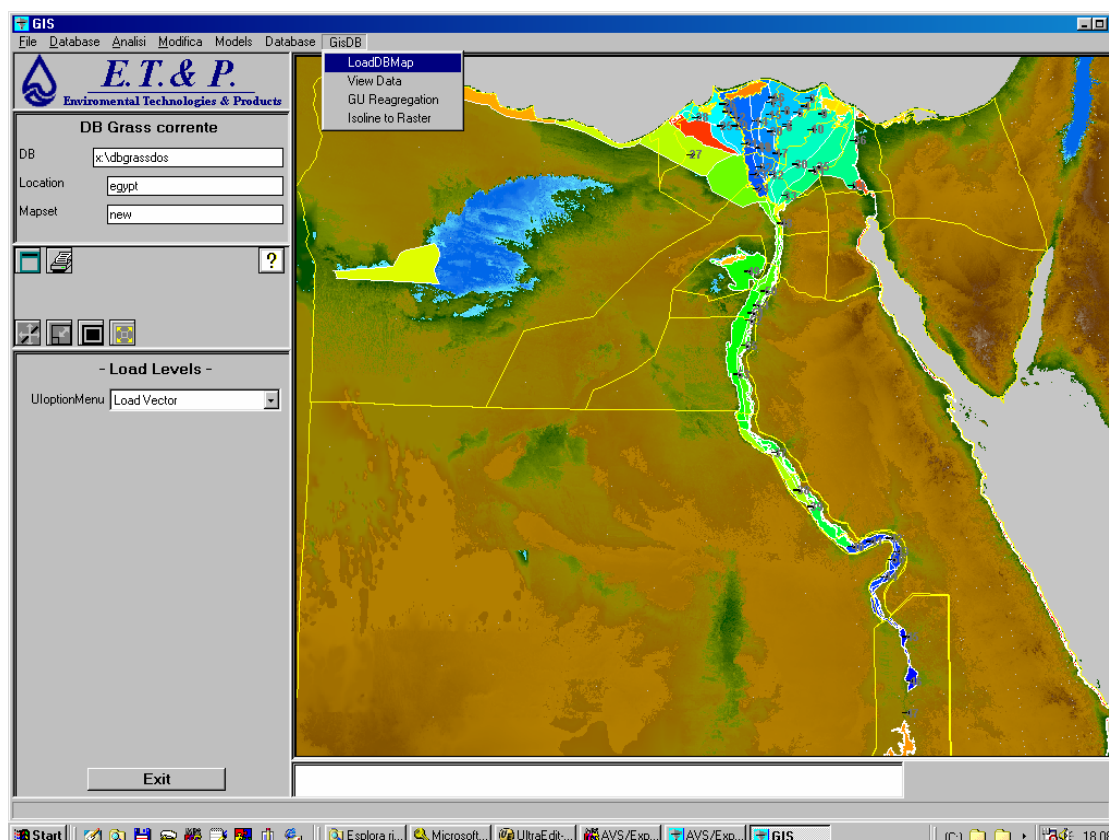


Fig. 18 The integration of GIS (GRASS), DB and models under the same DSS structure, allow for the automatic preparation of inputs to models and the thematic map viewing of results.

The objectives of the Project are the development of:

- A methodology for the integration of environmental and socio-economic aspects in the analysis of WR scenarios and development measures;
- A set of procedures, rules and relationships to facilitate the exchange of information among different organizations;
- An application to a representative case study;
- An integrated, open-architecture Decision Support System (DSS).

The project constitutes a noticeable improvement with respect to the very limited number of Water Resources Management DSSs that were developed in the recent years and that are currently available.

The project is developed around five basic functions:

- the **description** of the water system including both the hydraulic and the environmental characteristics through a number of **indicators**.
- the **assessment** of the state of the system in terms of sources, usage, water cycles (paths), environmental quality (water, soil, fauna, flora,...., difference between natural and artificial water cycles,....);
- the **forecasting** of the evolution of the water system and environment on the basis of assumed or envisaged *scenarios*, technical *alternatives* and management policies (*actions* described in terms of *decision variables*);
- the **evaluation** of the effects of actions, by observing the results on the system forecast on the basis of the different scenarios, alternatives and policies.
- the **consideration** of local, national or international legal constraints and directives to be mapped and related to the geographical and administrative boundaries.

The connection between the function of assessment, forecasting and evaluation must be achieved in through the integration of several data-processing modules and mathematical models. Therefore, an open and user friendly architecture was studied and adopted for accommodating mathematical models of different levels of aggregation and complexity (Fig. 19). The models are activated by the user through the GUI, which interacts with the Logical Co-ordination and Scheduling Unit (LCU). Using a set of pre-processors (filters), the LCU is able of preparing inputs to models by collecting the DB data, taking advantage of the GIS based geo-referencing. The same architecture is used backwards for storing and visualising the results. Storage in the DB is performed by means of post-processing filters, while the GUI helps the user in selecting, visualising and comparing results. Finally, the open structure of the system also allows for the use of external data and external models results.

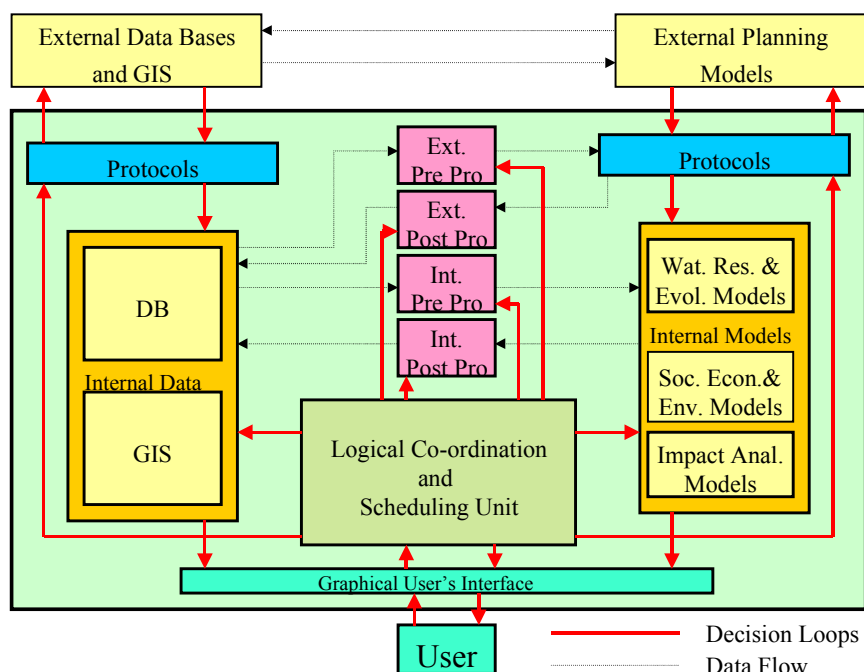


Fig. 19 A schematic representation of the system structure

The scope of the DSS is to build EIA reports on the basis of several pressure and state indicators.

Pressure indicators include among others:

- *Environmental*: consumption of water/chemicals/energy by crop, region pollutants loads to water bodies/fields changes of hydrological inflows pattern etc.;
- *Economic*: WR&Agro governmental investment costs, foreign, private investments GNP growth rate etc.;
- *Socio-economic*: Demographic growth rate; industrial growth rate by sector etc..

State indicators include: water flows, water quality, soils state (salinity, water logging); agro-sector employment; WR OMR expenditures and revenues; cost of water; value of agro production; agro export, import; economic efficiency by crop and region; economic efficiency of sectoral Development measures; sustainability of water use; all indicators of Quality of Life indices at different level of social, spatial and temporal aggregation.

The system operates on the basis of selected scenarios and actions. The simulation models (Table 2), run the different hypotheses over a defined time span (10-20-30 years) using all the available data (Table 3) and, at the end of the simulation process, the pressure and state indicators are then synthesised in order to offer an understandable report to the stakeholders.

Table 2 Models integrated into the DSS

MODELS		
Water Planner	Surface water quality	Socio economical and demographic
Agro-economic	Soil and crop load	Lakes
Lake Nasser simulation	End loads	Health
Lake Nasser policy	Ground Water quantity	Layout
Surface water quantity	Ground Water quality	Administrative

Table 3 Data categories integrated into the DSS

Irrigation	Groundwater	Agriculture	Environment	Economic	Demography
Irrigation	Groundwater	Agriculture	Environment	Socio-economic	Demography
Drainage	Desalination	Land	Water quality	Agro-economic	Quality of life
Canals	Domestic	Crops	Lakes		Health
Rivers	Industry	Reclamation	Meteorology		
Pumping Stations		Livestock			
		Fisheries			

Adaptability to the Water Strategy Man Project

The Graphical user interface of the DSS outcoming the Italian co-operation with Egypt has been developed with the AVS/Express software that is responsible to manage the access and data exchange between the Gis layers, the Database and the models. AVS/Express has well accomplished his tasks also for what regards the presentation of output results in terms of 2D tables and coloured plots. However, it is to be said that his major capabilities, which concern the 3D visualisations of data, have not been exploited within the development phase of this project, being a step further with respect to the primary purposes of it. The choice of A VS at the beginning of the project was guided, else to the 2D and 3D viewing enhancements and the management of time series data, by his capability to integrate external software written in different programming language such as C, C++ and fortran and for his compatibility to be used and linked to the available types of commercial Database Softwares. Some less positive aspects of AVS/Express concern the use of his own programming language and the fact that the construction of graphical user interfaces seems to be much more complex and time consuming than the ones built with visual basic. Until ESRI ArcView has been programmed only in the Avenue language, the AVS/Express has been a valid alternative for DSS biuldings. On the other hand, the recent release of ESRI ArcGis 8 has permitted to developers to program the ArcView Software in visual basic and C++, which allows to link and embed external routines, to customise toolbars and to add user-defined extensions that are suitable for specific realities and modelling issues. Furthermore, ArcView is worldwide used and most of the available data is in the well-accepted and

disseminated Shape format. For all these reasons the Egyptian Tool is not proposed as applicable as it is to the WSM paradigms nor easily adaptable to them.

2.4. A Spatial Decision Support System for The Evaluation of Water Demand and Supply Management Schemes¹

A prototype Spatial Decision Support System for the evaluation of water demand and supply management schemes is presented. The water basin is topologically mapped to a network of spatial objects representing the physical entities and their connections. Several GIS functions, which include data input/update, network derivation from the basin map and network building/modification are incorporated. The tool integrates suitable models for demand site requirements calculation and water allocation. Alternative scenarios can be constructed, trends and interactions of the complex water system can be analysed, strategies to solve water allocation conflicts can be evaluated and necessary infrastructure interventions can be planned in advance in order to meet water needs. The tool is demonstrated through a case study, involving the current situation and future policies for a typical Greek island.

Tool Architecture

The structure of the developed SDSS is presented in Fig. 20. The central objective in the design of the system is to integrate data, models and decision analysis processes into a unified software package. The system was implemented within the computational environment of Microsoft Visual Basic. The GIS functionality is embedded with objects of the MapInfo MapX ActiveX component.

Users interact with the system via a GIS map-based user-interface, which provides the functionality of inputting information and viewing of results through appropriate maps, diagrams and tables. A network representation of the hydrological basin is derived from the core database. Characteristic scenarios can be developed with the use of a network editing tool and future assumptions that affect demand, supply and hydrology can be specified. Scenarios are evaluated with the aid of a demand calculation procedure and a water allocation model. Scenarios can then be planned, simulated and evaluated and the decision-maker can undertake rational actions with respect to his objectives.

¹ The description of this tool has been prepared by E. Manoli, G. Arampatzis, D. Assimacopoulos of the National Technical University of Athens, by E. Pissias of the Technological Education Institute (TEI) Athens and by D. Xenos

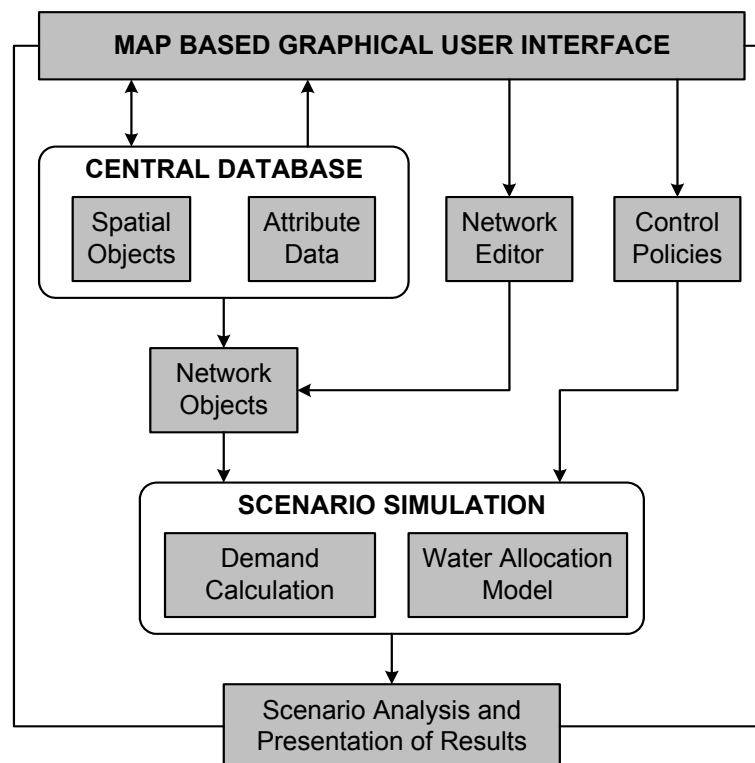


Fig. 20 Architecture of the Spatial Decision Support System

Database

The GIS database is the heart of the spatial and operational information system as well as the storage system that allows communication and intermediate storage between models and subsequent reporting modules. The object model of the database is presented in Fig. 21. The database has been developed around a geographical hierarchy, which is dictated by the very same nature of available information. The hierarchy is implemented through a collection of maps (chartographic representation) and a collection of tables with attribute data and time series (tabular representation), connected through the data-binding protocols supported by the MapX technology

For each area identified as demand or supply regions, irrigated areas, industrial plants, surface and groundwater resources, storage and distribution networks are retrieved from the database. Each entity is fed with appropriate attribute data, which refer to permanent and seasonal population, agricultural water requirement, water resource availability, their monthly variation and their associated economic cost and money flows.

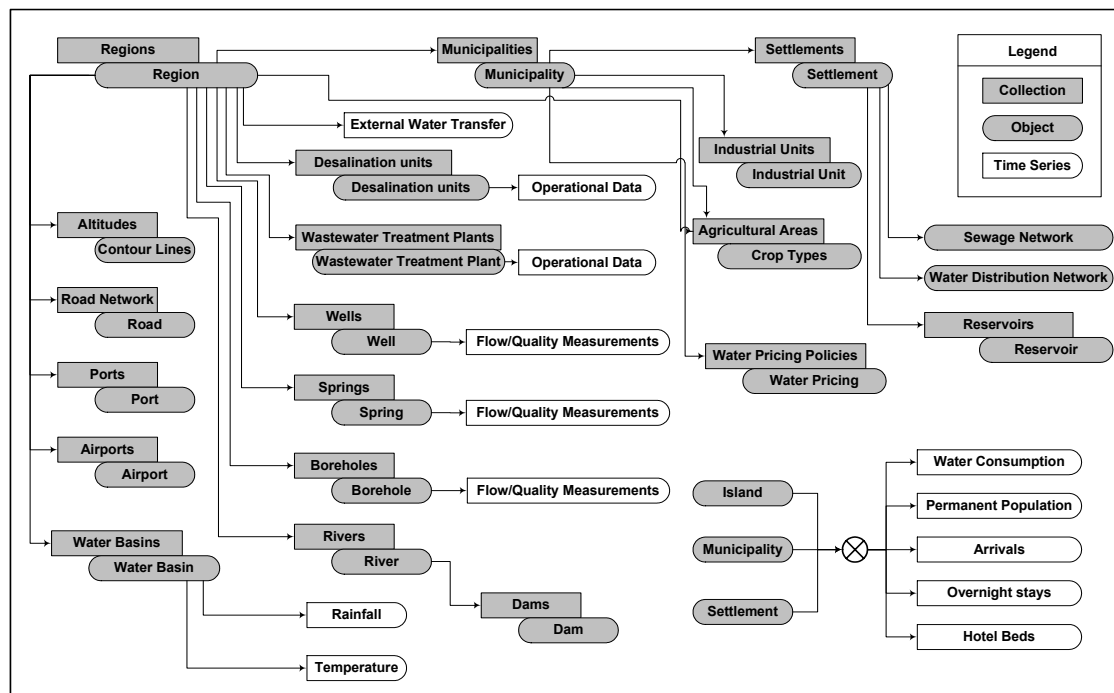


Fig. 21 Central database object model and attribute data

Supply Requirements Calculation

The estimation of the supply requirement over a specified time period is based on a hierarchical disaggregation of water demand data. The first level corresponds to demand sites. Below, specific activity levels are defined. Activity levels in the SDSS include permanent and seasonal population for settlements and towns and irrigated areas per crop type. Water demand is calculated by multiplying the overall activity level by a water consumption rate. Activity levels or water consumption rates can be projected using functions describing the specific characteristics of each demand site or activity level.

Water Allocation Model

Several methodologies have increasingly been used over the last decades for the optimal design, planning and operation of water resource systems. The two basic categories of water resource models are simulation and optimisation models (Wardlaw,1999). Mays (1996) carried out a wide review of these models. Some authors (Mannochi and Mecarelli, 1994; Reca et al., 2001) introduced economic objective functions in irrigation water allocation models. However, many of these models are not readily adaptable to the case of allocating water on a hydrological basin level.

In the present work, water allocation is achieved through a simulation model. A network representation of the hydrological basin is derived from the database (Fig 22). Nodes represent the connection between these entities. To capture the features of the water

systems' function, different types of node are incorporated. These include springs, wells, boreholes, water treatment plants, demand sites, etc. The links correspond to the man-made or natural water conduits, such as pipelines, canals, river reaches, etc. The framework of the network is constructed by connecting the nodes and links according to their physical locations in the water resource system.

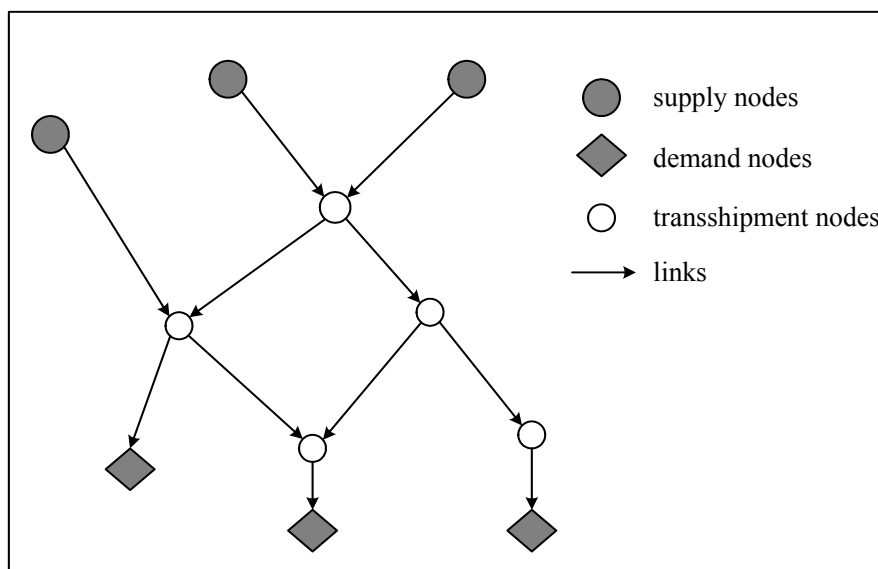


Fig. 22 Network representation of a water resource system

Each node i can be classified into one of the following three categories (i) supply node which is characterized by a positive monthly supply rate s_i , (ii) demand node which is characterized by a monthly demand rate d_i , and (iii) transshipment node. For each link j two characteristic variables are introduced: (i) the link capacity c_j which represents the maximum monthly flows allowed (unbounded links can be defined by assigning a sufficiently large capacity), and (ii) the link monthly flow rate f_j (the decision variables of the problem).

In situations of water shortage, a conflict arises of how to distribute the water available at supply nodes, among the demand sites that are connected to them. The model can solve this problem using two user defined priority rules. First, competing demand sites are treated according to their priorities. Each demand site is characterized by a priority, ranged from 1 (highest priority) to 10 (lowest priority). During a water shortage, higher priority demand sites are satisfied as fully as possible. These priorities are useful in representing a system of water rights. On the other hand, supply priorities can be used when a demand site is connected to more than one supply node. These priorities are attached to the links and are useful in ranking the choices of a demand site for obtaining water.

The mathematical concept of the model is to find stationary solutions for each time step (month). For each time step the problem is to find the flow on the network (a set of link flows f_j) that minimizes the water shortage on all demand nodes:

$$\text{minimize} \quad \sum_{\text{all demand nodes } i} \left(d_i - \sum_{\text{all incoming links } j} f_j \right) \quad (1)$$

subject to the following constraints:

- Supply constraints associated with all supply nodes:

$$\sum_{\text{all outgoing links } j} f_j - \sum_{\text{all incoming links } j} f_j \leq s_i \quad (2)$$

- Demand constraints associated with all demand nodes:

$$\sum_{\text{all incoming links } j} f_j - \sum_{\text{all outgoing links } j} f_j \leq d_i \quad (3)$$

- Flow conservation constraints associated with all transshipment nodes:

$$\sum_{\text{all outgoing links } j} f_j - \sum_{\text{all incoming links } j} f_j = 0 \quad (4)$$

- Capacity constraints associated with all links:

$$0 \leq f_j \leq c_j \quad (5)$$

The model is solved by first constructing a reduction to a standard maxflow problem and then using a standard algorithm to solve the maxflow problem. The maxflow model applies to a basic network, i.e. a network which has exactly one source node (s) and one sink node (t). A flow in a basic network is a set of nonnegative link flows f_j , satisfying the conditions that no link's flow is greater than the link's capacity c_j (Eq. 5) and that the total flow into each internal node is equal to the total flow out of that node (Eq. 4). By the above conditions, the total flow out of the source node is always equal to the total flow into the sink node. This common value is called the value of the flow. Given a basic network, the problem is to find a flow of largest possible value (a flow such as no other flow from s to t has larger value).

The model formulated above (Eqs. 1-5) is reduced to an equivalent maxflow problem using the following transformations (Fig. 23):

- A dummy source node (s) is added to the network.
- A dummy link from s to each supply node is added to the network. The capacity of each link is set to the supply rate of the corresponding node.
- A dummy sink node (t) is added to the network.
- A dummy link from each demand node to t is added to the network. The capacity of each link is set to the demand rate of the corresponding node.

It can be easily shown that the maxflow problem to the transformed network is equivalent to the original problem. The maxflow problem is solved using the Ford-Fulkerson method, known as the Augmenting-Path Maxflow algorithm (Dolan and Aldous, 1993; Sedgewick, 2002).

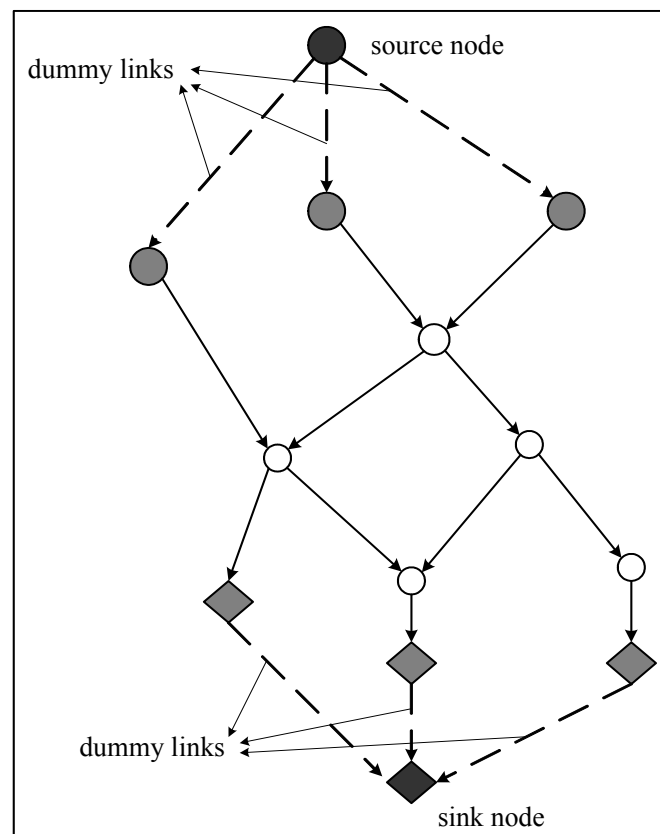


Fig. 23 Network transformations

To handle the priority system, an iterative goal approach is used inside each time step. The idea is first to come as close as possible to meeting the highest priority demand sites and then to try to come as close as possible to meeting the next priority demand sites but ensuring that the highest priority demand sites do not compromise.

SDSS Operational Aspects

The developed SDSS consists of three basic modules allowing for a complete representation of demand/supply scenarios. These are:

- Water demand analysis and supply requirements estimation module;
- Network editing module;
- Water allocation and water shortage estimation module.

All results are presented via fully customisable graphs and tables, in order to permit a complete evaluation of existing and proposed infrastructure for meeting demand needs.

For a demonstration of the SDSS application, a case study for the island of Syros (Fig. 24) was undertaken. Syros is located in the centre of the Cyclades complex, is the administrative centre of the prefecture and covers an area of 84 km². Due to the important administrative role of the island, the permanent population has shown a considerable increase during the last decades. The permanent population is 20220 inhabitants (2001 census), nearly 70% of which concentrated at the capital of the island, Ermoupolis. The rapid tourism development that has been experienced during the last 10 years has as a result the abandonment of traditional agricultural and stockbreeding activities.

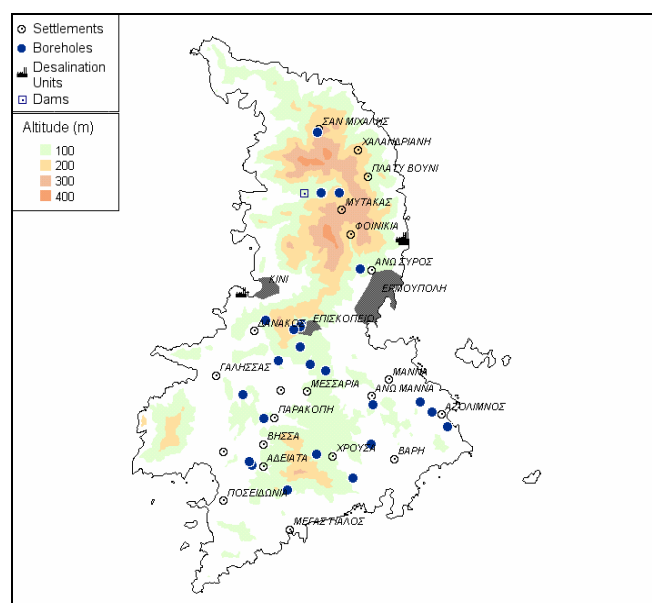


Fig. 24 Syros island water resources

Urban water consumption for the entire island in the year 2000 was about 900,000 m³ of which 25% was allocated for tourism activities. Irrigation withdrawals for the same period were estimated at 1,200,000 m³. Natural water resources are limited with scarcity problems being more acute during the arid summer period. With low rainfall

(approximately 400 mm/yr) there are limited options for the exploitation of surface water resources. Therefore, with the exception of Ermoupolis, which relies on desalination, irrigation and urban water demand are met through the extensive exploitation of groundwater resources. The depletion of the island's aquifers and overexploitation during the summer period continue to pose a threat for economic development and preservation of future water resources.

Water demand analysis and supply requirements estimation module

The disaggregation of water use sectors derived from the database is presented in Fig. 25. Activity level data, month variation, water use rates and projection functions can be modified for each scenario introduced. For the case study undertaken, parameters used are summarized in Table 4. Estimation of irrigation water needs was based on data from the 2000 agricultural census and consumption rates for the most important crops.

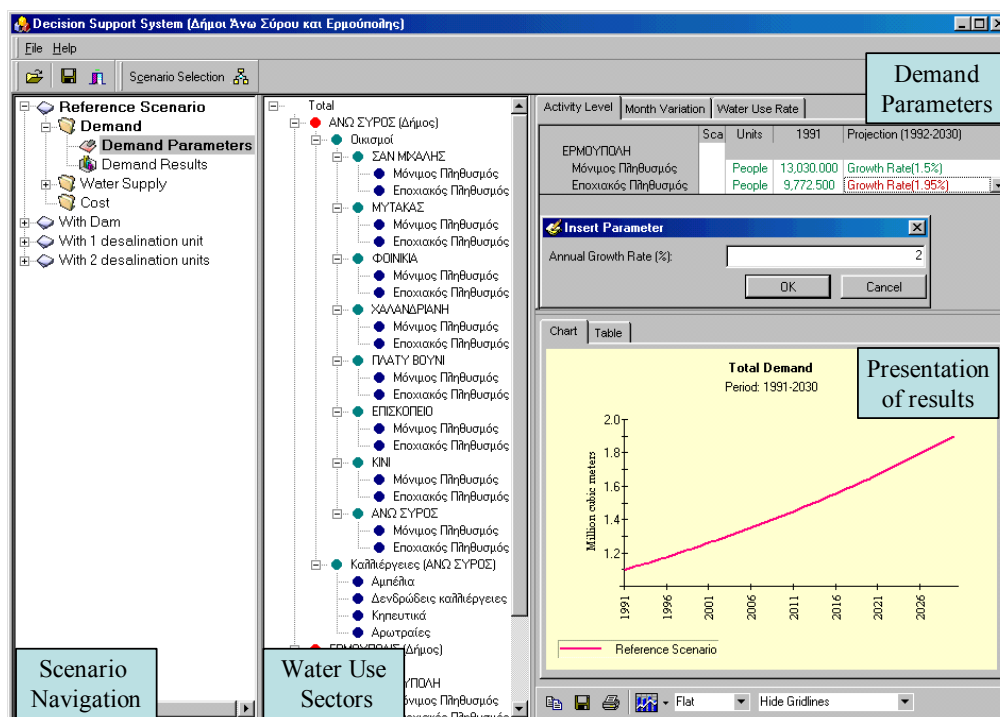


Fig. 25 Demand parameters and estimation modules

Table 4 Water Demand Estimation Parameters

	Permanent Population	Seasonal Population	Irrigation
Growth Rate	1.5 %	3 % up to 2010 1.5 % for the period 2010 – 2030	0 %
Consumption Rate	150 l/d/capita	150 l/d/capita	

Figure 26 presents the annual water demand for A. Syros and Ermoupolis agglomerations while Figure 27 depicts the monthly variation of water demand for irrigation and domestic use as it is estimated for permanent and seasonal population needs, in 2030.

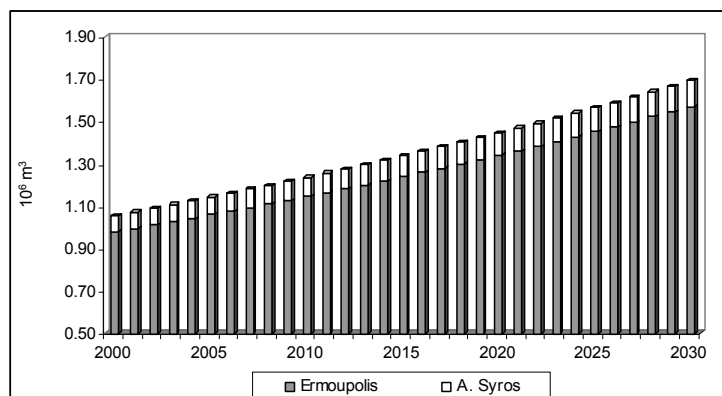


Fig. 26 Annual water demand for A. Syros and Ermoupolis

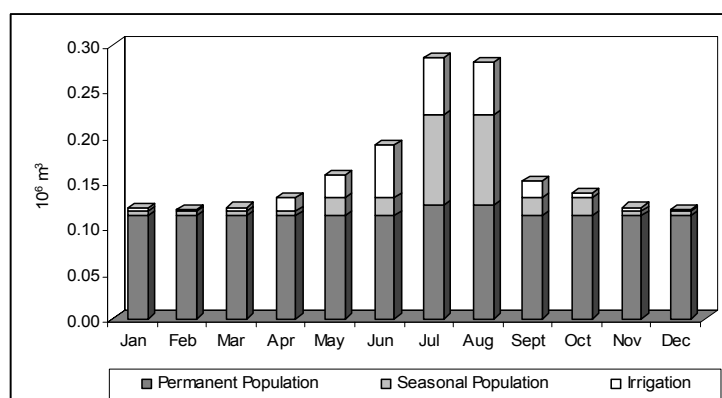


Fig. 27 The monthly demand in 2030

Network modifying module

The network derived from the database represents the base scenario or existing conditions. If the user wants to introduce changes into the system, he has to use the network building and editing module (Fig. 28). The module is based on the use of graphical tools for introducing nodes and drawing links, as well as related actions for appropriate modification and reshaping of the network. In all case, the user can benefit from the graphics tools supported by MapX GIS technology for performing the necessary structure and network interconnections.

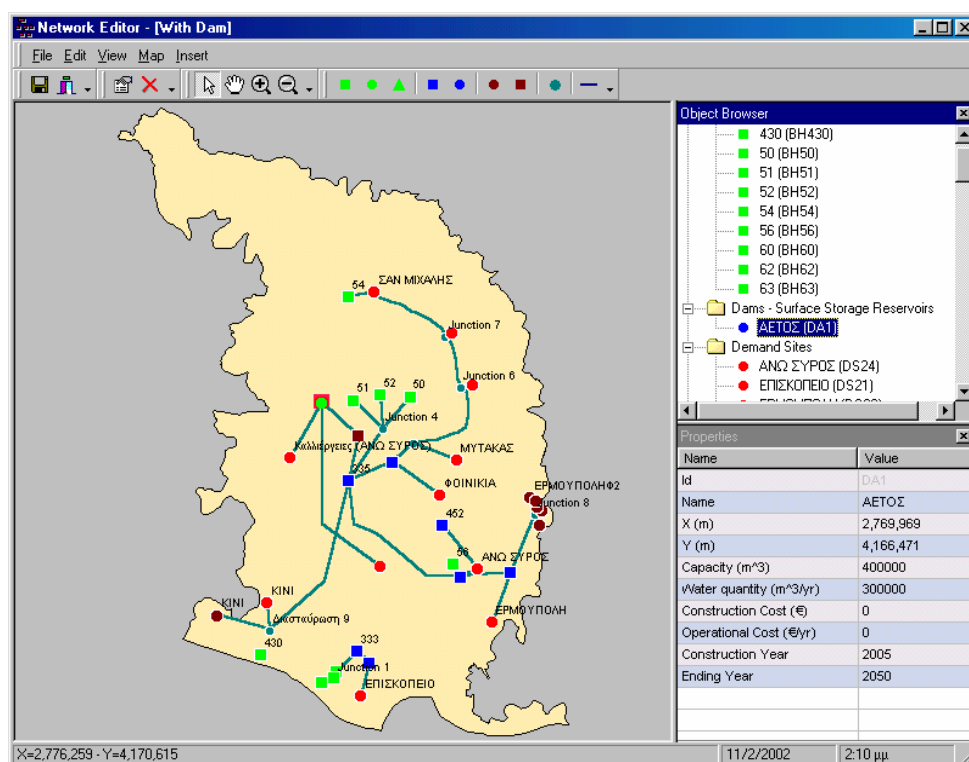


Fig. 28 Network modifying module

Alternative water supply scenarios were developed in order to meet the water needs of Ermoupolis, A. Syros and irrigation purposes, up to the year 2030. The latter involve evaluation of existing infrastructure, dam construction and determination of the appropriate time horizon for other interventions such as desalination unit construction. The present situation regarding water supply is presented in Table 5.

Table 5 Present water supply status for A. Syros and Ermoupolis

	Water resources	Total water supply (m ³ /d)
A. Syros	Boreholes	360
Ermoupolis	Desalination units	3,460

A number of studies have proposed in the past the construction of a dam in the Aetos basin. In the scenario of the present case study, the dam is expected to be fully operational by 2005. With a capacity of 400,000 m³ and a maximum annual withdrawal of 300,000 m³, it should primarily meet the domestic demand of A. Syros and Ermoupolis and secondarily irrigation demand. The proposed infrastructure is presented in Figs. 28 and 29.

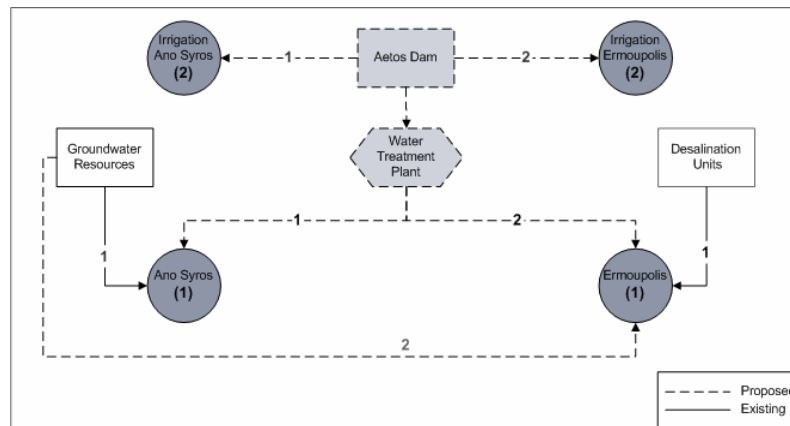


Fig. 29 Demand site priorities and network configuration for Aetos dam construction

Water allocation and water shortage estimation module

The results from the water allocation module indicate that existing network infrastructure and boreholes can adequately satisfy the population of A. Syros up to the year 2022. For the period 2022 – 2030 small deficits (5,000 m³ in 2030) are evident during the peak tourist season (July and August). However, the municipality of Ermoupolis experiences severe water shortages and cannot rely on the existing desalination units in order to meet the rapid demand growth (Fig. 30).

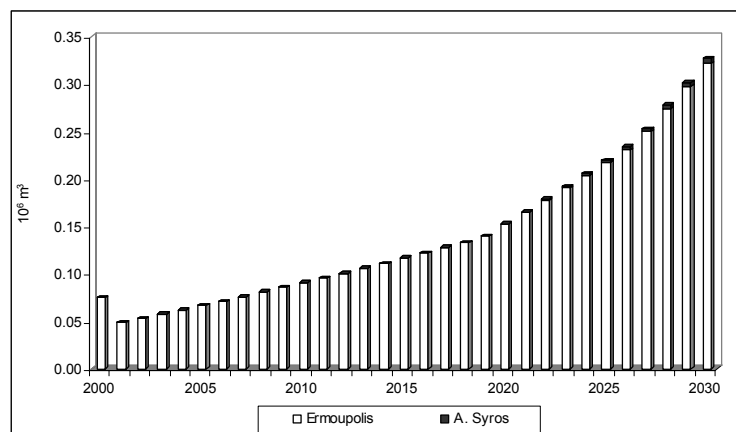


Fig. 30 Evaluation of existing infrastructure for Ermoupolis and A. Syros

The water shortage for the scenario with the Aetos dam construction is presented in Fig. 31. From the year 2010 a water shortage appears in the irrigation sector since water is allocated for the needs of Ermoupolis. Urban demand growth results in a direct shortage from the year 2014. What is important to notice is that the irrigation deficit is not constant as it would be expected from the estimation of irrigation needs. From the year 2024 it increases since water is withdrawn in order to serve the demand of Ermoupolis during the summer months.

As an additional water supply option, the scenario introduces a desalination unit for which according to Fig. 31, appropriate time for construction is around the year 2010. The estimation of peak month shortages and water availability indicate that with a capacity of 1500 m³/d, the unit will be able to meet domestic demand in Ermoupolis up to the year 2025, leaving sufficient water supply from the dam to meet irrigation needs. The unit should be rebuilt in the year 2025 with a capacity of 2000 m³/d in order to meet water needs up to the year 2030.

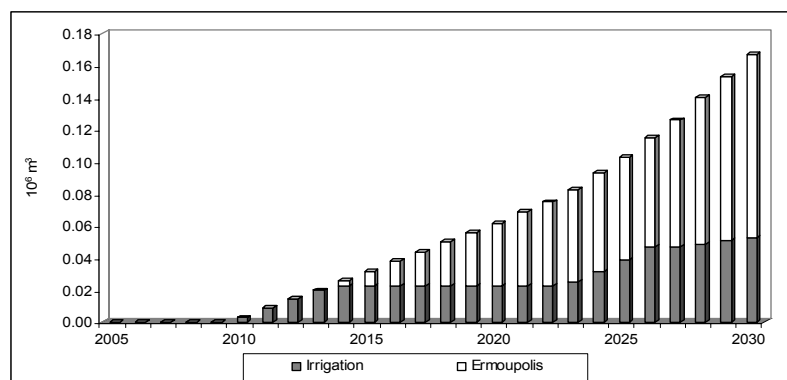


Fig. 31 Water shortage in domestic and irrigation sectors after dam construction

Conclusions

A prototype spatial decision support system for the evaluation of water demand and supply management schemes has been outlined. The system integrates a spatial database of the study area and its infrastructure, tools for network editing and specifying assumptions that affect demand, supply and hydrology, model to perform demand analysis and water allocation and components to manage and present the information. The tool was tested for a characteristic case study that demonstrated its effectiveness in analysing and supporting decision making.

Adaptability to the Water Strategy Man Project

This tool has been developed in Visual Basic and this fits with the intention of integrating ESRI ArcView Gis as Gis Software of the WSM DSS: from the release of ArcGis 8 it has become programmable by that language and the use of the Visual Basic Tools for Application enable programmers to manage external objects and features and to link them to a VB graphical user interface.

The graphical user interface, that is Gis based, is easy to use and intuitive and fully supports the DSS user in designing and updating the network of water sources and users, entering and managing data for each kind of node and viewing the allocation results.

The core allocation algorithm of the tool is based on a clear distinction of the network nodes in water supply nodes and demand nodes. This, together with the use of demand priorities and supply preferences, emphasizes an approach that is useful to analyse and solve possible water conflicts among different types of users and to put in evidence water shortages which may occur in the water resource system. Each particular water resource situation corresponds a certain scenario and each alternative scenario may be the expression of different planning and management decisions.

Finally, the Decision Support System here presented has been developed by the staff of Prof. Assimacopoulos of the National Technical University of Athens, which is one of the Water Strategy Man Project partners. This means the knowledge behind the package is already available being certainly an advantage with respect to the other programs reviewed.

2.5. Integrated Quantity and Quality Model (IQQM)

The Integrated Quantity and Quality Model is a hydrologic modelling tool aiming to simulate river systems and to support the planning and the impacts evaluation of water resources management options. It has been developed by the New South Wales Department of Land & Water Conservation, with collaborative assistance from the Queensland Department of Natural Resources (QDNR).

IQQM is a windows-based software and it is structured as a shell containing different modules linked together to form an integrated package. its components are:

- River system model
- Rainfall-runoff model
- Gate operation model
- Climate model
- Graphical output tools
- Statistical analysis tools
- Data retrieval and utilities

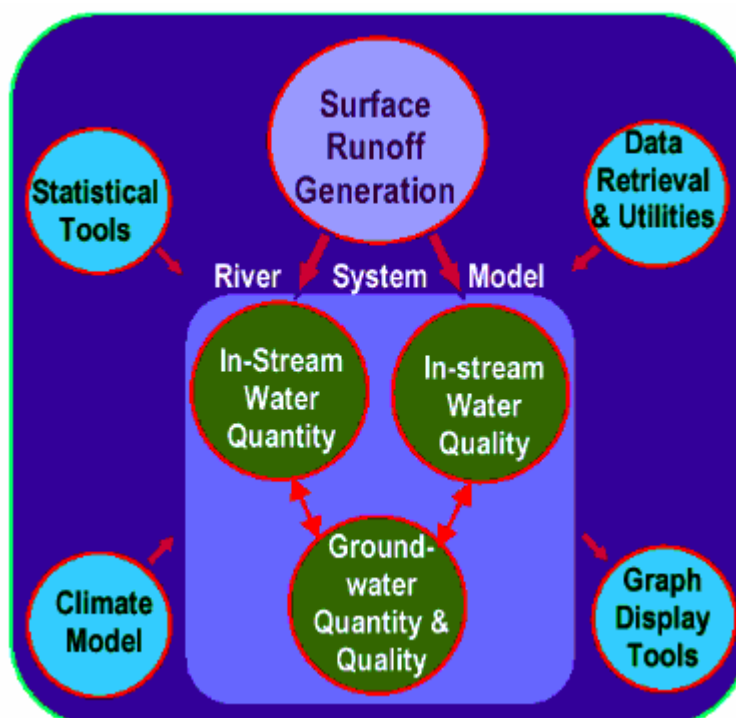


Fig. 31 Main IQQM Components

The graphical user interface starts with the *Function Menu Window (FMW)* that gives the access to the IQQM main modules. By entering the *River System Model* from the FMW, the user is requested to schematise the river system as a set of nodes and links. In order to support him in the network diagram drawing, a Gis map of the basin can be imported into the user interface from an external Gis application. Moreover, he can choose the types of nodes and links from a dedicated palette. Among the nodes considered there are reservoirs, irrigated areas, municipalities, wetlands, and industries.

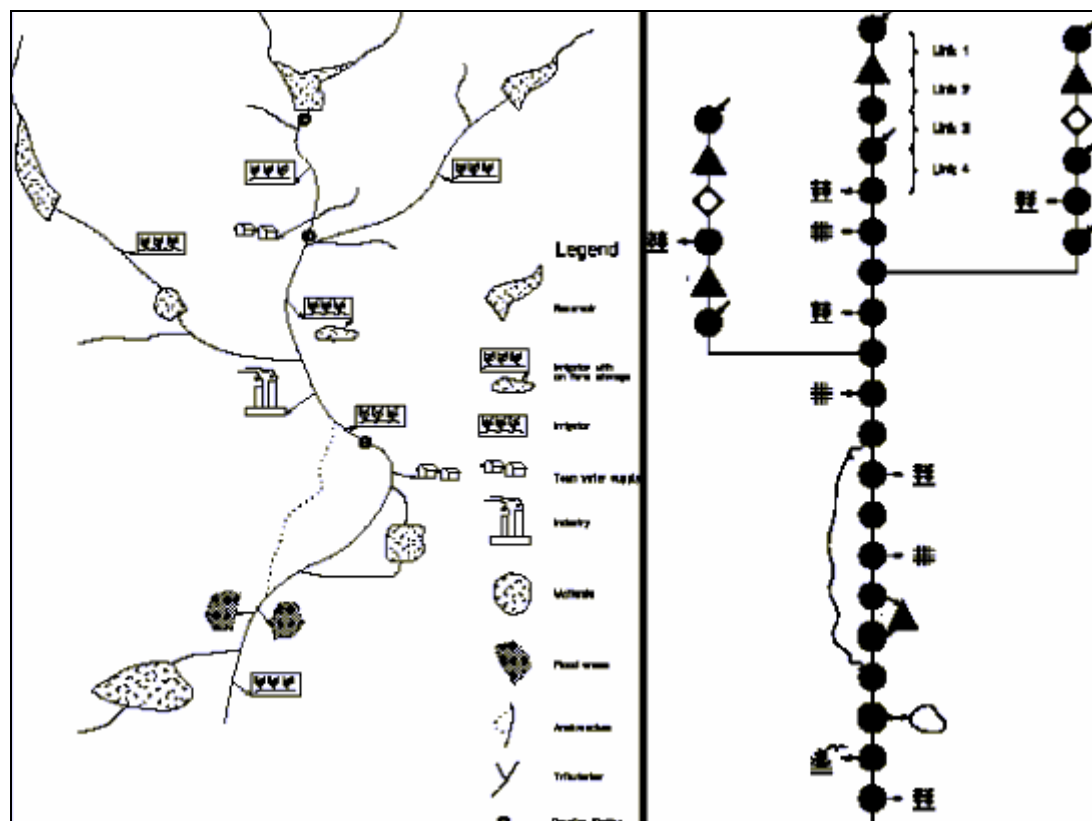


Fig. 32 Representation of a typical river system in IQQM

The *River System Model* consists of the two sub-modules *In-stream Water Quantity* and *In-stream Water Quality*. The former addresses the flow routing, the reservoirs operations, the assessment of water resource availability, the computation of urban, agricultural and environmental water requirements and the interaction between surface water and groundwater. The latter is based on the program QUAL2E, developed for the US EPA that can model the Nitrogen cycle, Dissolved oxygen (DO), Biochemical oxygen demand (BOD), the Phosphorus cycle, Coliforms, and Algae.

One of the primary uses of IQQM is to model the operation of storages. The *In-stream Water Quantity – Reservoir Module* is capable to consider and simulate on-stream and off-stream reservoirs and associated features such as, gated spillway operations, flood release operation, rule curves, constrained water transfers between storages in series and in parallel.

As far as the urban demand is concerned, IQQM is capable of simulating fixed demands with a monthly pattern, and demands subject to constraints, due both to river flow conditions and to headwater storage.

An irrigation module is responsible to consider all the processes driving the agricultural needs, such as precipitation, evapo-transpiration, water harvesting and re-use, infiltration and planting decisions and to calculate the relevant water demands. This is the list of features modelled by the irrigation module:

- Soil moisture accounting;
- different crop types;
- Simulating decisions of farmers regarding areas of crop to plant and irrigate in response to changes; in water availability and climatic conditions from season to season;
- Simulating water ordering and usage, taking into account on-farm storages where these occur; distribution losses, local runoff;
- Detailed modelling of on-farm storage operation;
- Multiple extraction points;

The *Rainfall-runoff model* used within the tool is the *Sacramento Model* developed by the US National Weather Service and California Department of Water Resources, and here adapted to use standard IQQM file input and output formats. The calibration of parameters has been improved as well. Here below a schematisation of the physical phenomenon studied by the models is showed.

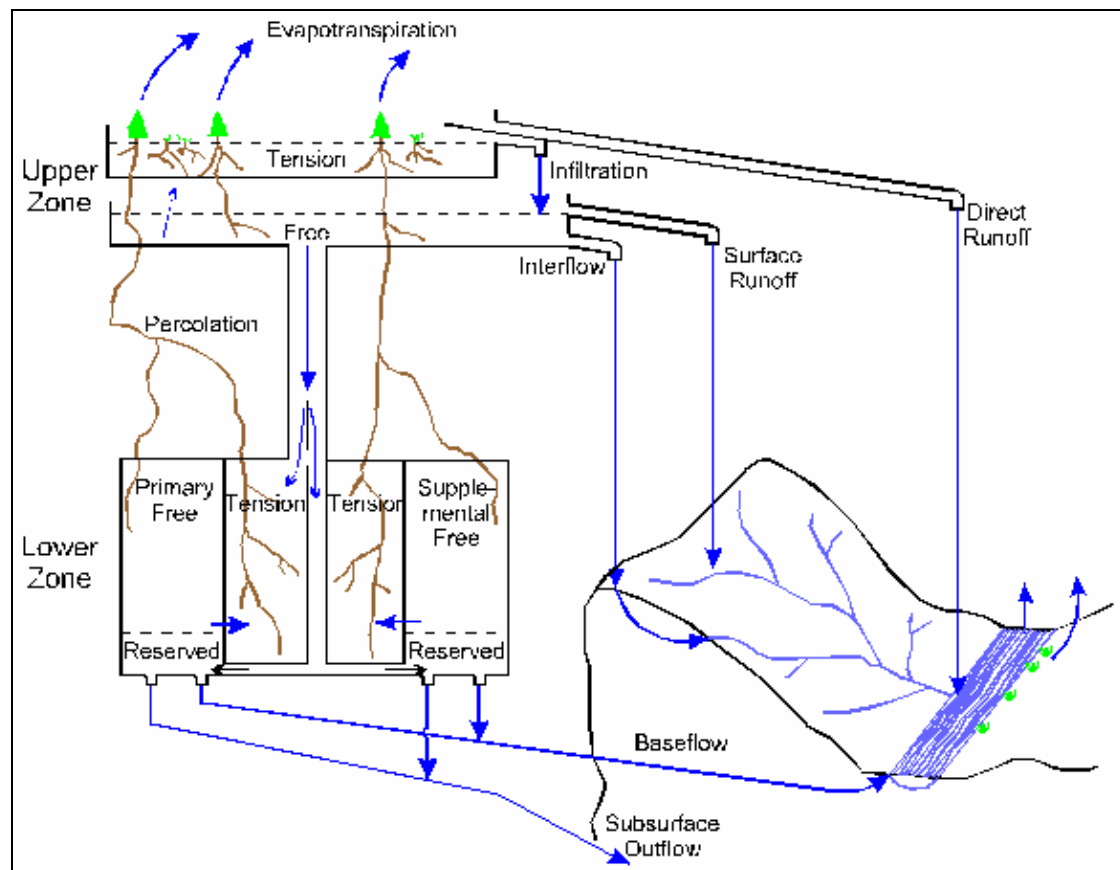


Fig. 33 Schematisation of the physical phenomenon studied within the Sacramento Model

The *Gate Operation model* simulates extreme flood behaviour in gated storages with the aim to minimise flood discharges downstream the dam without endangering, it allows the user to perform multiple flood scenario investigations.

The *climate module* uses short-term daily climate data and long-term rainfall data to statistically generate long term daily Evaporation, Minimum and Maximum temperature and Solar radiation.

The results of simulations as well as observed time series can be plotted for comparison in different types of graphs such as continuous line graphs, histograms, cumulative and frequency curves. A specific tool bar supports the user of IQQM to build the graphical displays and to customise the graphs he creates. The time interval of the data plotted can be an hour, a day, a month or a year. Over one hundred years of daily data can be graphed for up to five parameters simultaneously.

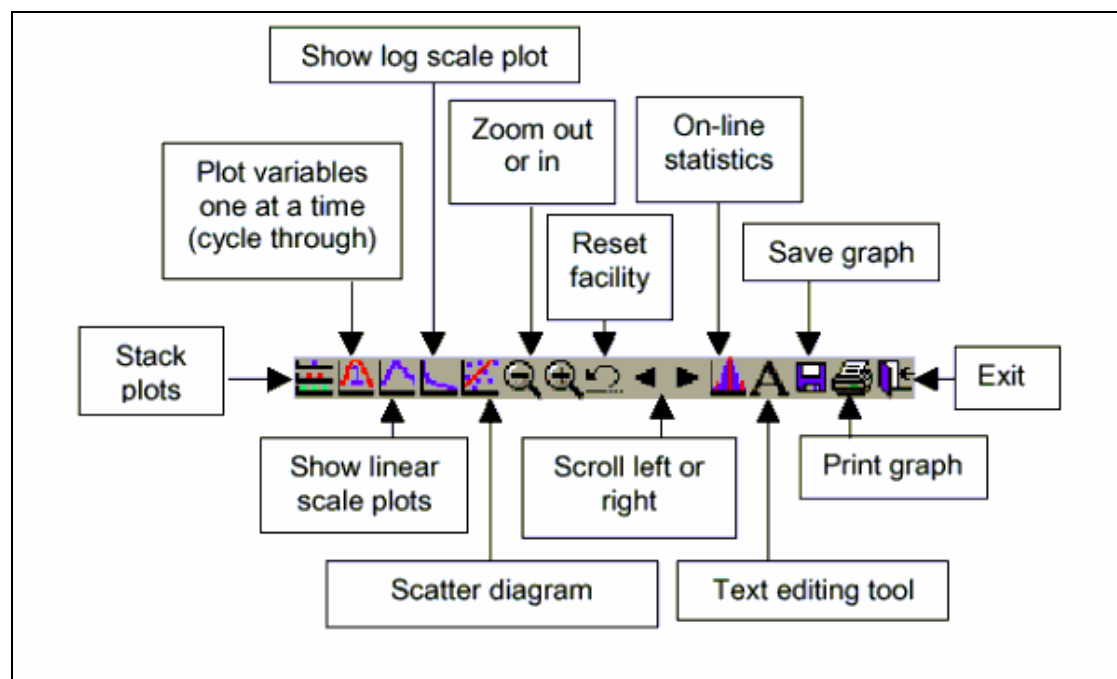


Fig. 34 Graphical display toolbar for all plot types

The *Statistical Tools* of IQQM are a set of routines which compute mean, standard deviation, coefficient of determination and efficiency and other statistics that are useful in the analysis of the daily, monthly or annual data available.

The *Data Retrieval and Utilities* prepare the data files used by the software, check that the file format is correct and change it if necessary. Moreover, they can manipulate data in terms of disaggregation of monthly or annual data in yearly data or combine different data files.

Adaptability to the Water Strategy Man Project

This model allows schematising the river system through nodes objects but they cannot be placed on a map. A Gis map can be imported in IQQM but it is used only as a visual reference for drawing the schematic. The model does not integrate Gis software so lacking of the related useful capabilities of data management and geo-referenced display. It also does not have a scenario manager nor a conceptual definition of scenario itself. These reasons are expected to be sufficient to say that this tool is not applicable to the WSM paradigms as it is.

2.6. Ensis

ENSIS stands for “ENvironmental Surveillance and Information System”. It is a tool for the environmental monitoring and protection consisting of two main Decisional Support Systems, WaterQuis and AirQuis. The former is concerned with water resources quality and has been developed by NIVA, the Norwegian Institute for Water Research, whereas the latter is concerned with air quality and pollution levels and has been developed by NILU, the Norwegian Institute for Air Research. Both the Norwegian Institutes have been supported by Norgit, an agency developing information systems for governmental organisations, research institutes and private sector. The attention is here focused on the WaterQuis DSS, but it is to say that both the DSS included in the ENSIS system use the same basic features and more, they share the same Database and are integrated under the same graphical user interface.

ENSIS starts with a standard windows application through which the user can access the GIS layers, the database and the models which are all integrated in the system. The GIS is programmed with MapObjects from ESRI, which makes it compatible with ArcView and ArcInfo.

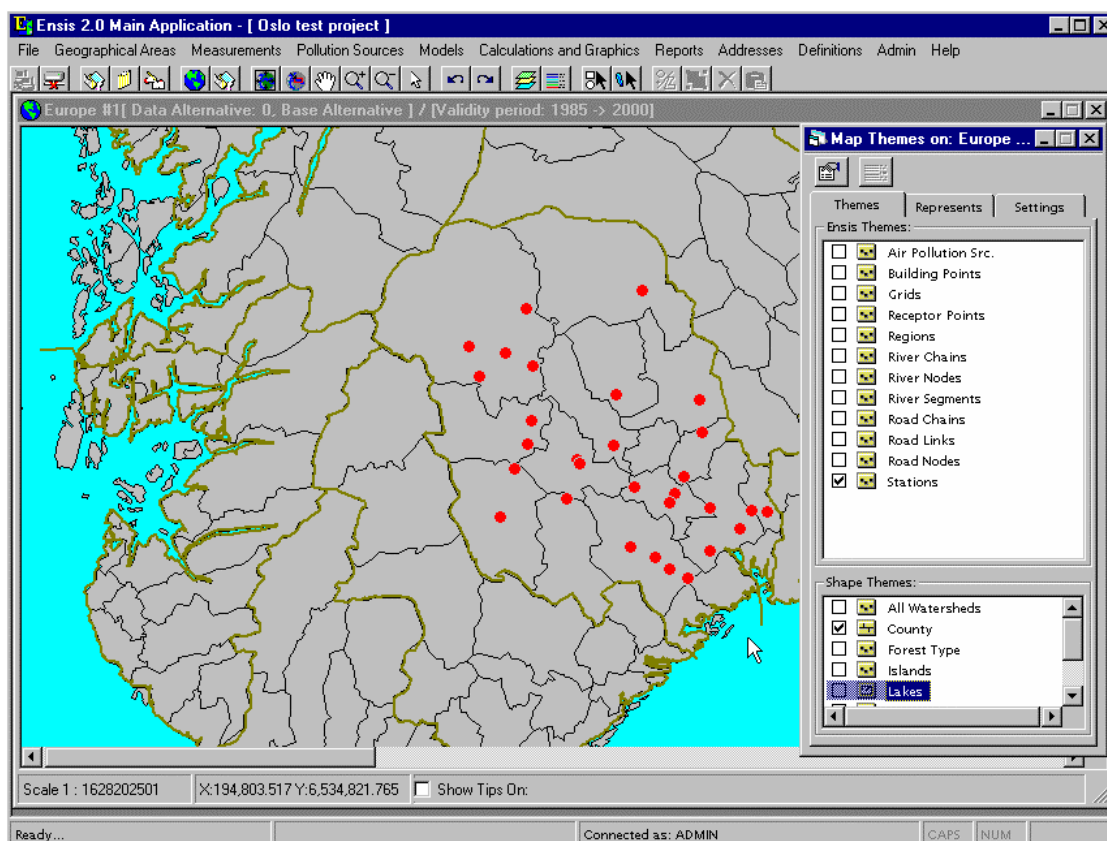


Fig. 35 Ensis Gis

The Gis layers permits the user to display specific water resource information such as pollution source and receptor points, gauging stations, and rivers on maps showing the geographic elements they are referenced to, for instance the lakes, the watersheds, the countries. Moreover, the data associated to each displayed element can be searched and accessed directly via the GIS interface. As an alternative, the user can enter the integrated Oracle Database and retrieve the data he desires by simply choosing the more suitable alphanumeric criteria among those of geographical location, time period for the measurements, or type of industry etc. The majority of data is organised in time-series, they could be for instance water quality measurements at determined river stations, and each of them is described by further detailed information such as instrument on the station, sampling method, time step, and analysis method. All this amount of details can be entered or just viewed by the user in relevant dialog boxes and menus.

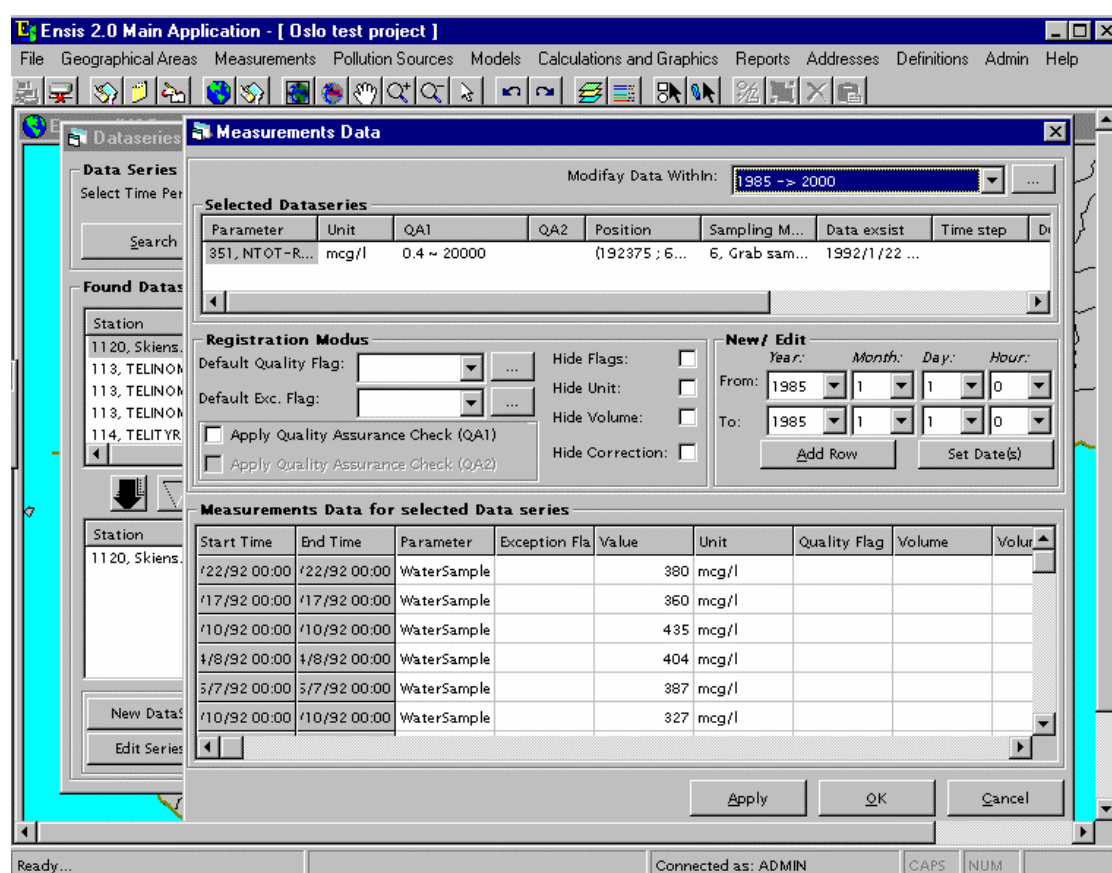


Fig. 36 Viewing the measurement values

The time-series can be plotted as well by the ENSIS Internal Graphics Utility. Interesting and helpful capabilities are those to display different plotted series, so that they could be easily compared, and to export the data series to windows software like Excel. This latter operation could be performed by one dedicated ENSIS routine or by a “copy & paste” from the Ensis time series graph to Excel Worksheets.

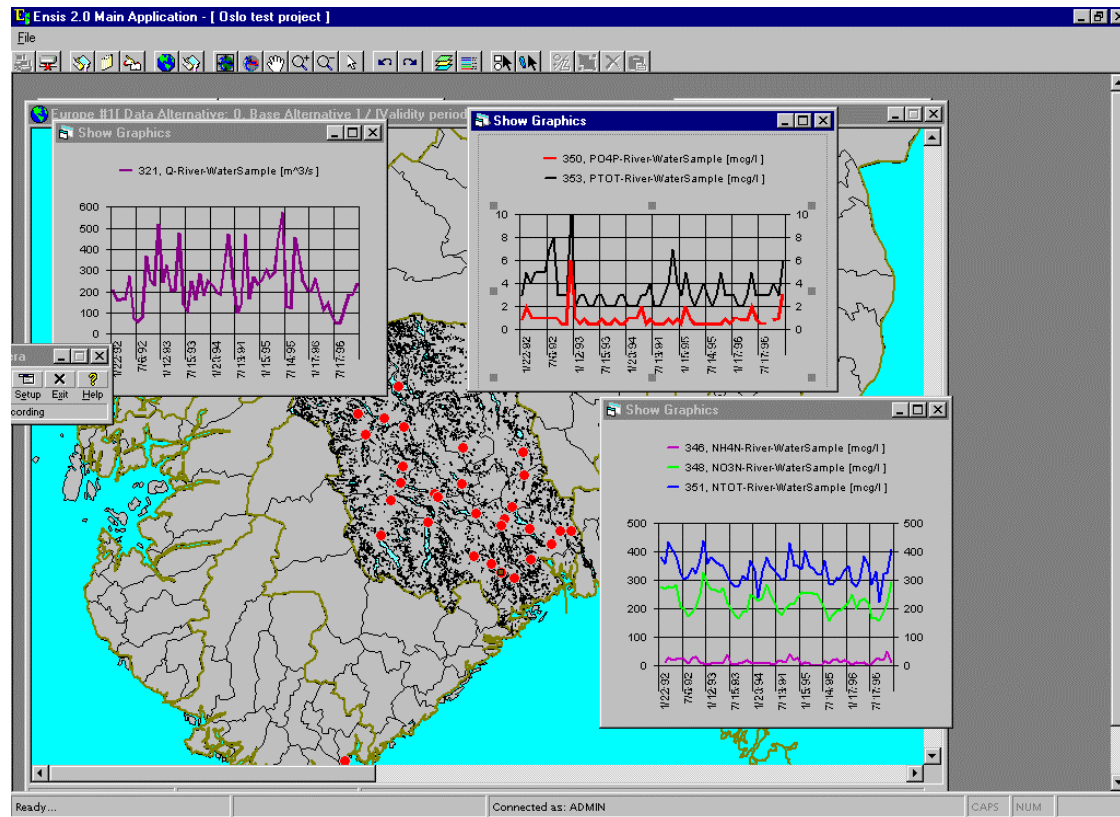


Fig. 37 Comparison of time-series

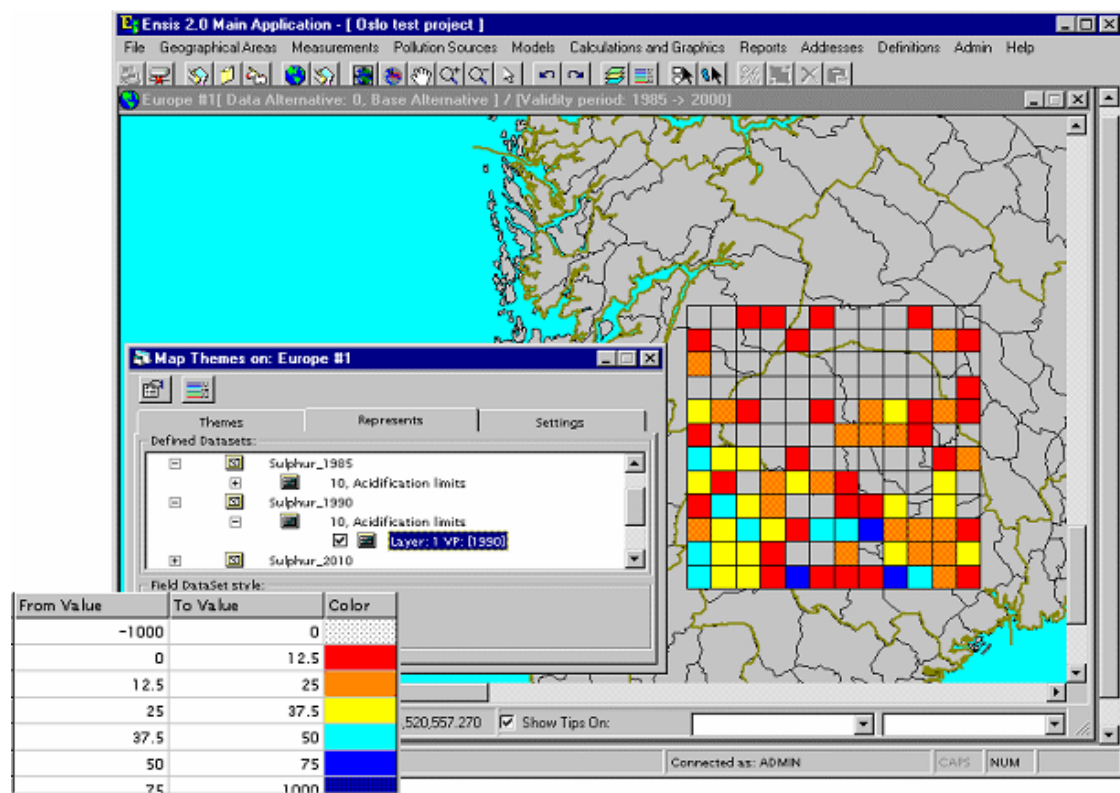


Fig. 38 Acidification limits displayed on GIS layers

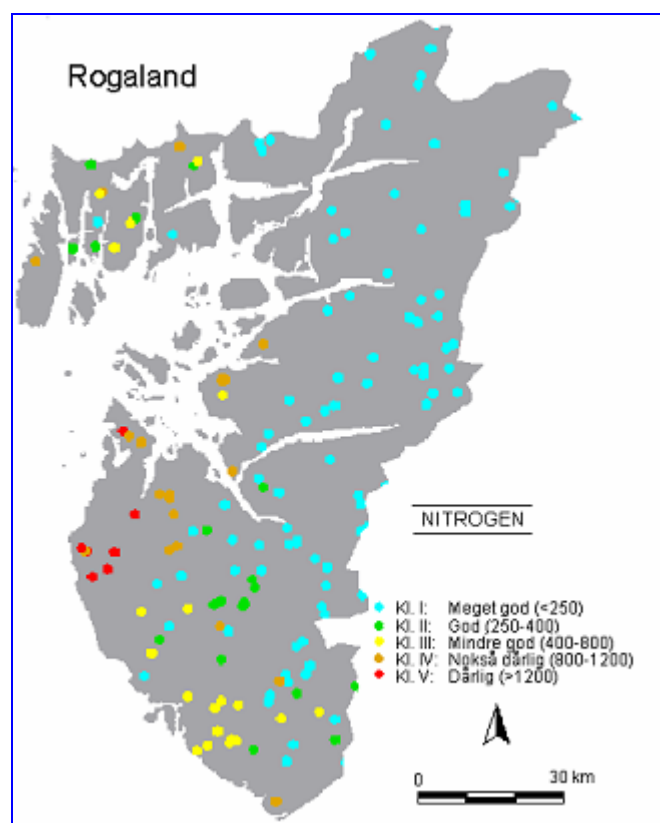


Fig. 39 Classification of water quality in Rogaland

The ENSIS system has a report generator that is helpful to present analysis and results in an easy and clear manner and to disseminate them on the internet. The standard report of ENSIS shows the water quality distribution in the studied country, in terms of different coloured spots displayed on the country layer. The different colours refer to specific ranges of qualitative description and numeric values giving to the report the aspect of a water quality classification.

The ENSIS system can encapsulate programs for environmental modelling and graphically show their output both graphically or as numeric tables, or process them statistically. WaterQuis DSS has models for calculation of pollution load whereas the AIR related AirQuis has atmospheric dispersion models integrated in it, covering air pollution on all scales in the urban environment.

Further WaterQuis-specific features are: the definition and record of information and data about catchments, rivers, lakes and coasts and the registration of discharge from domestic waste water, industries and diffuse sources.

The system is currently installed and applied by several Norwegian water resources authorities and in three different locations in China.

Adaptability to the Water Strategy Man Project

As from the acronym, Ensis is more a Surveillance and Information System based on Gis rather than a real decision support system. It is useful for creating and disseminating water quality reports and for time series visualisation and analysis. Even if it embeds water quality models for calculation of pollution loads and proper routines showing their output both in terms of tables or graphs, there is not the management and comparison of alternative simulation scenarios.

Moreover, water distribution in the area under surveillance is not addressed thus missing the step of water availability and demand evaluation, which is significant in the WSM project: it is the basis for the identification of possible deficit conditions and the building of proper strategies to face them.

2.7. Realm

The REsource ALlocation Model is a package for the simulation of water supply systems, developed in 1997 by Victoria University Of Technology and Department Of Natural Resources and Environment, in the State of Victoria, Australia. It was originally developed to run under the DOS operating system and it has been converted to run under Windows in 1999.

Realm simulates simple as well as large and complex water supply systems and both in drought conditions and normal ones with high stream flows. It can be used to study different water resource options, for instance new operating rules or physical system modifications and compare them graphically.

The water allocation is performed by a fast network linear programming algorithm that runs at each simulation time step. This algorithm optimises the water distribution on the basis of the carriers' costs: if a demand node is connected to the supply node by multiple different carriers, the one with the lowest cost is exploited first and if its maximum capacity does not completely satisfy the demand then the next lowest cost carrier is used. the program allocates water to as many carriers as are needed to cover the demand, always following the exploitation order as above.

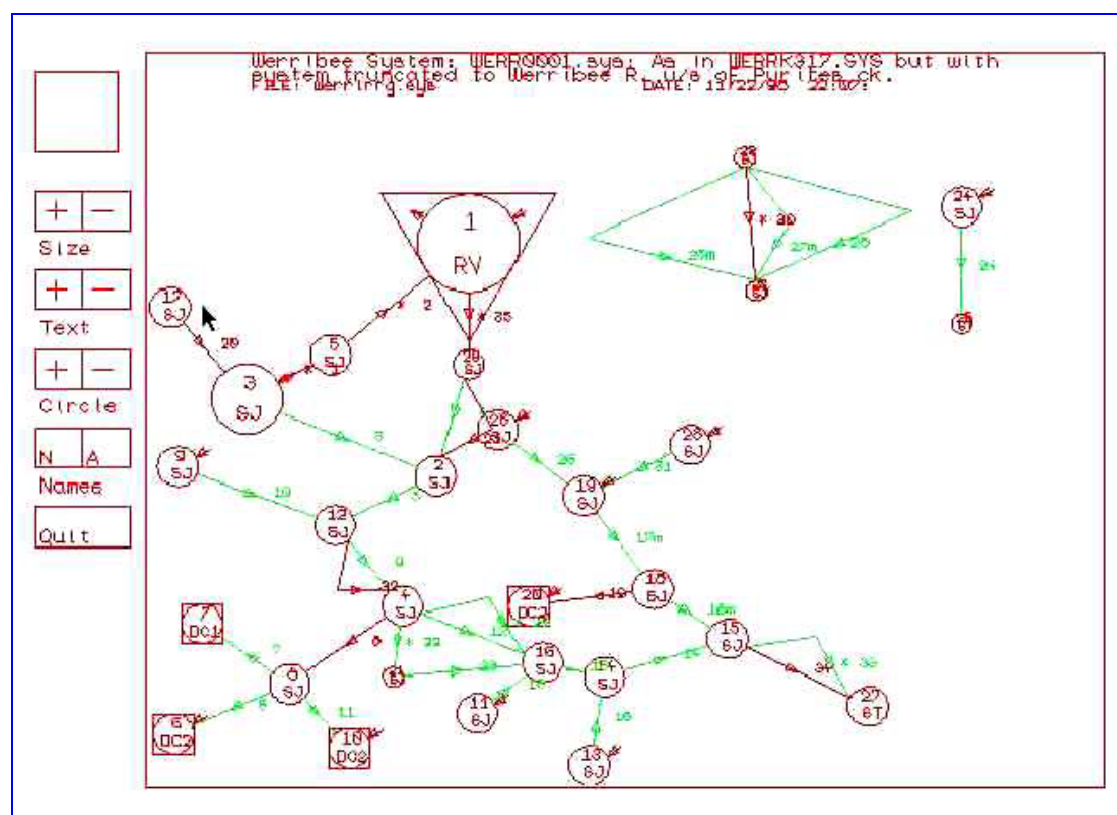


Fig. 40 REALM Screen Plot²

² The original background colour of some of the REALM windows whose images have been inserted here is black.

REALM is compound with a program manager, a graphical editor, a group of routines for listing, plotting and text editing, the simulation core. It has water stream flows and demands as input. The former consists of unregulated inflows entering the system and available at reservoirs, gravity diversions, stream junctions and harvesting nodes and they could be monthly weekly or daily. Stream flows also include climatic variables such as temperature and rainfall. The water demands consists of time series data specific to determined demand zones in the studied area and can represent historic water usage or forecasted needs.

REALM has a graphical editor which allows the user to draw the system network and to define the features of nodes (reservoirs, demand sites), links (here “carriers”) and their operating rules.

The system network could be drawn just by choosing specific types of node or carrier from a palette of buttons at the left and the bottom in the System Network Screen and positioning it into the centre of it by a simple “drag & drop”. The eight node types considered are: Reservoir, Demand, Irrigation demand, Diversion, Pipe junction, Stream junction, Groundwater, Stream terminator. Later the entire network could be properly viewed and zoomed by the “Network Plotting utility”.

The user can introduce the carriers connecting the demand nodes to suppliers by the same drag & drop. Carriers can be RIV type, representing river sections, and PIP type, represent pipes, aqueducts and general carriers that are not river sections. The user could access and introduce each carrier’s characteristics though the “pipe-river editing” window. The carriers’ attributes are: cost or penalty, used in allocation process, transmission losses, annual volume limit, capacity sharing among different demand sites both connected at the same carrier, minimum and maximum capacities and water quality parameters. The carriers’ capacity could be expressed as a function of many system variables and edited by the user in a dedicated menu.

EDITING PIPE/RIVER SECTION

Arc Desc

Cost	Offset	Loss	Annual Vol Limit	Capacity Sharing:-
0	0	0	0	Gp= 0 %Share= 0

	Minimum Capacity	Maximum Capacity
Jan	0	0
Feb	0	0
Mar	0	0
Apr	0	0
May	0	0
Jun	0	0
Jul	0	0
Aug	0	0
Sep	0	0
Oct	0	0
Nov	0	0
Dec	0	0

Edit Water Quality parameters Y/N N

Fig. 41 Editing Capacity Type 1 Pipe/River Section Menu

REALM manages the periods of low storage and stream flow through the “demand restriction curves” governing the manner in which each demand is restricted and its degree of severity. The package considers two types of demand restrictions, namely urban restrictions, to urban and industrial demand zones and irrigation restrictions, applied to irrigation demand zones.

An interesting feature of the software is the possibility to choose some nodes or carries of the system network from a list and highlight them in red. This could be very helpful in finding specific nodes and carriers in large networks.

Before running the simulation of water allocation through over the system, the user has to define the “simulation scenario” which is here intended as the set of run time parameters such as simulation period, stream flows and demand as input, initial reservoir volumes, initial irrigation deliveries, water quality initialisation and output options. The parameters’ definition is conducted through the relevant dialogs windows of the Realm Set-up program.

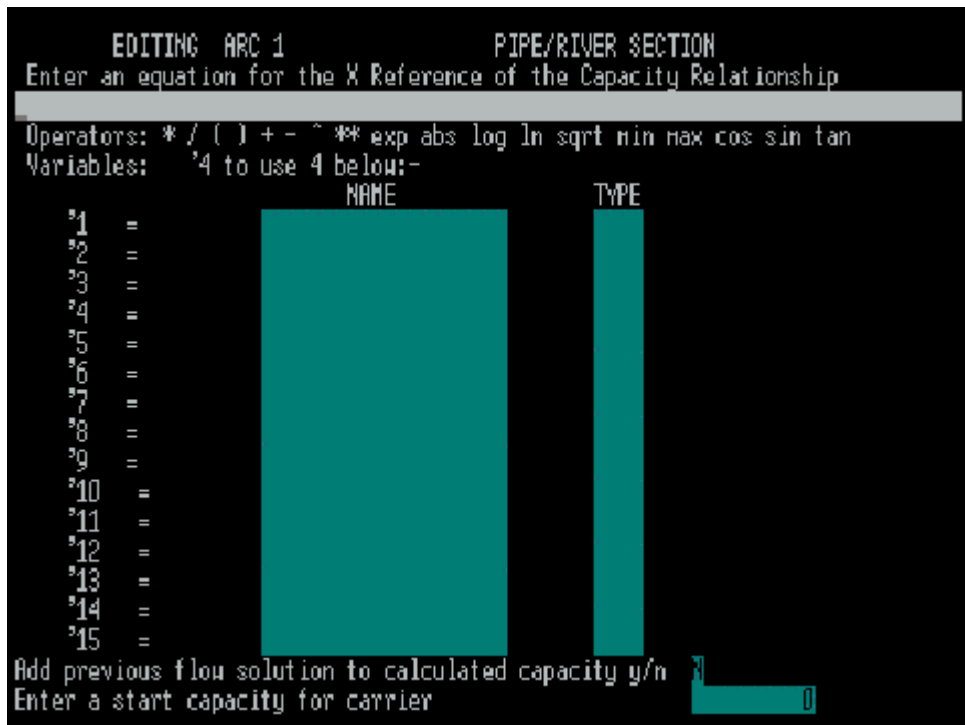


Fig. 42 Editing Capacity Type 3 Pipe/River Section Menu (Details of Equation)

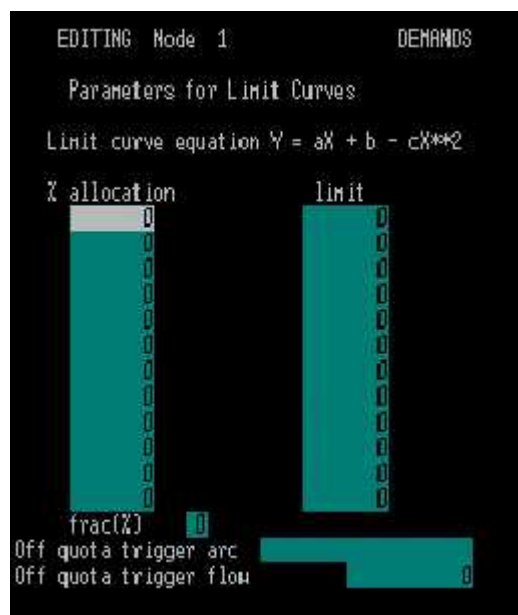


Fig. 43 Parameters for Limit Curves

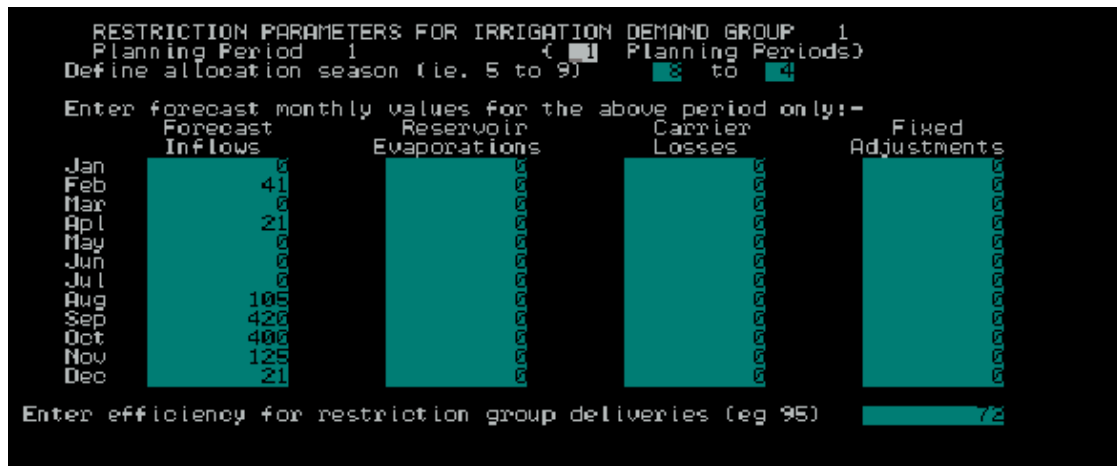


Fig. 44 Restriction Parameters for Irrigation Demand Group Menu

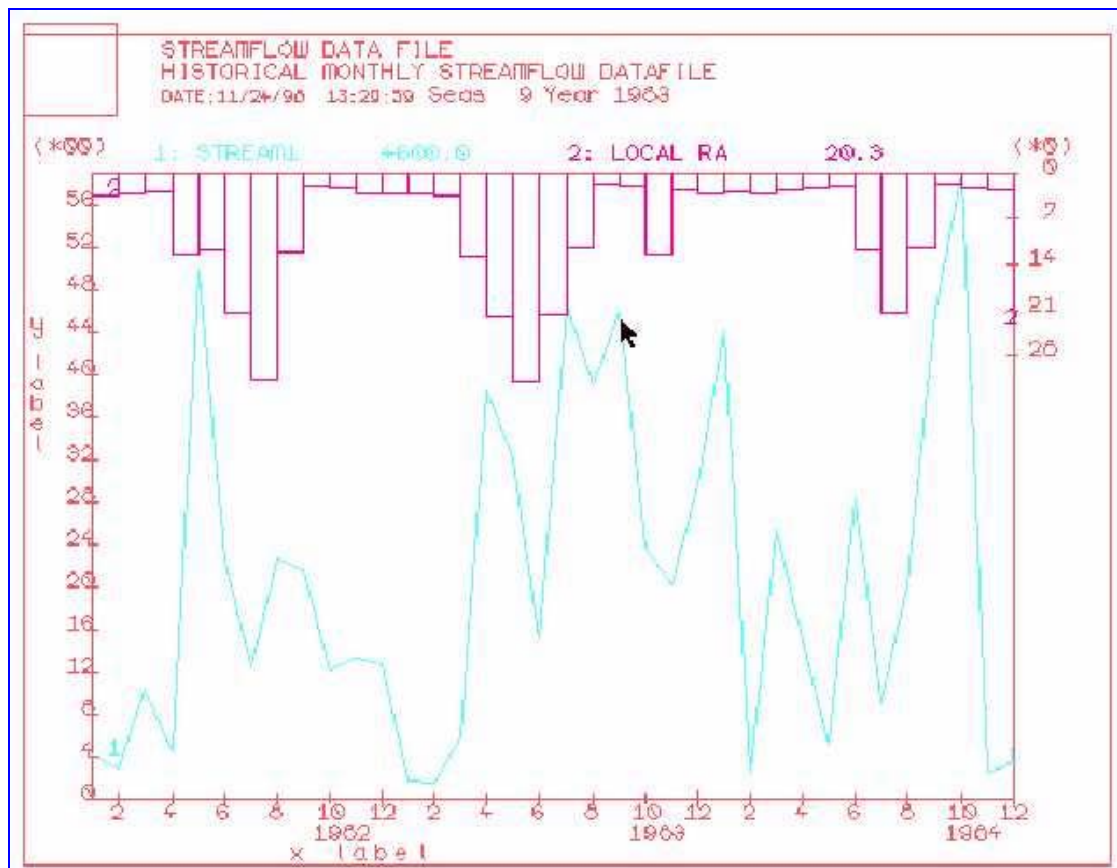


Fig. 45 Plotting from Top Down

Realm can generate several outputs, which fall into different categories, as the table below shows:

Table 6 Categories and outputs

Category	Output
Reservoirs	storage volume, spills, targets, inflows, evaporation, releases, storage level
Supplied demand	unrestricted demand, restricted demand, demand shortfall, rationed demand, restriction levels, supplied demand
Gravity diversions	intakes, spills, inflows
Pump diversions	intakes, spills, inflows
Groundwater	storage volume, spills, inflows, evaporation
Stream junctions	inflows
Carriers	flows, capacities, losses

The REALM package contains some output utilities which can be used by the user to perform basic processing of input-output data such as graphical plotting, data ranking from highest to lowest value, statistics computation as total, mean, minimum and maximum value, standard deviation.

REALM is currently used for all the major water supply schemes in the Victoria State.

Adaptability to the Water Strategy Man Project

Realm has a network editor that allows the user to schematise the system of water users but the elements of the network are not geo-referenced: this tool does not integrate Gis software and the user cannot import geographic maps and use it as network background.

The economic aspect of water resources is reduced to the mere costs of the carriers, which define the priority of use in the water allocation algorithm.

As the main task of this tool is water allocation, there are not impact analysis and multi-criteria approach. Also the concept of scenario is different from the WSM definition of exogenous variables: in Realm a scenario defines simply the sets of simulation parameters and initial conditions used within the allocation process.

For the reason above, this tool is proposed as not applicable to the Water Strategy Man Project.

2.8. Mulino

The acronym MULINO stands for “MULTi-sectoral, INTe grated and Operational decision support system for sustainable use of water resource at the catchement scale”. It is the main objective of the related "Mulino Project" funded within the European Fifth Framework Programme for Research and Technological Development and Demonstration. The project has started on January 2001 and has a duration of three years. At the time of writing this report, the first of the three planned intermediate versions of the tool has been presented and the second is currently under development. The Mulino consortium consists of specialists in hydrologic modelling, software development, economy, geography, sociology, agronomy and GIS coming from various European countries and co-ordinated by The Fondazione ENI Enrico Mattei in Venice, Italy.

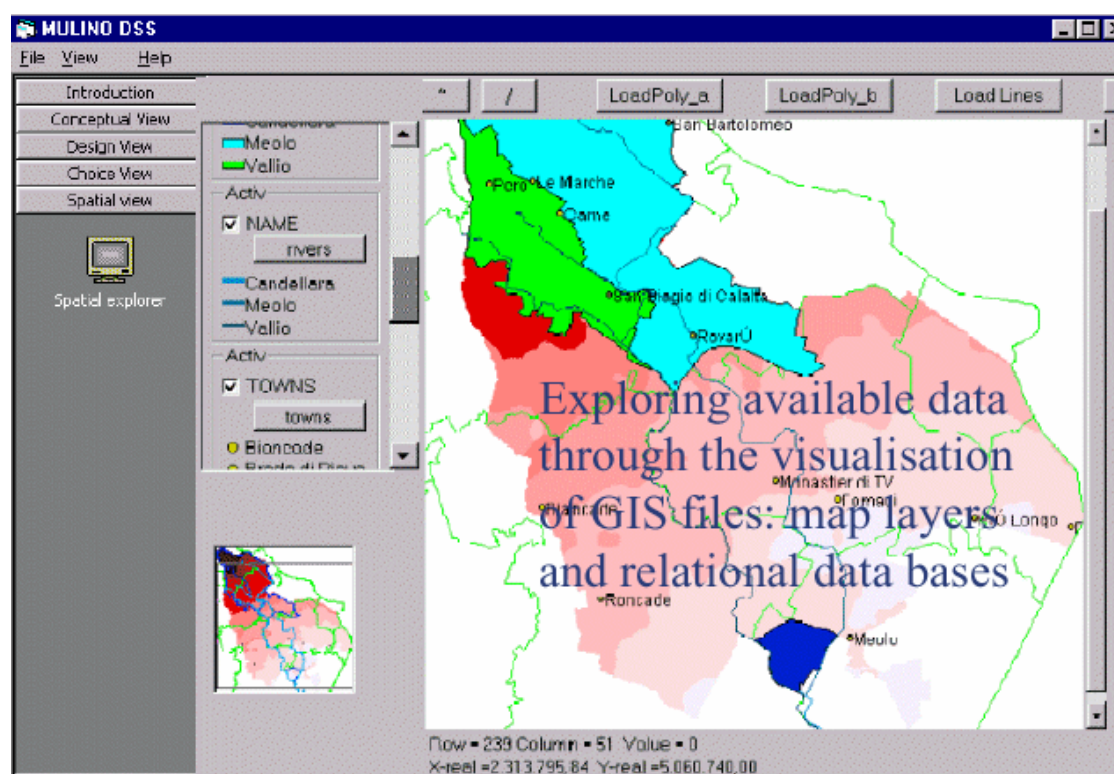


Fig. 46 The Spatial View of Mulino

This DSS integrates social, economic and environmental modelling techniques with the GIS capabilities, a geo-referenced database and a multi-criteria approach to the simulation results. Moreover, the core structure of the tool is based on the Drivers-Pressure-State-Impact-Response Framework proposed and used by the European Environment Agency.

The system has been conceived as an operational tool aiming to support and guide the Decision-makers step by step along the whole decision process, from the problem conception to the choice of the best policy to solve it. As an expression of this philosophy, a proposed series of “decision steps” has been encapsulated in the Mulino DSS itself and defined at the user interface level by the three Conceptual, Design, Choice Views:

- In the Conceptual View, the Decision Maker is directly involved, being requested to define the water resource problem and choose the decisional criteria which will be used to measure and evaluate the river basin status and the effectiveness of the actions conceptualised to improve it;
- In the Design View, the role of the technician is prevalent in that he has to implement the problem formulated by the DM and to find the practical solutions that will constitute the set of possible options to be investigated;
- In the Choice View, the DM together with the technician assigns weights to the options so as to select the preferred one;

In addition, the user can access the Spatial View and explore the geo-referenced data on the GIS layers describing the river catchement.

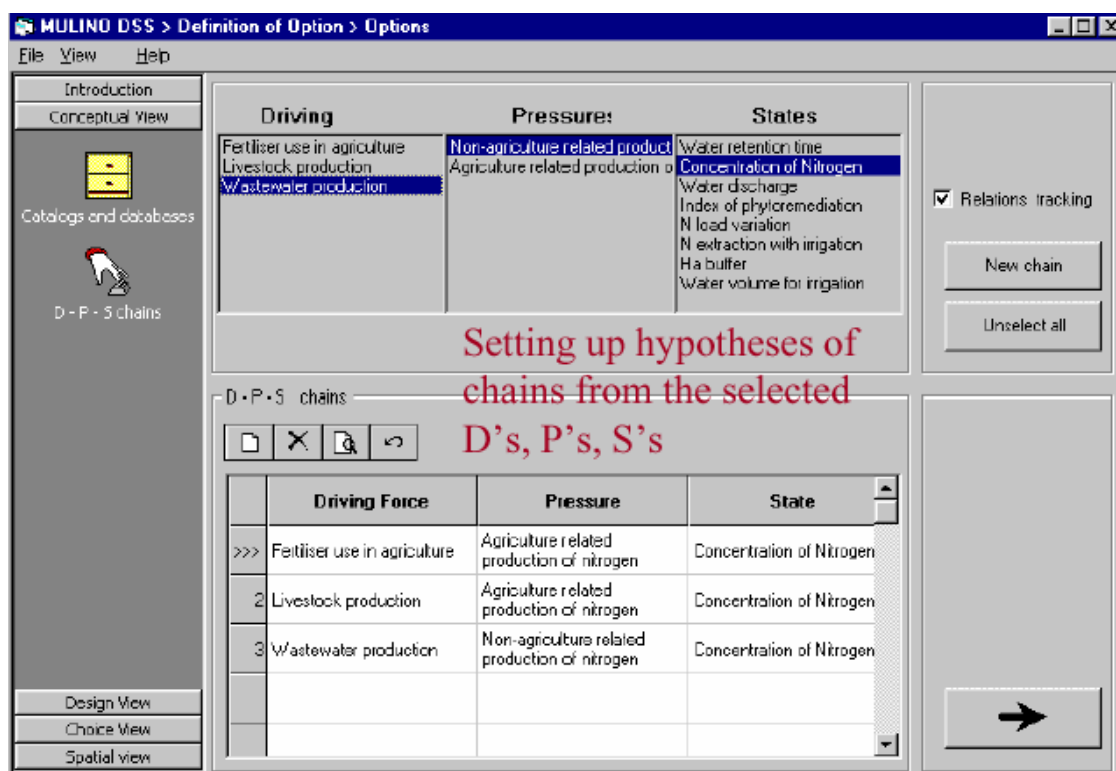


Fig. 47 The Conceptual View and the D-P-S Chains

The entire decision process is based on D-P-S-I-R indicators and the cause-effect relationships existing among them: the DM describes the problem in terms of a set of Drivers which lead to specific pressures exerted on the basin, so determining its status and propose alternate options to improve the status itself. The Decision-Maker builds up

the D-P-S chains in the Conceptual View of the interface, where he accesses a list of Drivers-Pressure-State indicators already available in the database and chooses those which are relevant to the conceived water resource problem and which are also linked by cause-effect relationships. The first version of Mulino DSS has been applied to the Vela catchment, near Venice. In this case the two following D-P-S chains has been defined: 1) use of fertilisers in agriculture and livestock production, Drivers, leading to production of nitrogen, Pressure, which increases the nitrogen concentration in the water basin, State. 2) waste water production, Drivers, leads to production of nitrogen, Pressure, which increases the nitrogen concentration in the water basin, State.

The Design view consists of two parts. The first is concerned with the creation and definition of the alternate options: the DSS User can edit a new option, delete an existing one from the list of those available and display the related chains of D-P-S indicators. In the other part, the User accesses the geo-referenced database through the GIS layers and extract the numeric values of the D-P-S indicators for each associated option. The result is an Analysis Matrix with the status indices as rows and the different options as columns. The options designed for the Vela catchment are the followings:

- EXCAV_MEO: excavation of a tributary, in order to increase the water retention time and as a consequence the potential self-purification effects for nutrient (N and P) discharges.
- DIV_CANDE: redirection of the discharge of an area (153ha) from the Vallio river into the Candellara canal that drains outside the lagoon.
- BUF_VALLIO: plantation of a wooden buffer strip along one of the main rivers of the catchment, the Vallio river, to improve the phyto-remediation effect.

The Analysis Matrix is the starting point of the Choice Phase in which the Decision-Maker manipulate the numeric values of the indicators, so as to investigate which option is more effective. First of all, the values of the matrix are normalised through some “Value Functions” described by the user in order to make the options comparable. Then the different types of state indicators are assigned a weight and are aggregated in just one value per option. Finally the aggregated values, each one being representative of the global effect of a certain action on the Basin status, are plotted on a graph and the Decision-Maker can choose the best alternative.

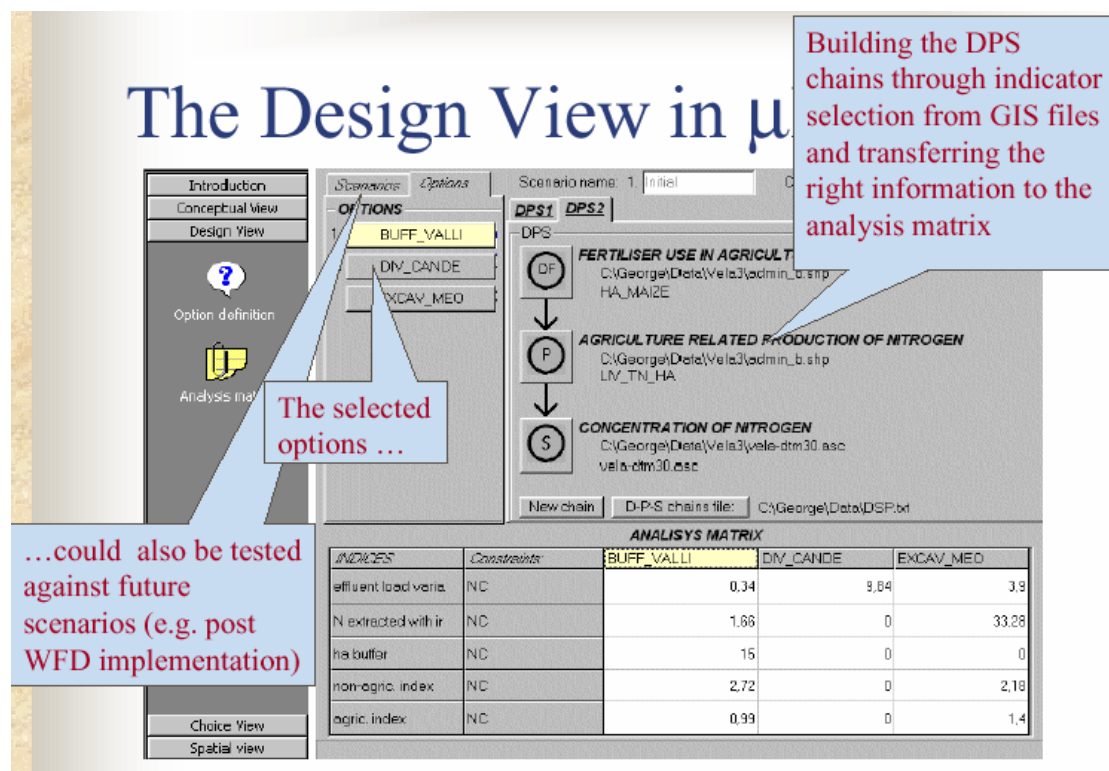


Fig. 48 The Design View and the Analysis Matrix

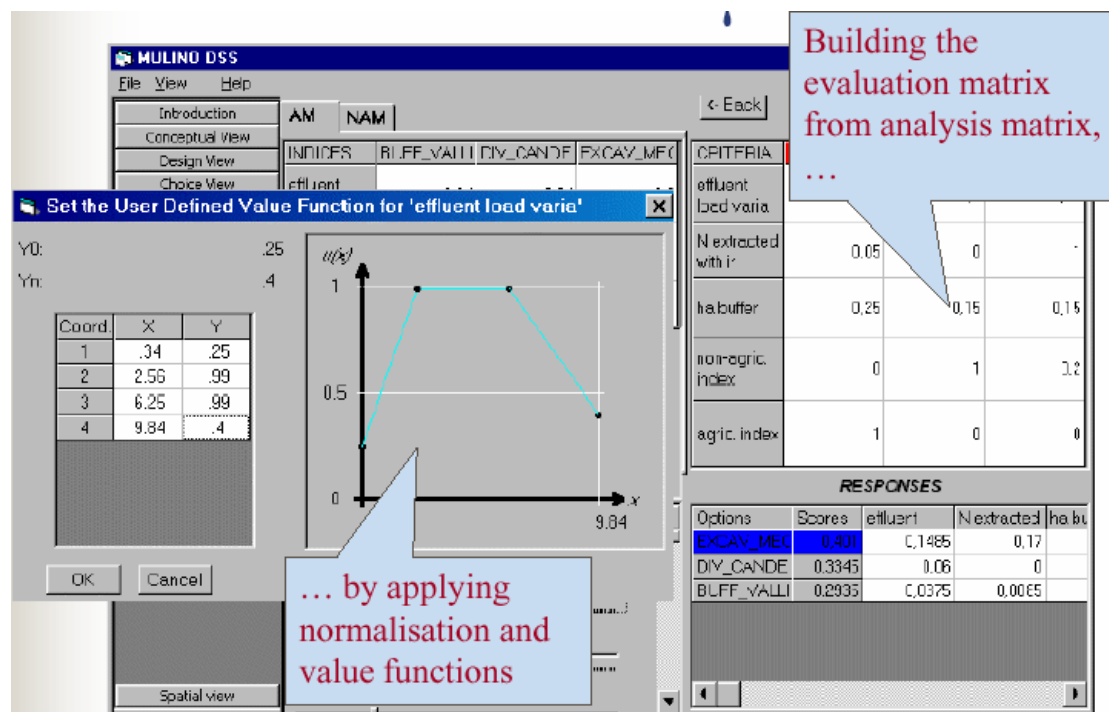


Fig. 49 The Choice View and the Value Functions

The decision process described above could be performed using different future scenarios in order to test the robustness of the best option. Scenarios are defined by the social, environmental and socio-economic settings that determine the drivers and pressures and state of the basin catchment.

Mulino DSS first version does not have its own dynamic modelling routines and it just works on top of external models but the full integration of simple hydrological models has been foreseen for the next two releases.

Adaptability to the Water Strategy Man Project

Current version of Mulino focuses on 1) defining the subject of water resource analysis, in terms of D-P-S chains, 2) defining available options to change the status and 3) evaluating proper state indicators for each strategic option. The tool is obviously not applicable to the WSM project as it is.

In the available documentation of Mulino there is nothing about a network editor or the simple hydrological models that are going to be integrated along the entire project. However, it suggests an interesting approach to problem definition and evaluation.

2.9. Ribasim

The RIVER BASIN SIMULATION is a model package for water resource planning and management at the River Basin level. It has been developed over the years since 1985 by Delft Hydraulics, Netherlands, and it is currently used by many national and regional agencies all over the world.

Ribasim allows to describe a basin in terms of water sources and users and to perform a simulation of the water distribution along a certain time horizon. It can be helpful to verify the possible water use conflicts among different types of users such as farmers or industries, to study the sustainable development of the river basin itself and to plan the adequate measures to solve the conflicts or to improve the water resource status in general. Moreover the water balances and the flow composition are the basis for further water quality analysis to perform by external models or by the Delft DeltaQ water quality model.

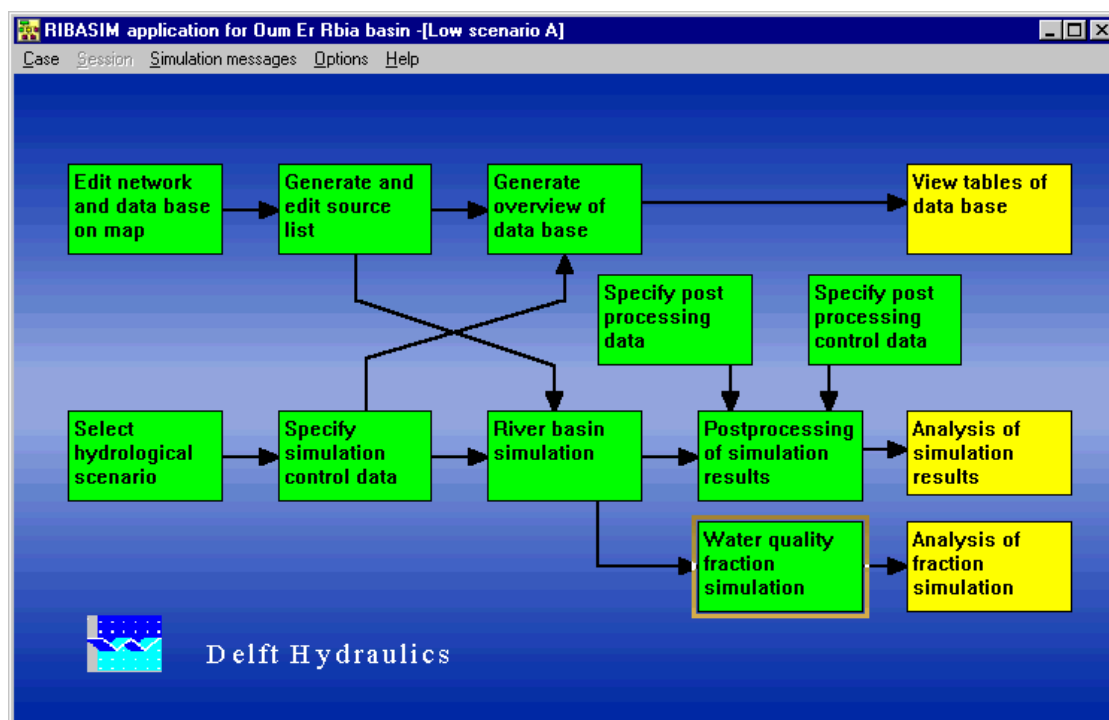


Fig. 50 The main view of the interface with the application steps.

Ribasim is a Windows-based software with a graphical user interface, a database, a simulation program and a tool for the results analysis. The main view of the User Interface shows a flow chart that has the purpose to guide the user in the model application to the desired River Basin: the blocks of the chart change their colour so as to show which step the user is currently performing and which are those already performed. The macro-steps are: 1) the creation of the network of nodes and branches as schematisation of the basin users, water sources and specific features 2) the data entry of

the necessary information in the geo-referenced database 3) preparation of input such as hydrological time series, operational rules for reservoirs, hydrobiological and crop requirements etc. 4) the simulation 5) post-processing of results and 6) their analysis.

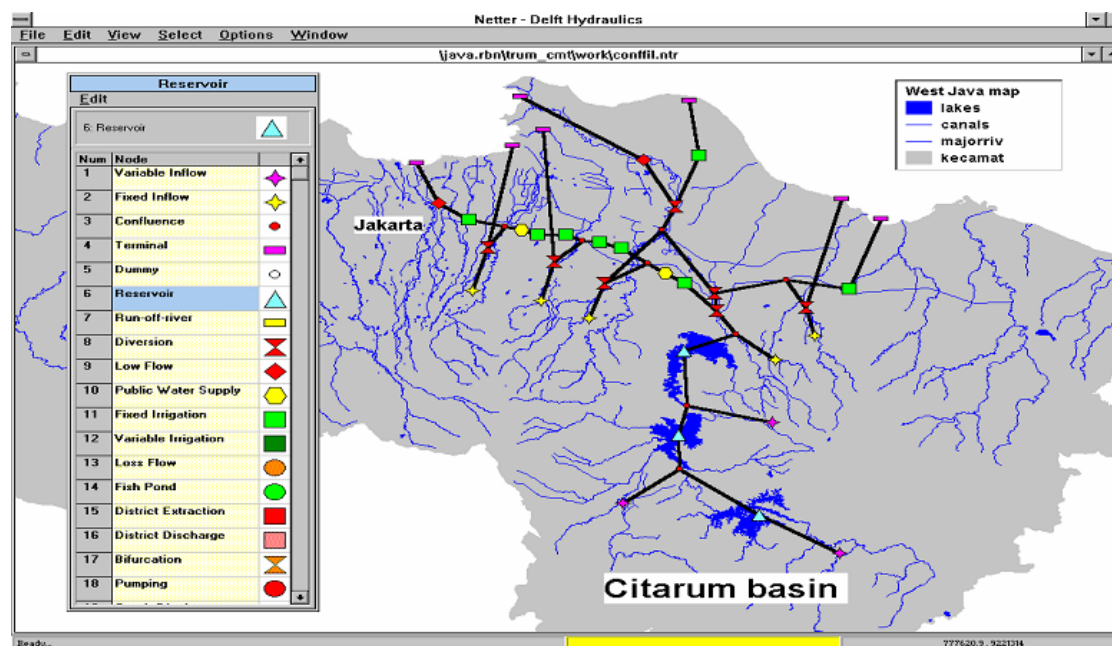


Fig. 51 The Netter and the network building

The schematisation of the basin consists of a network of nodes connected by branches. The user creates the scheme from the interface tool called “Netter”. It has a window where all the types of nodes are listed. The user chooses the types he wants and places them on the geographical layer of the Basin. Analogously is for the branches. The geographic layer could be imported from ArcView or MapInfo. The attribute data of the nodes can be entered in specific forms and tables just by clicking on the desired element of the layer. A number of consistency tests helps the user to fill the congruent data.

As far as the simulation is concerned, it is usually run over time series of many years to include the occurrence of dry and wet periods. The time steps are not fixed but variable and defined by the user: they can be for instance a day, a number of days or a month. It is to say that the Ribasim package is a tool that embeds many models among which the main one has the same name of the tool, Ribasim, and is responsible for the water allocation both at the basin level and within the district nodes. In particular, at the node level it is coupled with other models such as *Demes* and *Agwat* which estimate a more detailed demand for irrigation, industries and municipalities. Below, a table with the models used in Ribasim is presented.

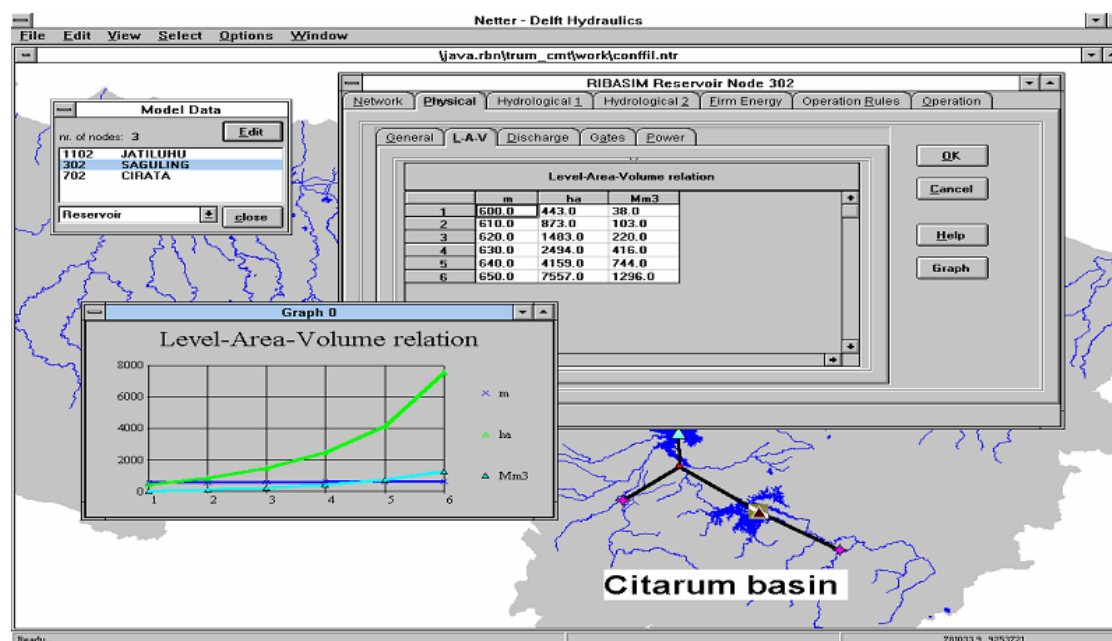


Fig. 52 Data entry and related graphs

Table 7 Models embedded in the Ribasim Tool. The description has been reported from the Delft Hydraulics Web Site

MODEL	SHORT DESCRIPTION
Samo	Determines per water district and per time step the runoff of non-irrigated areas, based on time series of potential evapotranspiration and rainfall.
Agwat	Determines per water district and per time step the irrigation water requirements and return flows under full supply condition for a variety of cropping patterns, taking into account farming and irrigation practices, and physical parameters related to soils and hydro-meteorological characteristics.
Fishwat	Determines per water district and per time step the fresh and saline water requirements of brackish water fish ponds (tambaks) under full supply conditions, taking into account various species to be cultivated, production technology (type of tambaks, required pond salinity's), climatological characteristics, and salinity's of the supplied water. Water demands are derived from water and salt balances.
Demes	Estimates the demand for domestic, municipal and industrial water supply based on projections of population and water using activities, a mode split between surface and groundwater, losses during transport and treatment, the applied level of technology, maintenance and management.
Ribasim	Computes the water distribution in the main distribution network and inside the water district by simulating the river and canal flows, operation of reservoirs (including hydropower production) and diversion structures. The model simulates the water allocation to the water users within the water districts and within a river basin.
Wadis	Determines the potential and actual crop yield and production costs of irrigated and rainfed agriculture per crop and brackish water aquaculture in each water district.
Delwaq	Determines the composition of the flow in any location of the main

MODEL	SHORT DESCRIPTION
	distribution network (river- and canal system) which forms a first insight in the quality of the water at that location. The model can be used as well to predict the water quality in the main distribution network under various hydrological conditions, pollution and sanitation scenario's.
Wlm	WLM (waste load model): estimation of the actual and future waste loads (point and non-point sources) on surface water. WLM provides direct input to the delwaq simulation model.
Stratif	Simulation of stratification layers in reservoirs.

At the River Basin level the water allocation follows the principle “first come – first serve” along the flow direction but the user can assign some allocation priorities to the demand nodes as well as define operation rules for water distribution and storage facilities. On the other hand, the allocation within the water districts takes into account also the output from the *Demes* and *Agnat* models and the runoff from the non-irrigated part of the water district, that is computed by the *Samo* model.

Ribasim enables the user to simulate and evaluate various “measures” and to compare their results. Measures can involve 1) the network infrastructure, with the building of new dams, reservoirs, irrigation systems 2) the water management, with the specification of new priorities or rule curves of reservoirs 3) laws and water use regulations which can influence the demand. A group of measures gives a “Strategy” and strategies define a “Case”. The program usually runs the reference situation first, that is called “Base Case”, and then a future situation, that is given by the reference case plus the chosen strategies.

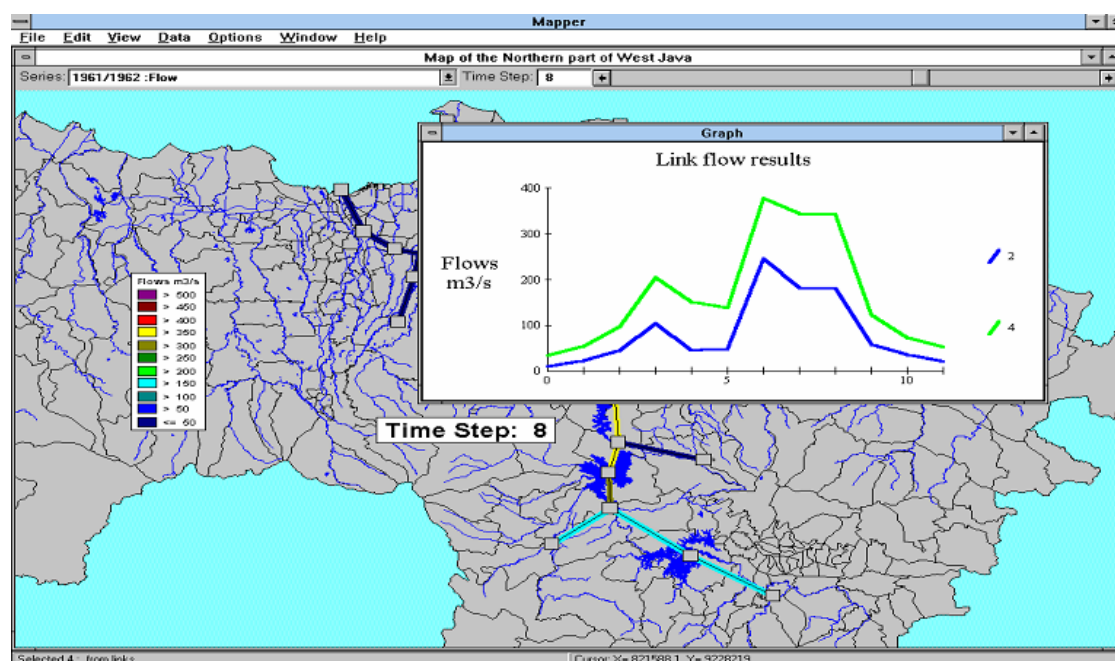


Fig. 53 The plotted results

The evaluation of the case results and the comparison of different cases are supported by graphs, thematic maps, tables or spreadsheets. Graphs of specific node parameters can

be accessed directly on the Gis layer by clicking the node and by selecting the desired parameters themselves. Among the output parameters there are the applied cropping pattern, the water allocation, the shortages per user, the actual surface or groundwater reservoir storage, the overall water balance of the basin and the energy production. Default Tables summarise main results such as the success rate, allocated amounts of water, water shortages, water utilisation rate, failure year percentage and energy production) whilst user-defined tables can display detailed results per time step for specific variables per node or link. Among the post-processing options, the user can choose an animated view where the amount of the water carried by the branches of the network is represented by the thickness of their lines. This view can be displayed for different times of the simulation period just by moving a proper time bar.

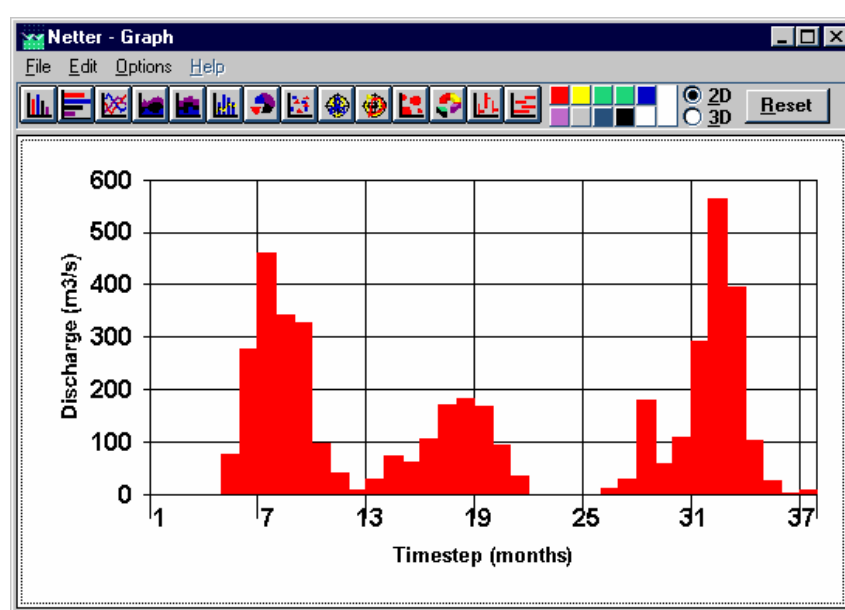


Fig. 54 A specific output can be plotted over the simulation period

Adaptability to the Water Strategy Man Project

The user can draw the river basin schematisation on a geographic layer imported from ArcView or MapInfo. However, Ribasim does not integrate Gis software.

Ribasim allows defining different hydrological scenarios as inflows input to the water resource system strategies or groups of strategies (*cases*) as well as. However there is not a real multi criteria approach.

2.10. Weap

The *Water Evaluation And Planning System* (WEAP) is a tool for water resources planning developed by the Stockholm Environment Institute's Boston Center at the Tellus Institute.

It aims to assist the decision Maker in storing and managing water demand and supply information, in forecasting water demands, water availability, waste generation and water costs and in evaluating water development and management options.

Weap21 is the last release of the software. It is windows-based and has been developed in Delphi by Borland. The graphical user interface consists of four different views, namely *Schematic*, *Data*, *Results* and *Overviews*. They are accessed by specific buttons on the *View Bar* placed at the left of the interface main screen, where each view is displayed.

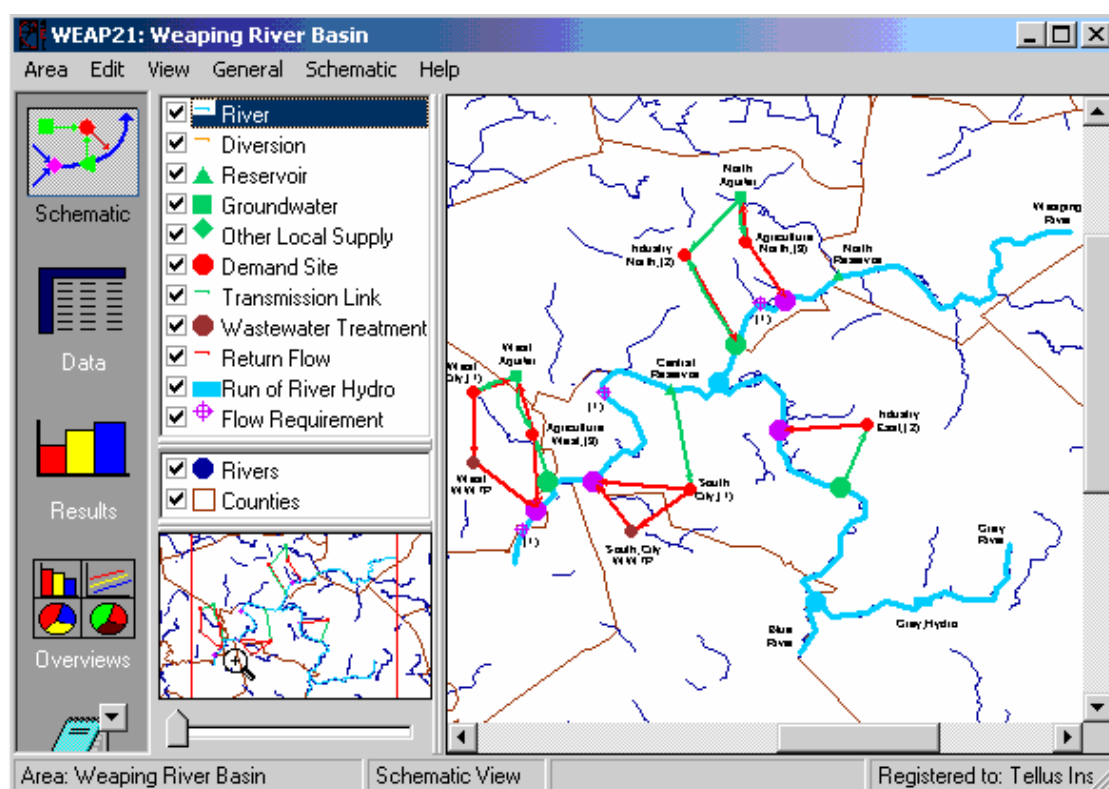


Fig. 55 The Schematic view of Weap

In the *Schematic View* the user finds a Gis layer of the area of interest and he can build the network of nodes and links representative of the water resource system of the area. Weap is usually applied to River Watersheds but the area could also be a larger or smaller geographic region. The user draws the node system directly on the gis layer by dragging and dropping the desired types of nodes and transmission links from a window at the upper-left listing them to the specific position on the map in the centre of the interface. After dropping the node type on the map, a pop-up windows requests some minimum

general information about the new node such as the name and if the node will be simulated in the default scenario. Further information to fill in depends on the specific element type and they will be described later on. The available network elements represent rivers, diversions, reservoirs, groundwater pumping stations, demand sites, wastewater treatment plants, hydropower stations and flow requirements. Nodes are linked by transmission links and return flows. The former are in green colour and carry water from the water resource nodes to the demand sites nodes. The latter exit the demand sites towards treatment plants or river locations. A small window just under the node types one, lists the Gis layers that can be loaded over the basic river basin map so as to add geographical information such as rivers, aquifers, lakes, seas. Both nodes or maps are loaded by ticking the elements with the mouse left button. The Gis map can be navigated by moving the little hand cursor over it and further a specific part of the map can be selected and zoomed.

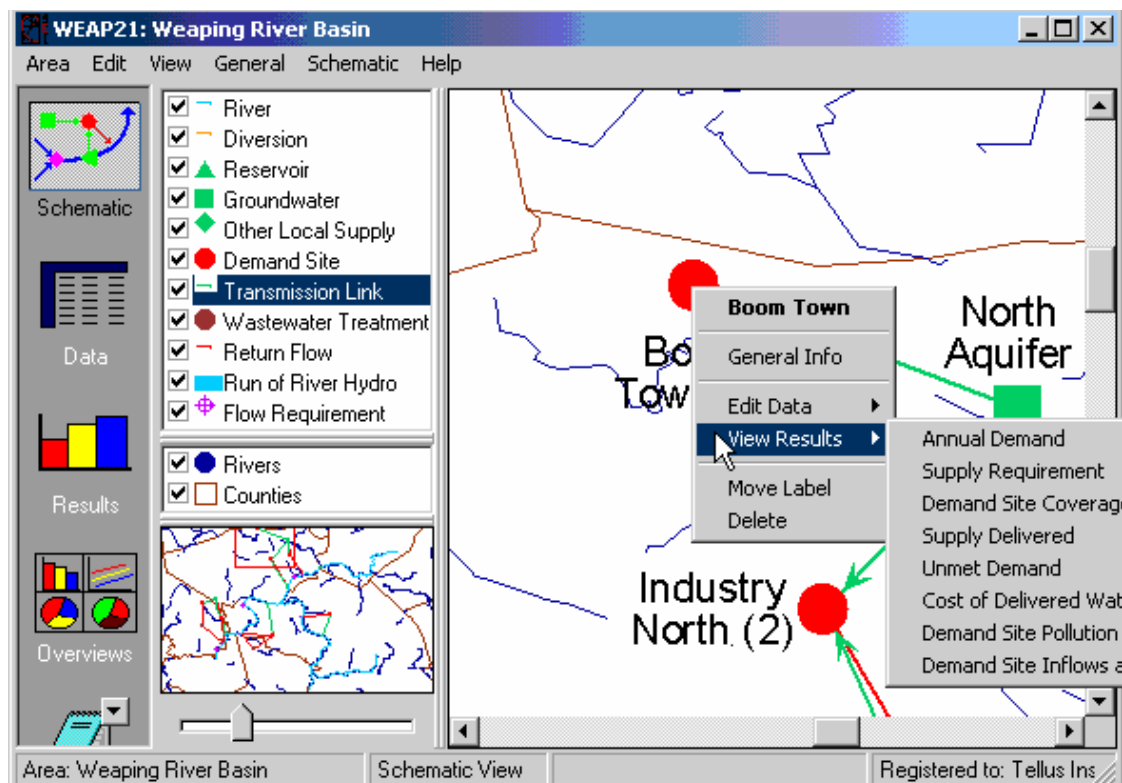


Fig. 56 The user can access data and results by clicking the network elements in the Schematic view

The Data View is used to organise, edit and model the data of the network elements. This view consists of four panels: the Tree on the top left, the Inset Schematic, on the bottom left, the Data Entry Tables on the top right and the Data Entry Results on the bottom right. The Data Entry Tables panel is the main subject of the view: here the user accesses the data associated to the network elements. In order to access the information of a specific node and to display it in the data entry, the node itself must be selected by clicking it in the inset schematic or by marking it in the tree. The inset schematic is small

map of the area which can be navigated and zoomed whereas the tree is a hierarchical outline similar to the folder structure of Windows Explorer and it used to organise the data under defined categories. The data entered in the Data Entry Tables appear in the Data Entry Results either as graphical charts or as tables listing the corresponding plotted values. More in details, the Data Entry Tables concern the variables describing the nodes and their trends over time. These latter are easily built by the user through a dedicated set of integrated functions. He has just to specify the function's parameters so as to define the variable behaviour. Examples of functions are the *Growth* and the *Interp* which calculate a value in any given year using respectively a growth rate from the base year value and a linear interpolation of a time-series of year/value pairs. Variable trends can be also built through dedicated wizards for monthly and yearly time-series construction. Once the user has filled-in the data, he can covert and display it according to different possible measurement units and scales. The list of units depends on the category of network elements they refer to. the Data Entry Tables also concern the management of scenarios, here defined as “ self-consistent story lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions”. The default one-year scenario is called *Current Accounts* and the corresponding data represent the status of the system in the specified year as a the starting point for all the simulated and alternate scenarios which will go from that year on. as said before, the behaviour of variables are built through mathematical expressions which can be constant or generating time-series of values. These expressions can be exported from one scenario to another that allows to minimise the amount of data entries and it facilitate the scenario editing and management.

As far as the tree is concerned, it is organised into six major categories, namely Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment and Other Assumptions. The Key and Other Assumptions are user-defined intermediate variables that can be referenced in any expression or function used in data and scenario definition. Example of assumptions are variables such as the Gross Domestic Product (GDP) and water price. The demand sites are cities, industries and agricultural area demanding for water and are described in terms of annual water use, monthly share of annual demand among all the sites of the same category, the loss and re-use rates within the demand site and the costs and savings due to the demand management. the supply and resource category groups all the water sources and network links. these latter are featured by the maximum flow volume loss rate and cost per unit of water delivered whilst each kind of source has its own specific variables. The hydrology category refers to future time series of inflows to the supply resources specified via mathematical expressions or month by month. The environment category concerns the pollutant generation and their concentration and removal within the treatment plants.

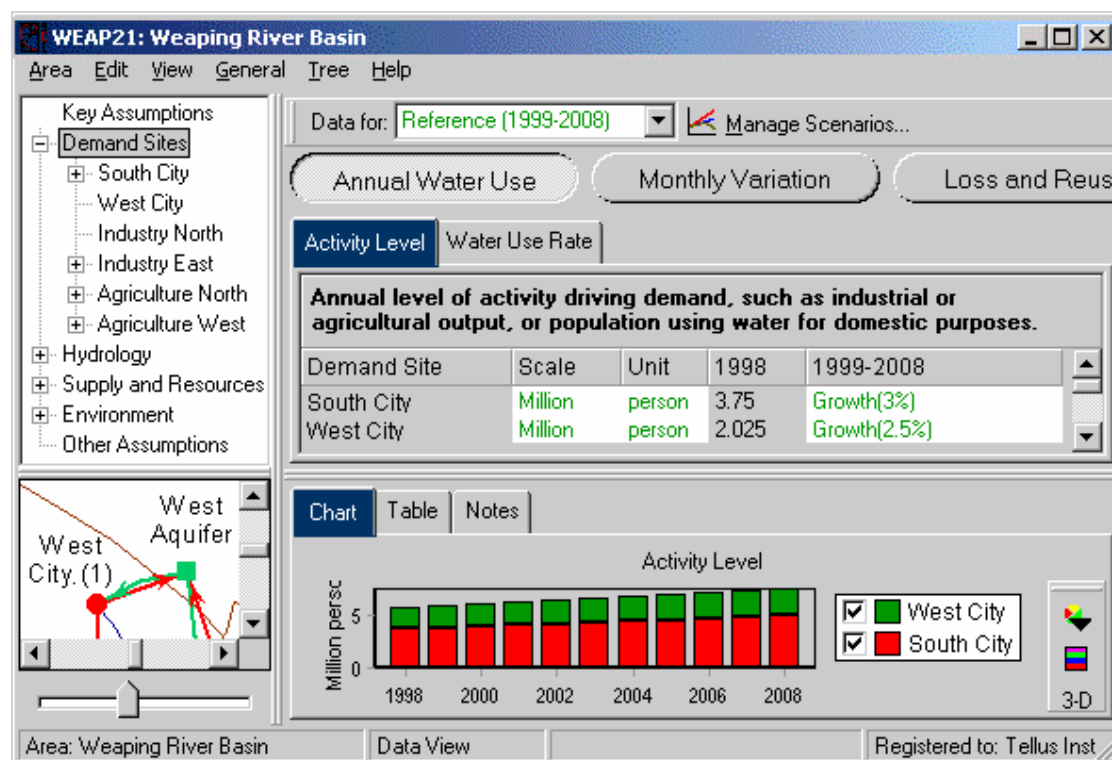


Fig. 57 The Data View of Weap

When the Weap user select the *Result View* from the *View Bar*, the system starts the allocation of water to the demand sites and the pollution calculation. The water resource system is schematised in Weap as supply nodes giving water to the demand sites and the water allocation algorithm is based on the concepts of *Supply Priorities* and *Demand Preferences*. The *Supply Priorities* are attached to the demand sites and establish the order they will be served by the supply nodes. Priorities can range from 1 to 99, with 1 being the highest priority and 99 the lowest. These priorities have a particular importance during water shortage conditions because they assign the demand sites with the highest priorities the right to have their critical water demands completely covered before lower priorities are considered. On the other side, the *Demand Preferences* are associated to the transmission links entering the demand sites and specify the preference for a certain kind of water resource rather than others, in case the site is connected to more than one resource. *Supply Priorities* and *Demand Preferences* can be entered or changed by the user from the Data view or directly on the river basin map in the Schematic View by right-clicking on the desired demand site or transmission link and selecting the general information.

After the simulation is performed, its results can be plotted in the same *Result View* or investigated in the associated data tables. The user can customise graphs and save them as favourites. More in details, he can choose the variables to plot, choose a specific month or display the entire time-series, plot information associated to just one network node or to all the node of the same type, for instance the groundwater storage for all the aquifers. Moreover, he can choose and change the graph type, select the scenario and

select and change the measurement units. The data table can be exported to excel by clicking the dedicated button and graphs can be copied and printed. The graphs previously saved as favourite can be viewed all together in the *Overview* so as to compare the different aspects of the river basin such as water demand and coverage, storage levels, pollutant generation and costs. The user can build and save up to 16 charts or tables per overview and create multiple overviews themselves. Each single graph of one overview can be further modified and saved again.

A fifth tool appears in the View Bar placed at the left of the interface main screen, that is just a word processor to write documentation on the network elements, trends built or expression used and attach it to the tree elements themselves.

WEAP has been applied in water assessments in the United States, Mexico, China, Central Asia, Africa, Egypt, Israel and India, aiming to:

- identify and evaluate the impacts of climate change on water for agriculture, recreation, hydropower generation, water for municipal and industrial use, habitat function and health, biodiversity, water purification;
- represent alternative water development and allocation scenarios;
- assess water supply augmentation through an inter-basin transfer within firm yield analysis;
- solve water use conflicts in river basins;
- develop supply and demand balances and alternative strategies to study the water costs in watersheds;

Adaptability to the Water Strategy Man Project

A tool like Weap could certainly represent a point of reference for the development of the WSM decision support system. Unfortunately it does not integrate a Gis software, this being certainly a limitation, and water demand is specified only through predefined time series not considering its possible update for economic or administrative reasons at each simulation time step.

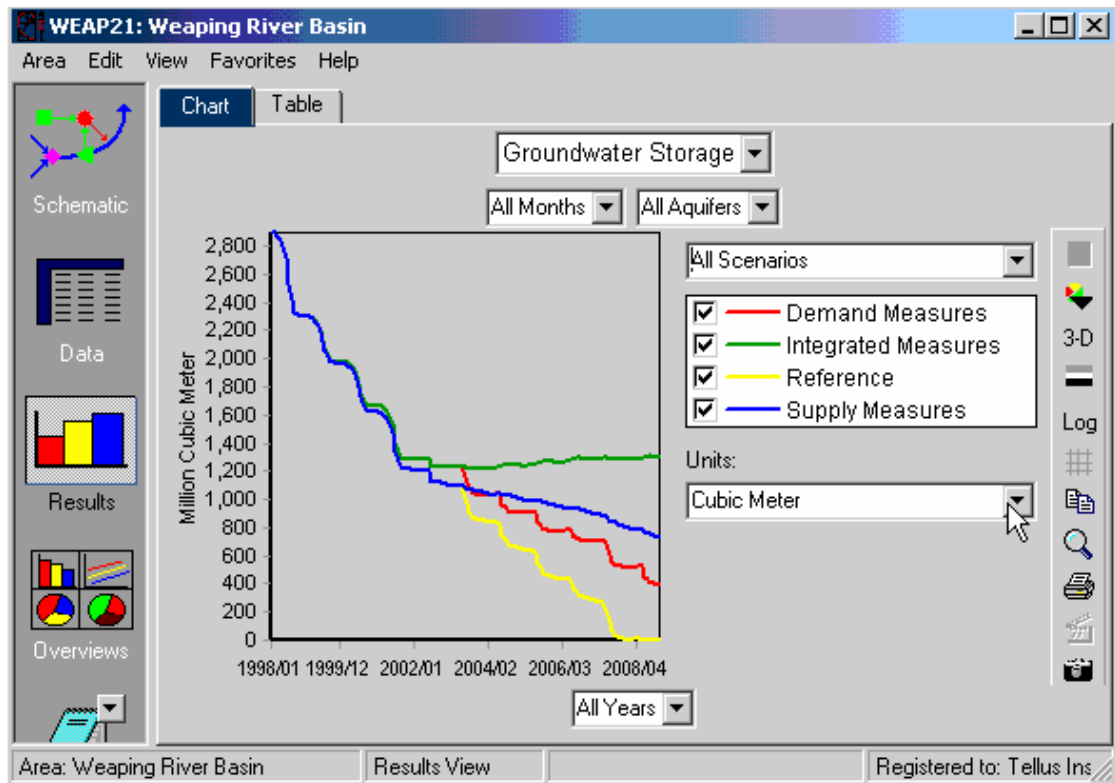


Fig. 58 The Result View of Weap

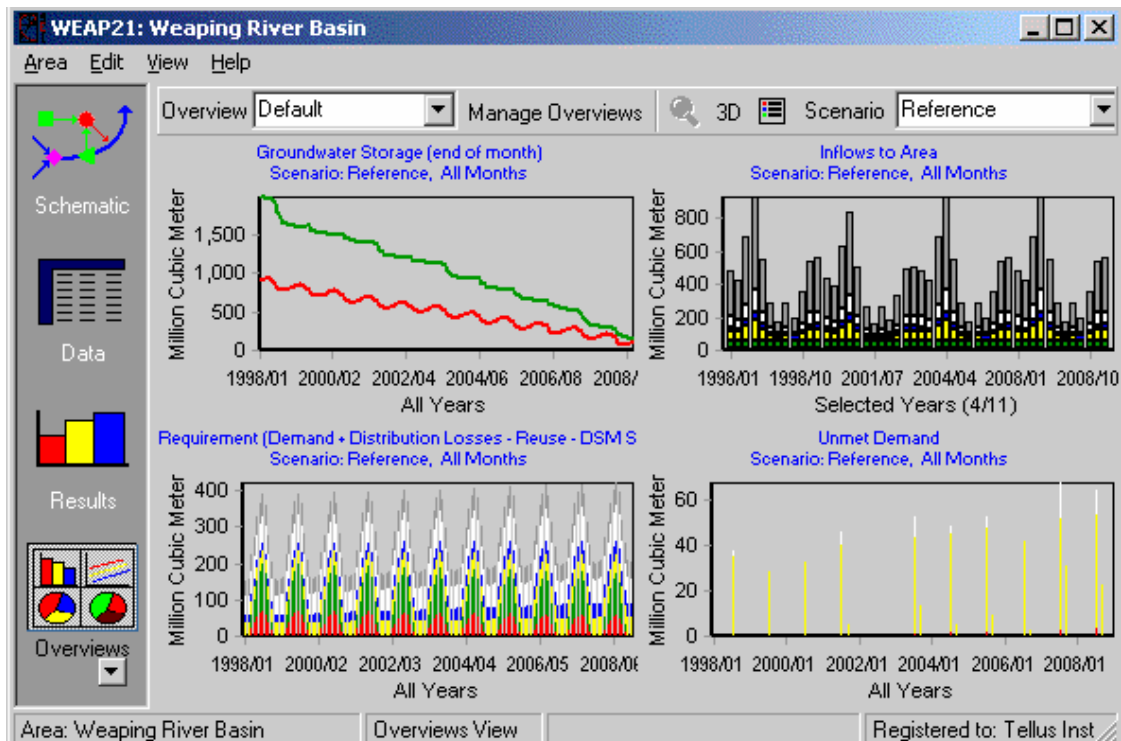


Fig. 59 The Overview of Weap

2.11. Waterware

Waterware is a DSS for integrated river basin planning and management, main objective of the European research program Eureka-EU487. Within the project, the software prototype was originally applied and tested to the Thames River Basin in England. Then it has been further developed through a series of applications to the Lerma-Chapala basin in Mexico, the West Bank and Gaza in Palestine, and the Kelantan River in Malaysia. WATERWARE is one of the first examples of systems integrating suites of models and tools aimed at comprehensive impact analyses.

Among the Water resource issues addressed by Waterware there are:

- To determine the exploitation limits of available water resources and the planning and development of new ones in time and space;
- To evaluate and assess the sustainability of water supply development as far as regards the impacts on the environment;
- To formulate strategies to track down pollution in rivers and aquifers and control the effectiveness of environmental legislation;

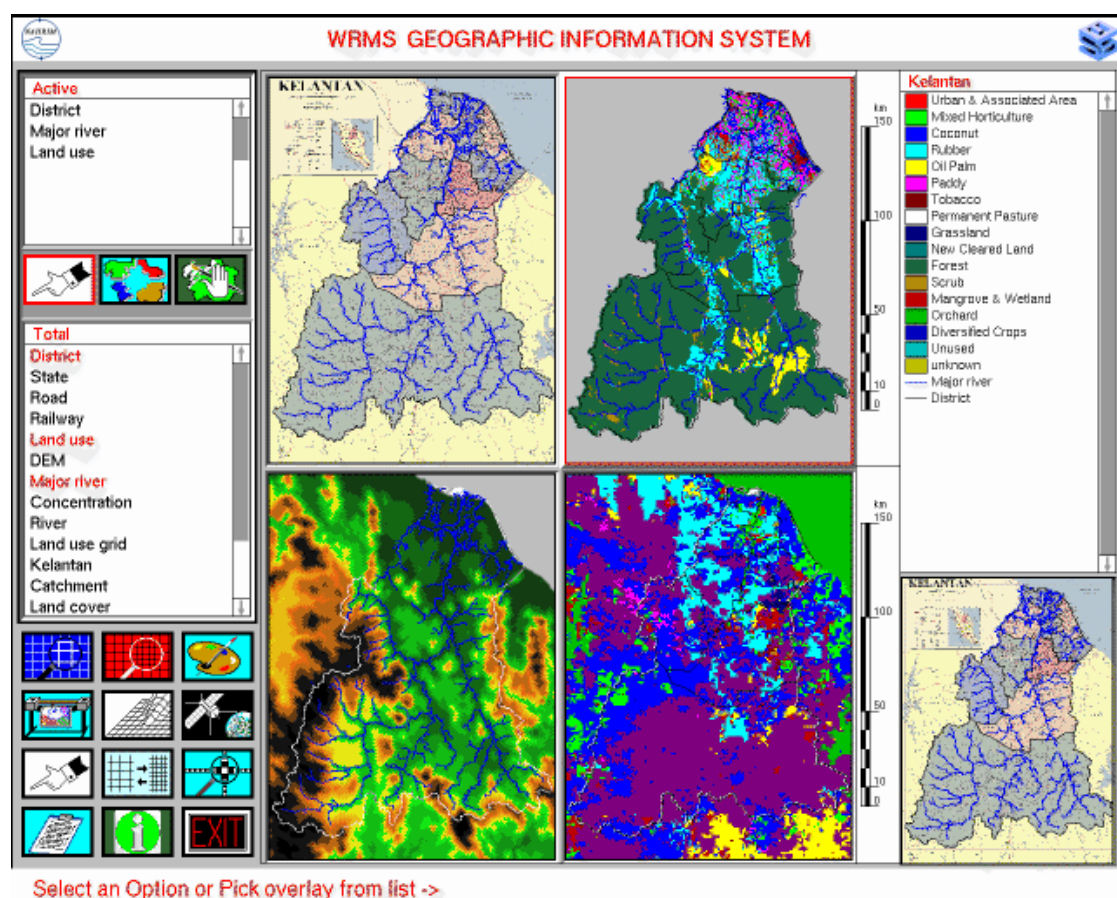


Fig. 60 GIS layers drainage network, land use, soil, and DEM

Waterware is coded in C/C++ but it is capable to integrate models written in the Fortran programming language. It has been developed as an open, object-oriented architecture running on UNIX servers and compatible with ArcInfo and Grass. Waterware consists of the following components:

- User interface
- A GIS providing hierarchical map layers for spatial reference and direct data input for the simulation models. It is integrated with a database, the models, and the other utilities as well as http servers supporting remote access through the Internet.
- Geo-referenced database with HTML documents to easily navigate through background information on legislation, pollutants, emission sources and coefficients, models, health effects, and control technologies
- A graphical river network editor
- A suite of simulation models:
 - a) Mono-dimensional stochastic river water-quality model.
 - b) Bi-dimensional finite-difference model of groundwater flow and contaminant transport
 - c) UN Food and Agriculture Organisation's CROPWAT model to estimate the crops water requirements
 - d) rainfall/runoff model
 - e) a water resources planning model
- Utilities for time series analysis and reporting
- A rule-based expert system for Environmental Impact Assessment

Waterware works with a variety of geographic, hydrological, meteorological, and economic data. Examples are: maps with administrative boundaries, land-use, DEMs, temperature, precipitation, pollutant concentrations, investment and operational costs and all the parameters specific to each simulation models.

The river basin is schematised by a set of *RiverBasinObjects* that are: climate stations, flow stations, water quality stations, observation time series, abstractions, settlements, industries, irrigation districts, animal farms, treatment plants, water works, sub-catchments, dams and reservoirs, natural lakes, aquifers, wells, weirs and falls, gates and sluices, cross-sections, boreholes, and scenic sites. Each type of object represents a *class* of elements that have been assigned a common set of properties and functions. The former describe the status of the element whilst the latter drive their behaviour in time.

The different objects are linked explicitly according to their role in the water basin system: for instance, a reservoir object receives water from the upstream sub-catchment and can feed a downstream irrigation area or some industries. Moreover the storage level of the reservoir or the hydro-meteorological data can be monitored through the gauging station class of objects.

The models embedded in Waterware simulate the basin objects' behaviour providing their input from the geo-referenced database and displaying their output on the GIS maps. Each model affects its own set of river basin elements and is linked to the others within the computational chain of their respective input and output. In fact, the rainfall-runoff model calculates the runoff from the catchment object under specific land-use, water use, and meteorological conditions and passes it as input to the water resources model that compute the balances and supplies to settlements, industries and irrigation districts. On the other hand the water resources model provides input to the water quality model that operates on nodes such as treatment plants, industries, and municipalities.

The user can access each model and river basin object by mean of dedicated windows and menus. Examples of that are presented below.

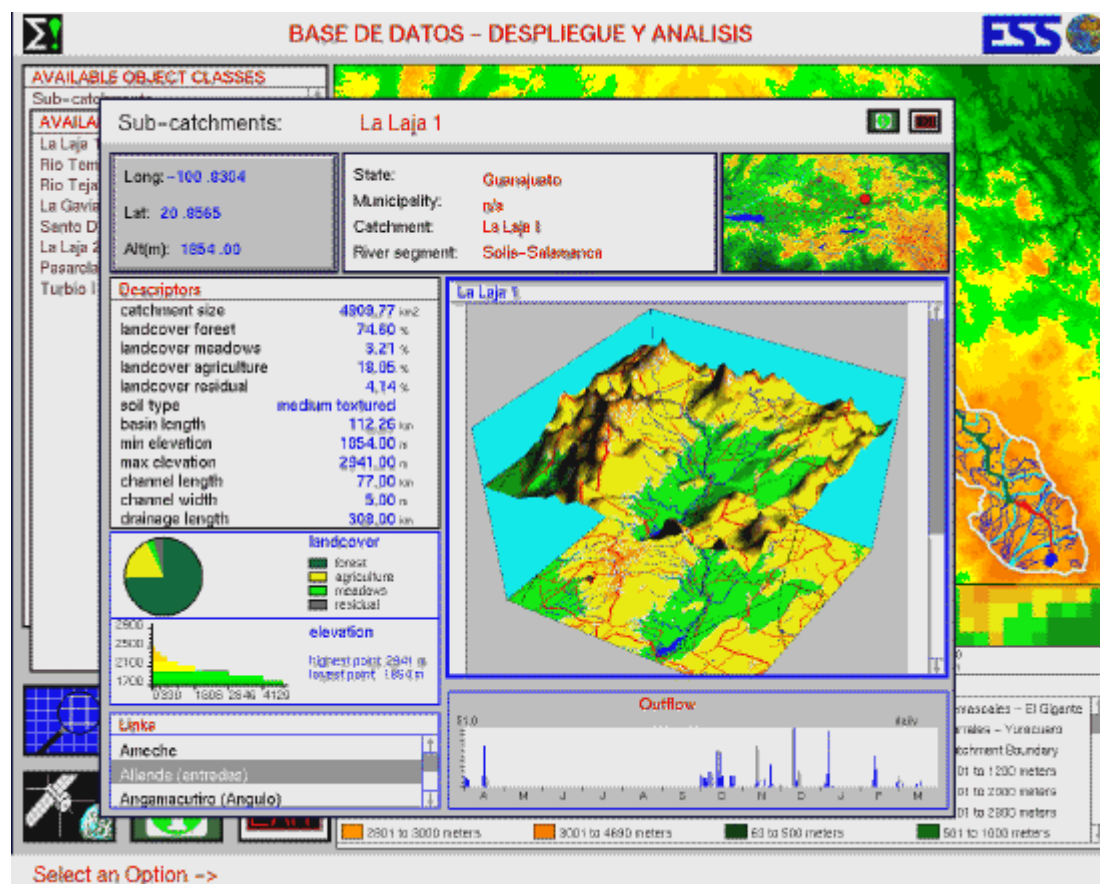


Fig. 61 The window for a sub-catchment object

Rivers are represented in Waterware as classes of *RiverNode*, *Reach* and *CrossSection* objects linked together to shape the *RiverNetworkObject*. The river network is built through an interactive editor where the user associates properties and geographic reference to the river elements and link them to the existing river basin objects.

As far as the data analysis utilities is concerned, they go beyond the basic functionality of displaying the time series data, scrolling, zooming, data aggregating and unit converting. Data associated to individual gauging stations can be accessed by selecting them either from a list of stations or from maps and are analysed in the spatial context of the station itself. There are functions that allow the selection of sub-periods of time-series, their interpolation and the search for the maximum common temporal coverage for a set of stations. Moreover the data can be tested in terms of spatial homogeneity and seasonality of specific values and the cumulative distributions of time-series of different neighbour stations can be compared.

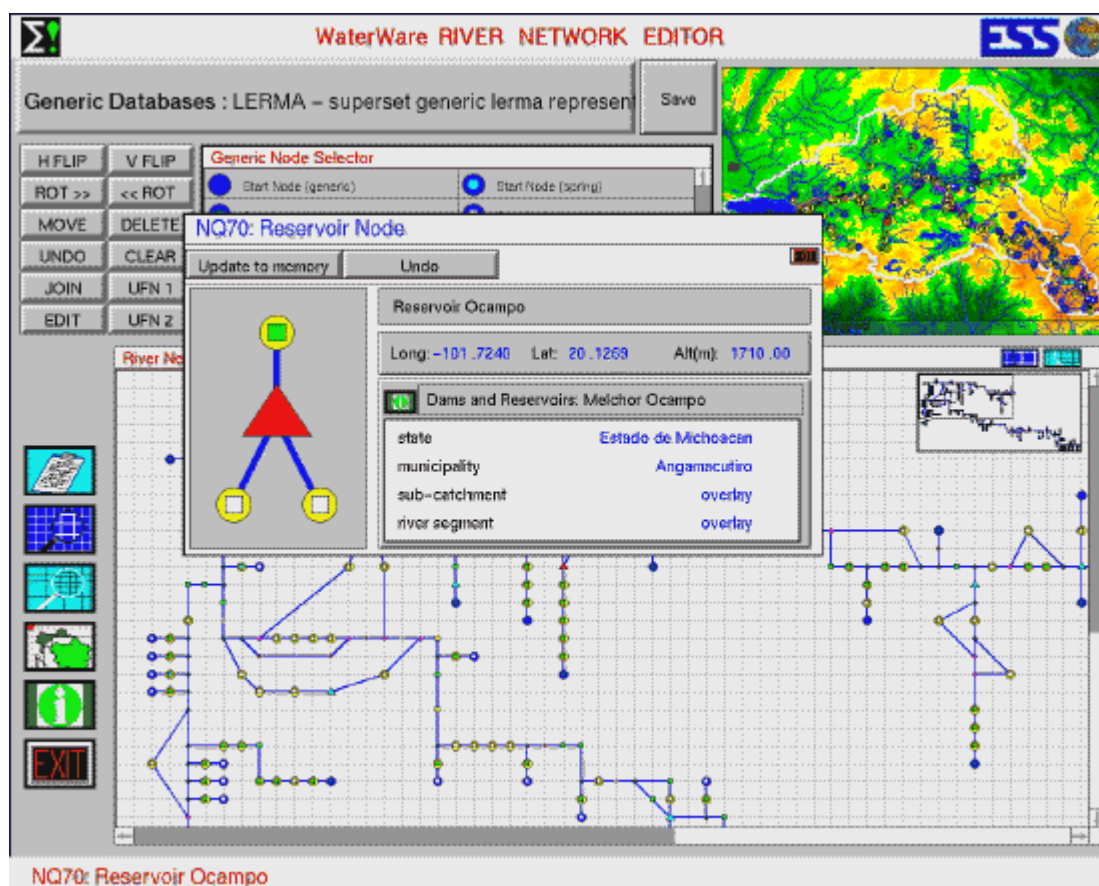


Fig. 62 The Interactive River network editor of Waterware

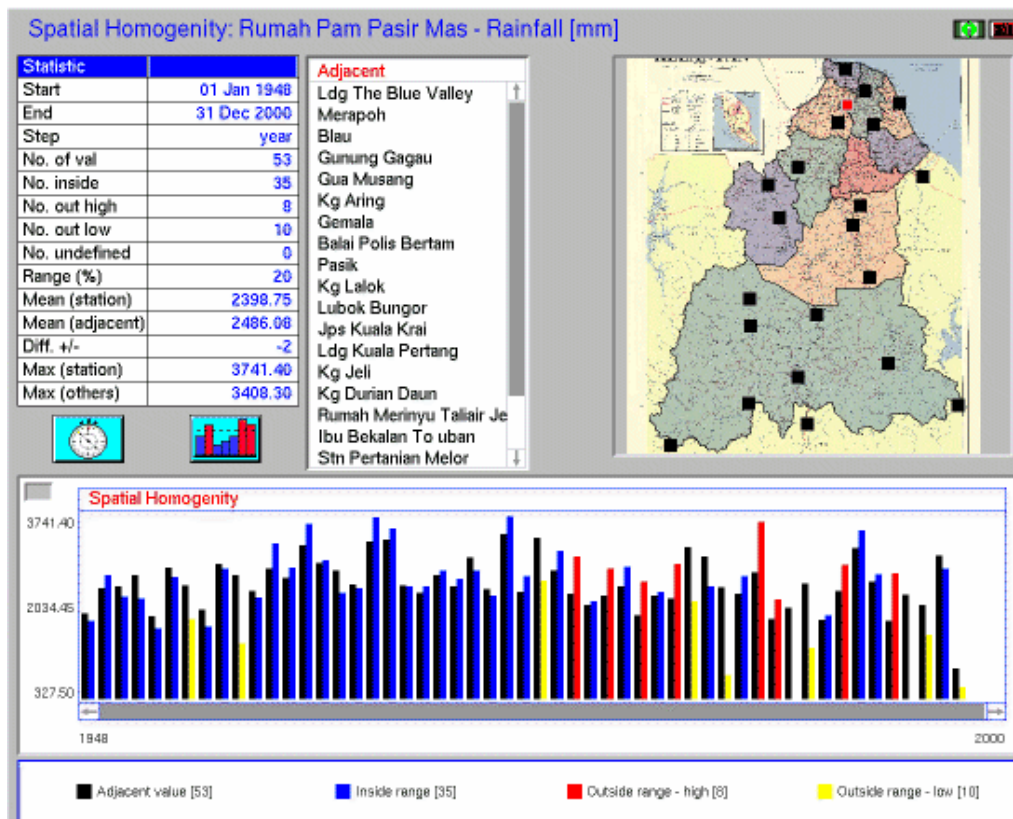


Fig. 63 Examples of time series analysis: selection of stations and spatial homogeneity

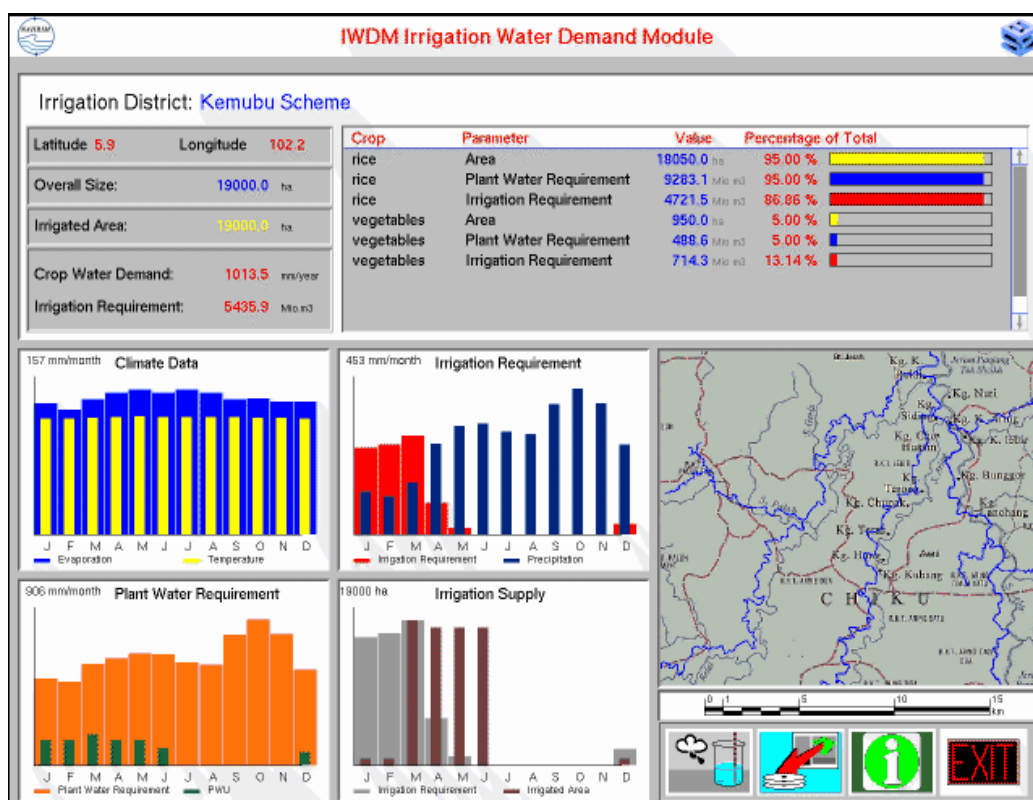


Fig. 64 The Irrigation Water Demand Model window

Adaptability to the Water Strategy Man Project

At a first sight Waterware gives certainly a positive impression: it has been developed as an open architecture integrating water quantity and quality models, it is linked to a geo-referenced database, it has a graphical network editor and uses geographical layers that are compatible with ArcInfo and Grass. However, some doubts arise, from the documentation available, about the possibility to easily adapt this tool to the WSM paradigms. First of all it runs on running on UNIX servers while the WSM DSS is presumed to be Windows-based. The models used within Waterware are all conceptually linked together in a sort of informatic chain: during the simulation they are launched according to a predefined sequence and output of a model represents input for the next ones. This is not an unusual way to perform the simulation. Anyway it represents surely an obstacle to addition of new modules or modification of the existing ones, at least for the need of adapting input and output to common standard file formats.

Waterware does not operate with economic, hydrologic or climatic scenarios and does not integrate a framework for result comparison and definition of strategies or options to improve the water availability or to solve water pollution. It has more the role of information system rather than of a system supporting Decision Makers towards an integrated and multi-objective analysis, planning and management of water resources.

For these reasons Waterware is proposed as not applicable or adaptable to the WSM project.

2.12. Aquatool

Aquatool is a generalised decision support system for water resource planning and operational management at the watershed scale. It has been developed by the Universidad Politecnica de Valencia, Spain, and it is currently used and improved by several Spanish River Basin Agencies among which those of the Segura, Tagus and Jucar Rivers.

This Windows-based DSS consists of modules for the basin management simulation and optimisation, for modelling of water flows in aquifers, risk assessment, analysis and report of results. These components have been coded in different programming languages such as C++, Visual Basic and Fortran as they have been developed in different time steps and kept separate each one from the other so as to make Aquatool highly flexible to work with and to upgrade and develop as well.

The user accesses the modules from a graphical interface, which support him also in the representation of the river basin. The system schematisation can be drawn over a geographical layer of the basin's hydrology that can be imported from other GIS. The elements of the scheme concern: node with storage capacity like lakes and reservoirs, diversions and junctions, natural channels, aquifers, evaporation and infiltration losses and water users such as irrigated zones, municipal and industrial supply and hydroelectric plants. All these objects are listed in a specific toolbar. In order to draw the system the DSS user has to select the elements from the toolbar and click the location on the map where he desires to place them. An interesting feature of the tool helps the user to find the location of a determined object in case of large water systems, compound of lots of elements: there is a list of all the geo-referenced nodes and links placed on the map layer which can be sorted alphabetically or by type element. Once a particular element is selected within the list, the window moves to the location of the element in the graphical representation.

The basin's elements are geo-referenced and their physical characteristics and operating rules can be inserted into the Aquatool database directly from the map layer loaded on the user interface: database forms, relevant to each type of basin element, open by double-clicking the elements themselves on the map. Some variables defining the operating policies are the following: target as well as minimum and maximum volumes of reservoirs, inter-reservoirs relationship and priorities of use, minimum flow in rivers and flow requirements for hydroelectric plants, target water demand for each agricultural, industrial and domestic areas and their demand priorities that are used in the water allocation.

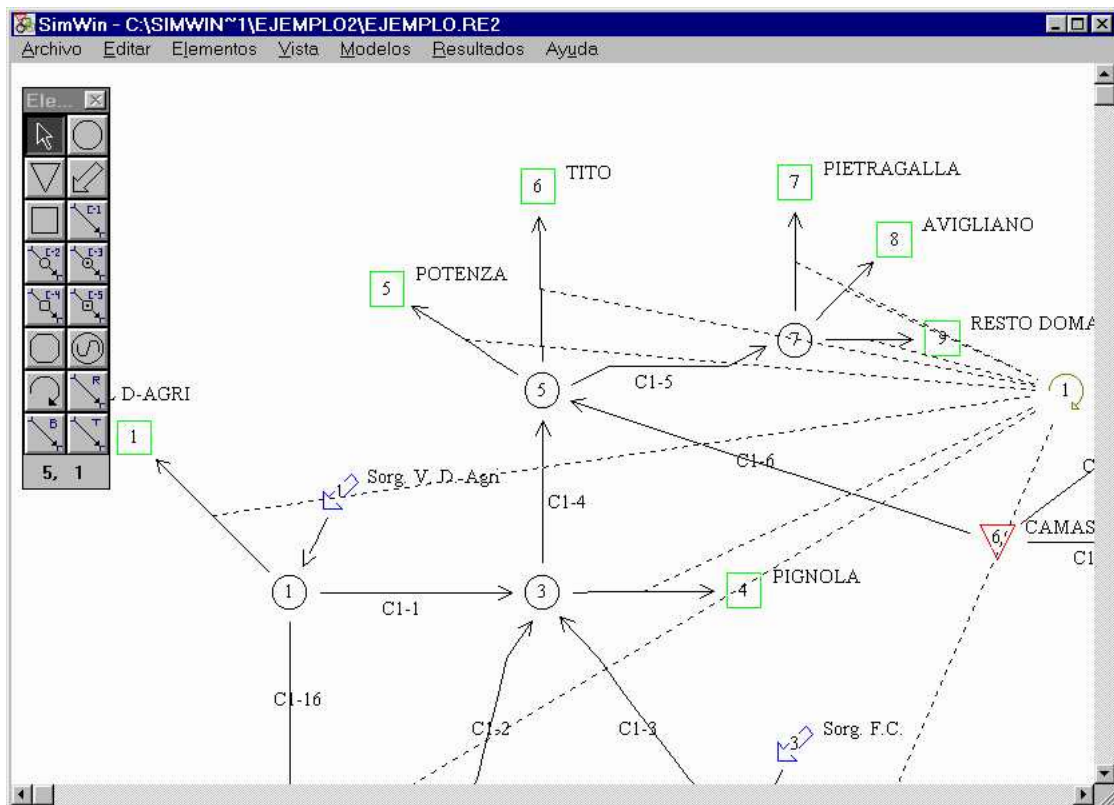


Fig. 65 Building the river basin schematisation

The screenshot shows two overlapping dialog boxes. The top one is 'Descripción del embalse' with fields for 'Nombre: EMB1-Alarcon', 'Infiltración' (Coef. A, B, C), 'Número prioridad: 1', and 'Volumen inicial (Hm³): 270'. The bottom dialog box is 'VOLUMENES' and contains a table with columns for 'Volumen máximo', 'Volumen objetivo', and 'Volumen mínimo' across months from October to March.

		Volumen máximo		Volumen objetivo		Volumen mínimo	
Oct	Abr	1112	1112	900.000	900.000	30.000	30.000
Nov	May	1112	1112	900.000	900.000	30.000	30.000
Dic	Jun	1112	1112	900.000	900.000	30.000	30.000
Ene	Jul	1112	1112	900.000	900.000	30.000	30.000
Feb	Ago	1112	1112	900.000	900.000	30.000	30.000
Mar	Sep	1112	1112	900.000	900.000	30.000	30.000

Fig. 66 Accessing the geo-referenced database from the basin scheme

The SIMGES Fortran-coded mathematical model performs the simulation of the operational management of the system on a monthly basis. It is responsible of the water

allocation to the user nodes affecting the water basin and considers the conjunctive use of surface water and groundwater. This issue is remarkable in most Spanish basins as exploitation of aquifers help considerably to face the scarcity of water and the competition between conflicting users. For that reason the model takes into accounts detailed relationships between the surface water source and the aquifers and includes a broad spectrum of approaches for modelling groundwater:

- aquifers with no discharge other than pumped water are represented as single cells in which mass balance is performed;
- aquifers with discharge through a spring, for which the flow is assumed to decline exponentially with storage until the storage level goes under the spring level;
- aquifers hydraulically connected to one or two surface streams, conceptualised as rectangular, homogeneous aquifers for whom analytical solutions have been studied at the Universidad Politecnica de Valencia and later included in SIMGES;
- distributed model of heterogeneous aquifers of irregular shape whose efficiency is strictly related to the possibility of using pre-processed data as input to SIMGES. This pre-processed data is prepared by the *module of aquifer per-processing and simulation* of Aquatool;

Of course the choice of one approach in place of another can depend on the amount of data available from hydrological and geological studies and the level of desired degree of detail required to represent aquifers realistically.

OPTIGES is the optimisation module of Aquatool. The algorithm considers and works with just some of the basin elements drawn by the DSS user, in particular: nodes with and without storage capacity, channels, hydrological inflows, water demands and return flows. OPTIGES is based on the conservation of mass within the network of nodes and flows and uses an iterative function which minimise the weighted sum of the water demand deficits and minimum flows by accounting for instance reservoirs' evaporation and return flows. The weights reflect the priorities of use assigned by the Decision-Maker to the different users in the basin. OPTIGES results can be plotted so as to support the analysis and comparisons of different management solutions and operating rules.

SIMRISK is a module for risk assessment in real operational management of the system. it simulates the basin under several series of synthesised future hydrological inflows consistent with the initial conditions of the system and calculates the probability distribution function of water deficits, volumes of reservoirs, deficit in ecological flows and water quality indices. The Decision-Maker can analyse the results both in tabular and in graphical form and evaluate if the risk of failure of the chosen operating rules and management options is acceptable or not. In case the estimated risks are too high to be assumed, he can decide to assign some restrictions of supply use to some or all the basin water users and run again the risk assessment module. The degree of restriction can be

the same for all the demand nodes or specific to individual users or group of them. The risk assessment process ends when acceptable risk is reached.

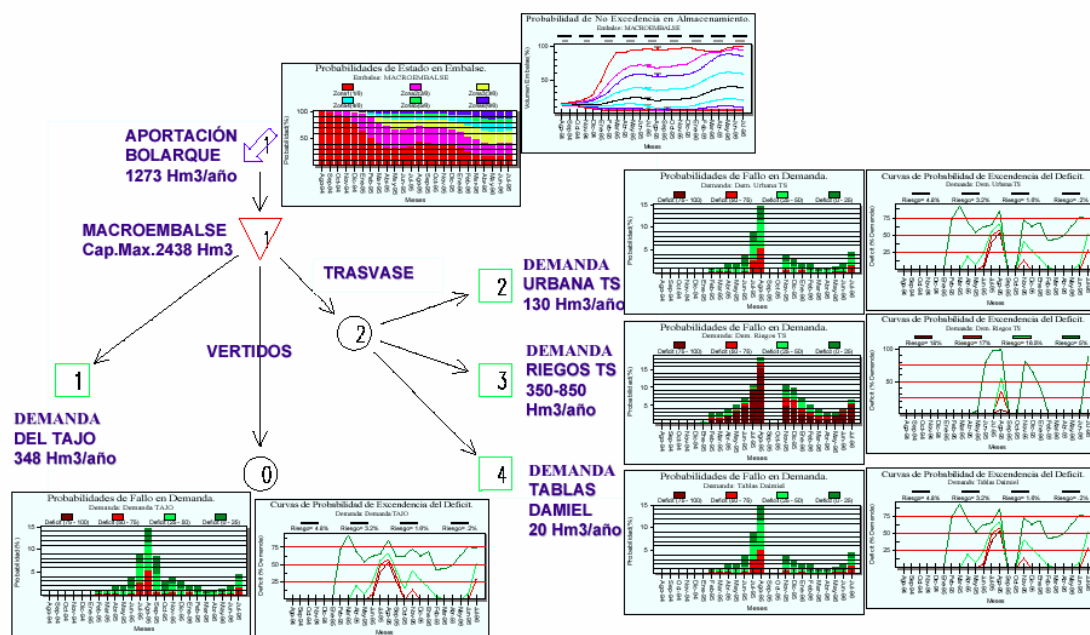


Fig. 67 Risk assessment analysis for a sub-watershed of the Tagus Basin

The tool has also a module for the water quality assessment of a river basin. It simulates the behaviour over the time horizon of pollutants' concentrations and calculates simplified water quality indices in each node and stream of the basin.

The Aquatool's Graphical Analysis Module provides the DSS user with graphs, table and report files supporting him to investigate decision variables' values resulting from simulations and optimisations as well as to display hydrologic time series and parameters. Results are saved in the geo-referenced database and their corresponding plots and tables can be easily accessed and retrieved for each element of the basin schematisation by pointing the element of interest on the map.

In conclusion, Aquatool permits the simulation and comparison of different operating policies and hydrological data in order to analyse planning decisions and determine tradeoffs between different hydrological scenarios. Moreover it provides risk assessment and evaluation. Aquatool is a living project at the department of Hydraulic and Environment Engineering of the Technical University of Valencia: at the time being economic and ecological modules are under development.

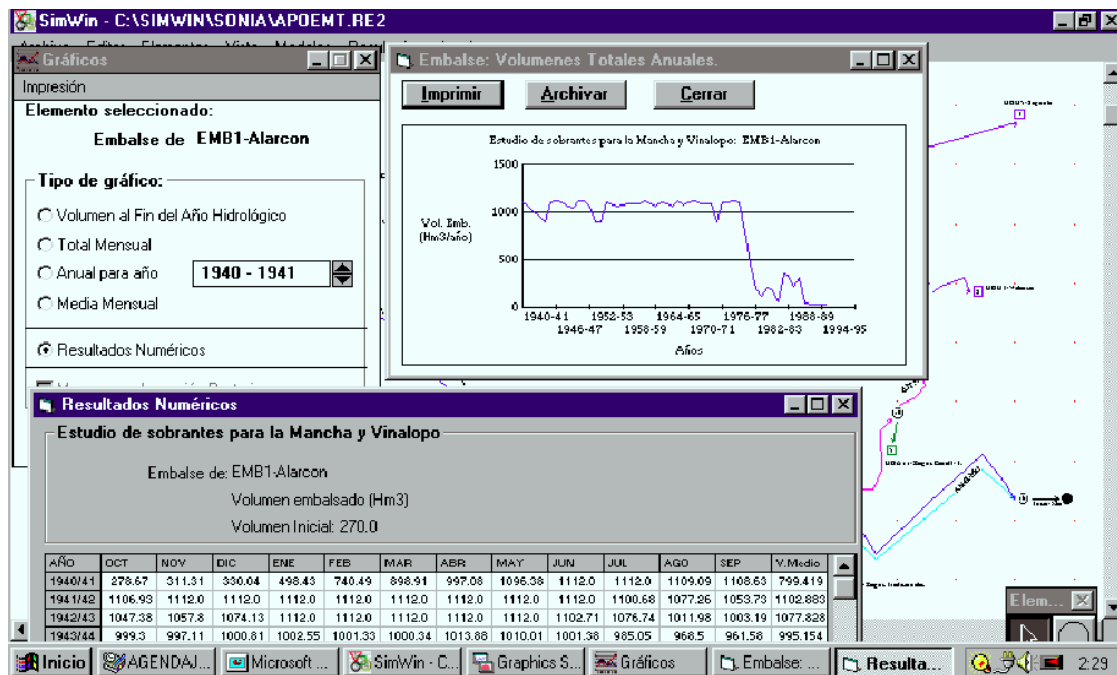


Fig. 68 Example of tabular and graphical display of results for a specific reservoir of the system

Adaptability to the Water Strategy Man Project

Aquatool is not linked to a Gis software and current version does not have an approach comprising also economic and ecological aspects. Besides, strategic actions such as construction of new supply nodes are not considered.

2.13. Iras

IRAS is the acronym for *Interactive River-Aquifer Simulation* program. It is a tool for simulating surface and ground water resource and their reciprocal interactions and flow exchange over space and time. IRAS has been firstly developed in 1994 and later updated in 1998 by the Civil and Environmental Engineering Department of Cornell University and the Resources Planning Associates Inc of Ithaca, New York State.

IRAS is Windows-based and has a graphical user interface supporting the user to study the generic water resource system. Through the interface, he can:

- draw and define the features of the WR system components as a network of nodes and links
- edit data and operating rule characterising each type of network element
- prepare input files and parameters of the simulation modules
- plot input and output time-series over time and space
- display simulation results geographically
- calculate and view statistics of simulation results

Iras Network

The IRAS network elements can represent various components of any interacting surface-groundwater system. Nodes represent components or points of interest where simulated variable values are recorded and where inflow, outflow, consumption, diversion, or storage events can take place. The user of IRAS can choose among the following types of nodes:

- artificial reservoirs, whose release or discharge are governed by operating policies accounting for target volume, satisfaction of downstream demands, etc.
- natural lakes, whose outflow or discharge is determined by the topography of the basin and hence is a function of its volume or surface-water elevation
- wetlands
- confined or unconfined aquifers, distributed either horizontally or in multiple layers
- groundwater withdrawal or recharge sites,
- gauging stations where time series of flow, natural recharge or quality parameters are available
- demand sites, either consumptive or non-consumptive

- waste water discharge sites
- hydropower plants, connected either to rivers or reservoirs. They are not real node but are conceived in Iras as items featuring river links. Hydropower can be placed a on any link and the flow entering the link is assumed to be available for the production of energy
- confluences and diversions

Links represent the transfer of water between two nodes and can be uni-directional or bi-directional type if water goes respectively one direction only or both of them.

Uni-directional links are:

- natural streams or river reaches connecting two surface-water nodes. River reaches are stretches of river which may be connected to hydroelectric power plant or pumping stations.
- diversion canals, drainage ditches or pipelines

Bi-directional links are:

- generic links transferring water between two nodes, in particular links connecting aquifer or wetland nodes

The schematic network is draw by the user in a blank Iras window. A digitised geographic map of the area can be loaded in the interface window as a black and white image so as to facilitate a consistent placement of nodes.

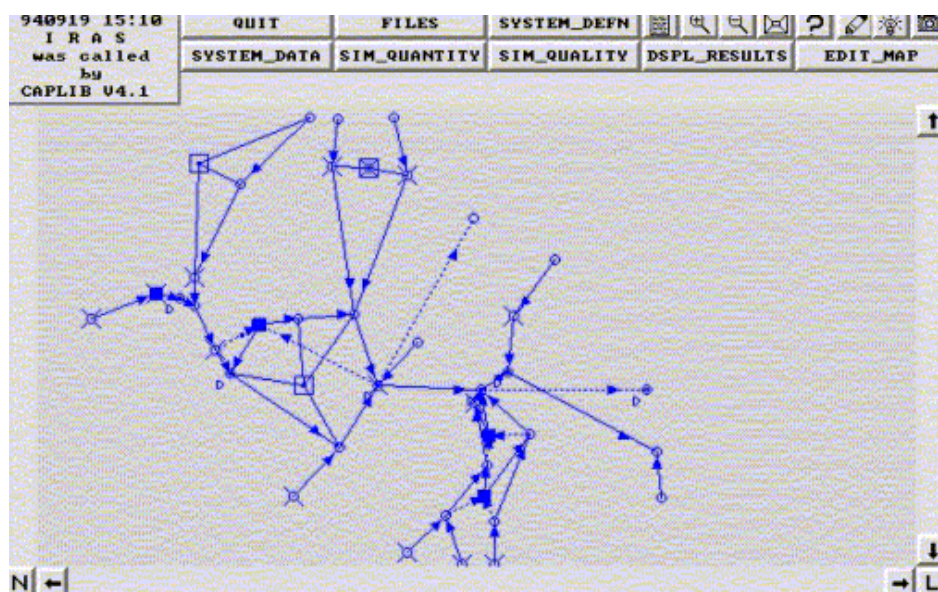


Fig. 69 An example of schematic representation without background mapping: the Raritan River-Aquifer system in New Jersey

Data Entering and requirements

The type of each node and link determines the corresponding kind of data needed to simulate it. When the user adds a new network element in the drawing network window, the Iras program automatically recognises its type and creates the appropriate dialog box and data slots for entering all the needed data. Node and link dialog boxes for data entry or modification can be displayed by clicking on the node or link. Hereunder data requirements for some types nodes and links are listed:

All Nodes

- Gauge-Flow Multipliers. Each node in the network may assume the role of a gauging station monitoring natural water flows. However, in case data time series are not really monitored or available in a newly defined *gauging node*, this latter is treated and described as a *fictitious station* that is conceptually associated to a real neighbouring monitoring point. The fictitious node generates its own data series from the associated real station by multiplying each real value by a proper calibrated factor, namely Gauge-Flow Multiplier, in a sort of spatial interpolation or extrapolation. On the other hand, Gauge-Flow Multipliers can also be defined for all the other kinds of node, here having the alternate role of converting the measurement units of monitored flows from the user defined ones to those needed by simulation modules.
- Quality Parameters. If the node is a storage node and water quality is to be simulated, the user must define the values of the average daily growth or decay rate constants and the transformation rate constants for each water quality constituent being simulated and for each within-year time period.
- Elevation Data. Elevation data at a node are needed anytime hydropower or pumping may be considered on any of its incoming or outgoing links. If the node is a storage node, storage volume elevation functions should be defined. Elevation data are also required to define storage-area-discharge-seepage data at all storage nodes.
- Loss Functions. Water can be lost due to evaporation or seepage at any storage node and the user must define the appropriate loss functions at each applicable node for each within-year time period. Note that the word *losses* in Iras means amounts of water exiting the water system definitely. According to that, seepage volumes from surface water bodies or adjacent aquifers entering other aquifers are not to be defined as losses and their transfer should be represented through a proper link connecting these two relevant nodes.

Demand Node

- Water demand targets for each within-year period must be specified for each demand node. They are the water requirements of the node to be met by simulated water inflows. Note that each node in Iras can be designated a demand.

- Water sources identifiers and factors. Each demand node can have a set of assigned possible sources of water, being any reservoir or release-rule site. The user has to specify *target-deficit factors*, constant for all within-year periods, that are used to calculate the additional release requested in case of water deficit. Unequal multipliers assigned to multiple upstream source sites also establish the priority of each source site for meeting demand deficits. These priorities should be considered when assigning values to source node multipliers

Reservoir and Natural Lake

- Storage volume capacity and initial storage volume
- Minimum release or discharge as a function of storage volume
- Elevation-storage volume-surface area functions and daily evaporation loss rates
- Daily seepage volume loss as a function of storage volume
- Values of growth, decay and transformation rate constants of water quality constituents

Aquifer and Wetland Node

- Initial storage volume
- Evaporation and seepage loss as a function of surface area or storage volume
- Storage-elevation (head) function if energy consumption from pumping is to be calculated on any of the connecting links.

Gauging stations

- *Gauging stations* are placed along rivers or in every site where natural uncontrolled inflows are calculated, for example based on measures of precipitation and evaporation to get the net recharge. These natural uncontrolled inflows represent the water input to the river system. Stations can also observe wastewater flows at treatment plant sites. The user must prepare a file with the time series of flows and aquifer recharge data for each station of the schematised network.

Waste Water Discharge Node

- Number and type of waste or water quality constituents and their average initial concentrations for each discharge node and for each within-year period. Concentrations of natural inflows entering the system at the discharge nodes must also be defined.

Surface-Water Link Data

- Detention storage (volume in link if flow is 0) and initial link volume if flow routing and/or water quality simulation are implemented.
- Flow loss as a function of flow in the link
- Values of water quality constituent growth, decay and transformation rate constants for each water quality constituent being simulated, and for each within-year time period
- Hydropower capacity, minimum turbine flow, plant factors and energy production constant, if hydroelectric energy is produced on the link
- Energy consumption constant, if pumping can occur on the link.
- Link flow capacity, if it is designated a diversion link.

Aquifer and Wetland-Area Link

- Links connected to aquifer nodes are named *groundwater links* and links connected to wetland-area nodes are named *wetland links groundwater link*. Flow pumping policies as function of current storage volumes in the aquifer or wetland nodes are to be defined.

Diversion Link

- Maximum link flow capacity

OK RELEASE RULE NODE 4 ?	
NODE NAME:	Reservoir
INIT. STOR.:	400.0
CAPACITY:	700.0
LENGTH:	0.0000
ELEVATION:	0.0000
GAGE TABLE	ALLOCATIONS
EVAPORATION	RATE TABLE
QUALITY	FUNCTIONS
RELEASE RULE	

OK ALLOCATIONS ?			
Junction	CONSUMPT.	L2	L6
0.0	0.0	0.0	0.0
30.000		30.000	
65.000		30.000	35.000
435.00		400.00	35.000
CLEAR	MORE		
PERIOD:	1		

OK LAKE NODE 3 ?	
NODE NAME:	Lake
INIT. STOR.:	0.0000
CAPACITY:	100.0
LENGTH:	0.0000
ELEVATION:	0.0000
GAGE TABLE	ALLOCATIONS
EVAPORATION	RATE TABLE
QUALITY	FUNCTIONS

OK RELEASE RULE FOR Reservoir ?		
	Initial	Final
Max. Storage	550.00	600.00
Release	70.000	60.000
Min. Storage	350.00	400.00
Release	45.000	45.000
ZONE:	3	PERIOD: 2

OK RATING TABLE FOR Lake ?				
ELEVATION	AREA	VOLUME	DISCHARGE	SEEPAGE
0.0	0.0	0.0	0.0	0.0
24.000	400.00	39.000		
28.000	800.00	63.000	20.000	
30.000	1400.0	85.000	80.000	
31.000	2100.0	100.00	250.00	
CLEAR	MORE	COMPUTE	PERIOD: 1	

Fig. 70 Dialog boxes with entered data for selected nodes and links. They are accessed by right clicking on the relevant network node or link.

Simulation

The IRAS simulation takes place in a separate program module, namely IRAS_s that reads database files, containing the data entered for each network element by the user, and files with monitored natural flows and their relevant concentrations.

The IRAS_s program simulates water resource systems over multiple within-year time periods that may be months, weeks, days, or time periods of different durations. The within-year time periods can be up to 60 and may cover an entire year, that is not necessary, and in this case many years can be simulated, each one with different within-year time periods.

All inflows, consumption rates, evaporation and seepage loss rates, and wastewater input data are assumed constant within each within-year period. The within-year periods should be defined in a manner that captures the significant changes in inflows, wastewater discharges, demands, and parameter values affecting water quality, as applicable, for the particular system being simulated.

Each within-year period is divided into a number of simulation time steps of equal duration, at least 12, a day being the minimum time step.

All simulated variables such as actual flows, consumptions, diversions, storage volumes, losses, energy produced or consumed and water quality are computed at each simulation time step according to a predefined sequence:

- a) Inflows, Losses and Reservoir Release Targets. In this first step the natural inflows (recharge flows) at aquifer and wetland-area nodes and the estimated evaporation and seepage losses at each storage node are calculated. These losses at each node are based on the current storage volume at the node and are calculated from the elevation-storage area or storage volume-area functions and daily evaporation rates and daily seepage loss functions, entered by the user. Reservoir release targets, which are not necessarily the actual reservoir releases, are also computed based on current reservoir storage volumes and capacity, on downstream demand target deficits and on a specified minimum required release. The discharge from each natural lake node is computed as the storage volume less evaporation and seepage losses plus inflows.
- b) Initial volume and inflow at all nodes, surface-water node consumption and outflows, and surface-water link inflows and outflows. If hydropower production or pumping occurs on surface-water link, then the energy produced or consumed is computed based on the link inflow and the storage heads at the two nodes the link connects.
- c) Bi-directional link flows between aquifers and/or wetlands. These flows are function of current storage volumes, the physics of groundwater, overland flow and pumping policies. If hydropower and/or pumping is defined for any of the bi-directional links, the energy produced or consumed is also computed
- d) Groundwater and wetland inflows, outflows and storage volume. Water exchange with neighbouring rivers is taken into account too. Water flows within aquifers are calculated with the Darcy's Law for saturated flows in at least semi pervious material. This law assumes that the flow is laminar and proportional to the difference in pressure heads between the two water bodies times the area through which the flow travels divided by the length of the flow path.
- e) Water quality. The simulation of water quality in storage nodes representing natural lakes, reservoirs, groundwater aquifers, or wetland areas, and in links representing stream reaches or surface water diversions, is based on the

simulated flows and storage volumes. Water quality constituent inputs at each node are defined by the concentrations, of each constituent in the uncontrolled flows entering each node. For water quality simulation storage nodes and surface-water links can be subdivided into a series of storage elements of equal volume where complete mixing is assumed. The volume in each element of a node or link is the total node or link volume divided by the number of user-defined volume elements. The instantaneous rate of change in mass of a water quality constituent in a storage element equals the incoming mass less the outgoing mass less the decay or consumption of that constituent mass plus its growth or increase in mass resulting from the transformation of other quality constituents in the storage element. The differential equation defining the rate of change in the mass of a constituent in a storage volume element can be approximated by the finite difference equation for each simulation time step. IRAS bases the change in constituent masses due to growth, decay and transformation only on the initial constituent concentrations rather than average concentrations in each simulation time step. Errors caused by that assumption may be reduced by adjusting the values of the rate constants for growth, decay or consumption of constituents during the calibration process.

Displaying Simulation Results

The output of IRAS includes the initial and final storage volumes and the average flow, quality, energy and power conditions for each of the user-specified within-year periods in each year of the simulation. The outputs at a given node or link can be displayed as time-series plots. Each simulated variable can be assigned two threshold values, defining three possible range of values for the variable. Green, yellow and red colours can be assigned to various ranges of variable values judged by the user to be satisfactory, marginal, or unsatisfactory, respectively. Plots having the three coloured areas in the background may be created so as to analyse the behaviour of a variable in a graphically. The colour-coded representations of the ranges of these selected variable values can be also displayed geographically on the schematic network or map, if defined, over successive time periods: nodes in the network scheme change colour according to the range of values assumed by the variables. This provides a means of identifying relatively quickly the locations and times where the system may be stressed. Furthermore, defining thresholds will also permit the computation of system performance statistics and probability distributions of both red and yellow zone deviation extents and durations.

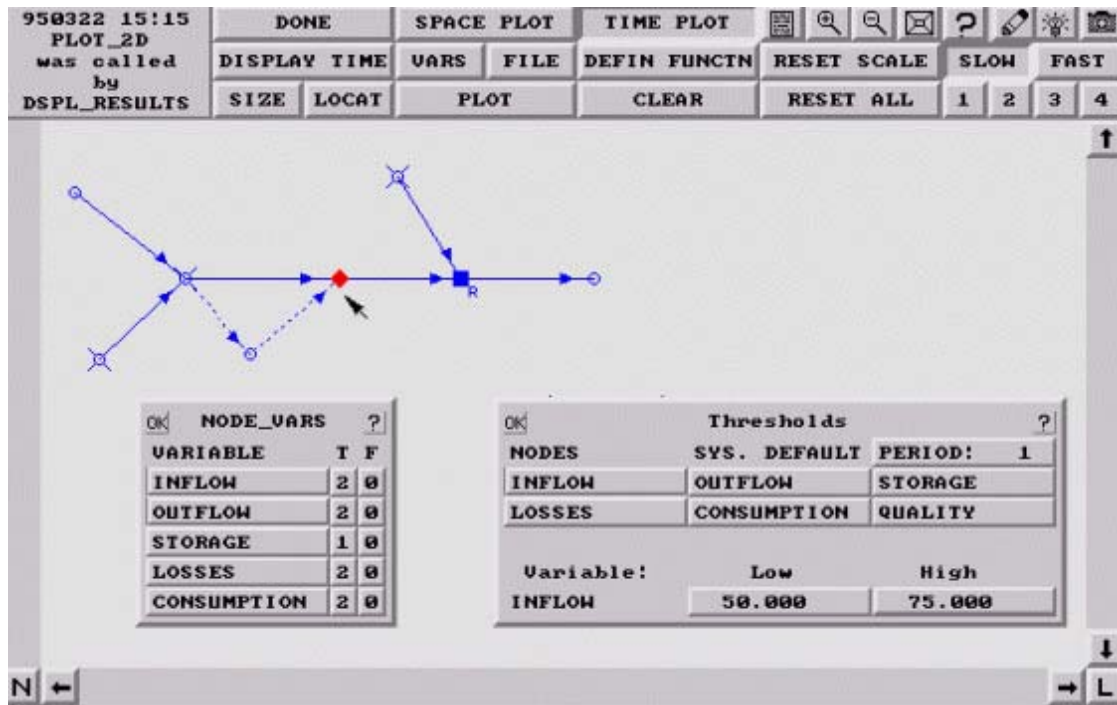


Fig. 71 Assigning thresholds values to variables permits to check visually their behaviour over the simulation time steps: nodes in the network scheme change colour according to the range of values assumed by the variables. This kind of visualisation may be performed for each simulation variable.



Fig. 72 Coloured display of a lake storage over years

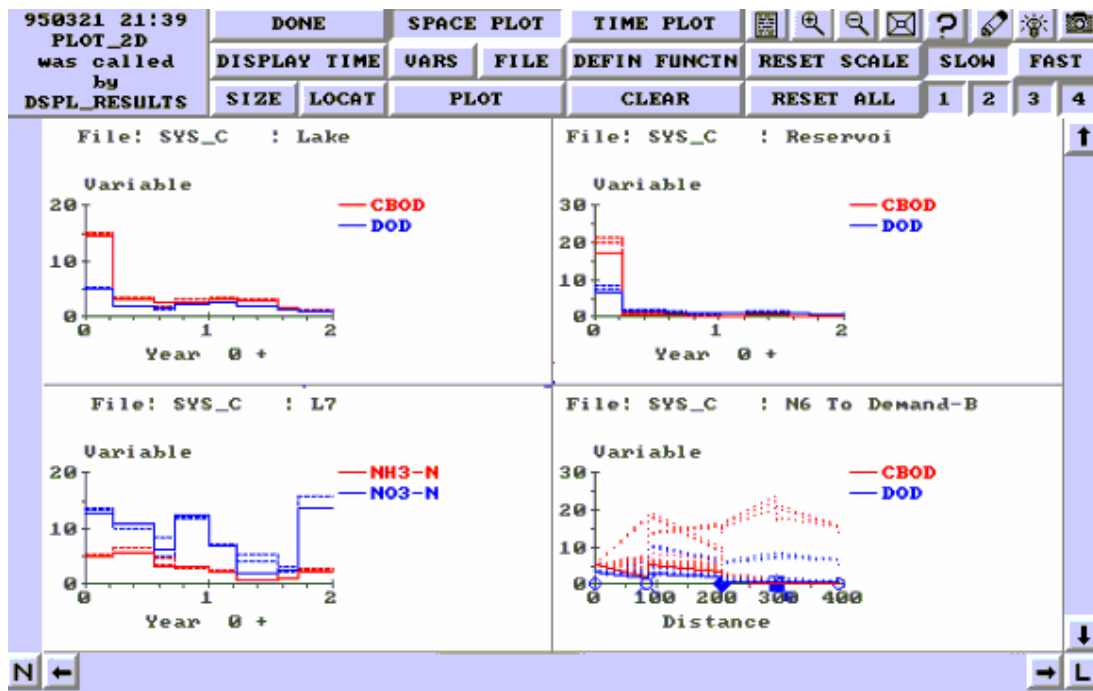


Fig. 73 Displays water quality output data

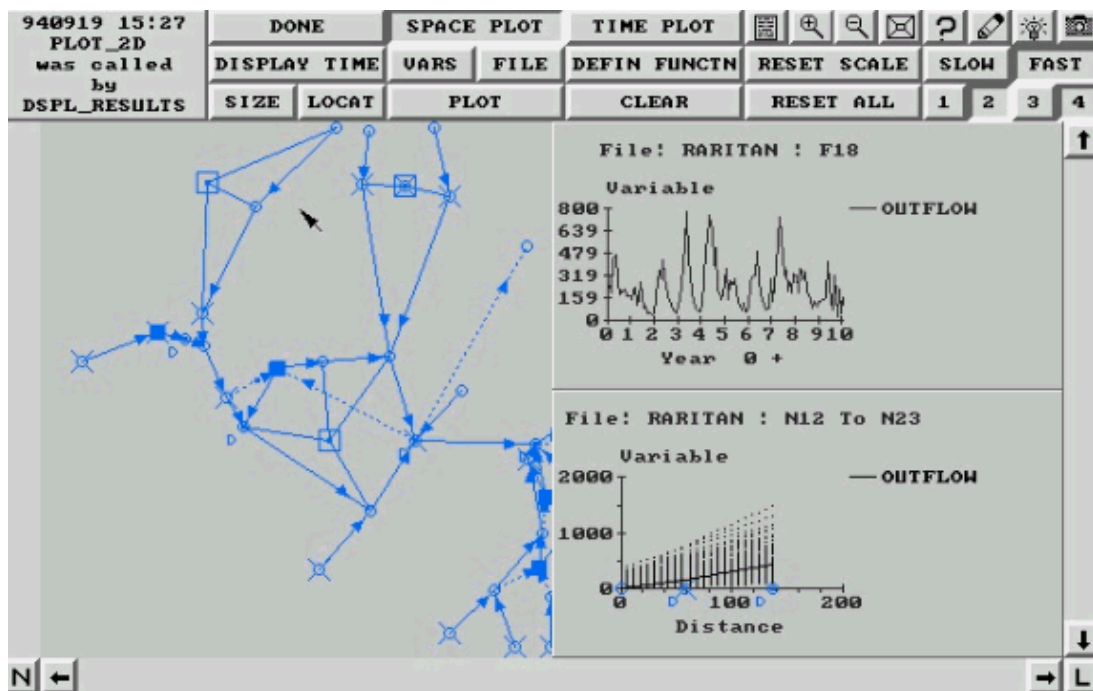


Fig. 74 Displaying outflows from a node

Adaptability to the Water Strategy Man Project

Iras does not use geo-referenced data and Gis software. It seems that economic analysis and relevant indicators are not taken into account. Besides, there is not a definition of scenarios and related management. Also, the number of different link types connecting the nodes is exaggerated and can lead to confusion. Iras is not proposed as applicable to the WSM paradigms.

3. Methodologies

3.1. An economic model for water allocation in North Eastern Spain

The hereunder short description is cited from: Jorge Bielsa & Rosa Duarte, *An economic model for water allocation in north eastern spain*, Water resources development, Vol. 17, No. 3, 397-410, 2001

The paper above describes a method for allocating water between two competing water users such as irrigation and hydropower. The central problem addressed is the conflict arising between different water uses due to multiple reasons such as restrictions in water supply, increased water requirements for existing and new irrigated areas or simply a decline in precipitation. The key concept concerns the application of environmental and institutional water rights that have been assigned to them by national or local regulations. The water rights, which are defined by the order of priority of the uses and by the amount of water allocated, can be exchanged between the users based on economic issues so as to reach a convenient cooperative agreement. An application of that has been carried out for the Vadiello Reservoir in the province of Huesca, North Eastern Spain where irrigation and hydropower activities are rivals one with the other in the use of water released downstream the reservoir. Conflicts have been solved by re-distributing the water rights of each of them over time. It is the case of a dry period due to a decline in precipitation, with a reduction of 30% of fresh water available in the stream flow. A deficit of water for irrigation occurring in the second part of the period was faced with a renouncement of a part of water right in the first period from the side of the hydroelectric firm, so as to leave water in the reservoir, in exchange for a larger one in the second. An alternative distribution over time may also affect the water payments: the renouncement in the first period is compensated by a water use free of charge in the second period.

3.2. Development and evaluation of multiple-objective decision-making methods for watershed management planning

The short description below is cited from: Lamy, Bolte, Santelmann, Smith, *Development and evaluation of multiple-objective decision-making methods for watershed management planning*, Journal of the American Water Resource Association, Vol. 38, No. 2, April 2002.

The paper describes the use of a multiple objective methodology and the application of a Gis based tool, namely *Restore*, in two watersheds of Oregon's Willamette River Basin. *Restore* has been developed to support watershed councils to identify and evaluate areas for restoration activities and prioritize the problems at the watershed level. Watershed restoration planning is approached as a holistic activity based on the collection and

manipulation of information defining a watershed in terms of social, economic, biological and hydrologic issues. *Restore* allows the user to visualize all the collected data so as to facilitate the specification of the objectives to be addressed and the restoration options to be considered in creating a restoration plan. The decision making process included in *Restore* comprises the following steps:

- Description of decision situation
- Identification of Decision Making variables
- Identification of the attributes store in the database that are suitable to describe the problem
- Definition of rules and constraints
- Landscape generation and evaluation
- Selection of the preferred watershed restoration plan and its implementation

The first step, assessment of the decision situation, is started by dividing the watershed of interest into cells, of at least 12 ha of territory, that may be considered as individual homogeneous units with respect to land use, soil and drainage.

Decision Making variables are defined in the second step. They are the objectives and restoration options suggested by the Water Councils and may concern site modification or change in the management practice. Examples of the former are the installation of a riparian buffer along a watercourse or the reduction of toxicant use in agricultural fields. *Restore* includes five main objectives, having 28 sub-objectives and 20 restoration options. They are defined hierarchically so as to provide the Decision Makers with a logical framework that structures their priorities and concerns. The five main objectives addressing the sustainable development are: 1) Maximize water quality 2) Maximize water availability 3) Maximize habitat quality 4) Maximize social conditions and 5) Maximise economic benefits. The Restoration options considered within *Restore* include filter strip, woody buffer, wetland restoration and alternative system cropping and agricultural riparian buffer. The user of *Restore* assigns a weight to each objective and selects the desired sub-objectives. This operation is performed for each cell of territory.

The third step in the watershed analysis is the identification of the attributes characterizing the site under study. They include land use, hydrology, topography and proximity to landscape features as wetlands, roads, streams and urban areas.

Next step involves the attachments of rules and constraints to each cell. They express the socioeconomic and environmental impact assessment of the different restoration options as a function of the cell position. At first, the combined analysis of constraints and the cell position, this latter being strictly connected with the cell attributes, determine the types of restoration option that should be properly considered for the specific cell. Then,

if constraints are satisfied for a set of options, the same restoration options are assigned a sort of rules that score them based on their ability to meet each of the five objectives.

Last step is the generation of the *efficient landscape*. Restore computes the efficacy of each restoration option with respect to the five objectives as a weighted summation of the utility of each option to the same five objectives. Then options are ranked based on their efficacy and the preferred one for each cell is established. The *efficient landscape* is a visualization of the cells of the area under study, where cells assume different colors according to the preferred type of option.

4. Conclusions

Some decision support systems, tools and models supporting water resource analysis and assessment have been presented in this report. The focus has been given to those packages having at least:

- a graphical user interface, able to display information and help a technical user to access and display the available information
- a geo-referenced database which may be accessed directly from a geographic map by a simple right click of the mouse
- Gis software embedded in it or the capability to import maps from external ones
- a suite of models, at least an allocation model able to distribute water to multiple users of a network, also with the help of specific rules or priorities
- a tool for schematising the area under study as a network of nodes and links where nodes represent the available water sources and different types of water demanding users such as irrigation sites or industries whilst links stand for river stretches of artificial canals and pipelines carrying water from supply nodes to demand nodes

Some of the reviewed tools organise input and output in a sort of scenarios which may be finally compared to establish the best simulation results or to put in evidence some simulation periods where deficit situations occur or water quality standards are not satisfied. The concept of scenario conceived by these tools is different from the definition of “developments which can not be directly influenced by the Decision Maker such as Weather, Market Prices etc” given by the WaterStrategyMan Methodology group and should be modified in case of adaptation to the WSM case studies. The analysis of scenarios should be coupled with the definition of proper strategic option to be applied to the simulated water resource system so as to improve negative situation as above. The modelling packages presented lack of a framework for defining strategies: they support the visualisation of results both in graphical and table format but leave to the technical user or the decision maker the further step of drawing conclusions and imagine suitable strategic measures. It is common opinion of the WSM Methodology Group of Partners that a list of measure should be suggested the DSS user to facilitate the integrated water resource planning and management.

References

Mike basin

- [1] Manuals and documentation downloaded from the Mike Basins web site:
<http://www.dhisoftware.com/mikebasin/index.htm>

Basins

- [2] Brown, L. C., and T. O. Barnwell, Jr. 1987. *The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual*. EPA-600/3-87/007. U.S. Environmental Protection Agency, Athens, GA. May
- [3] Bicknell, Imhoff, Kittle, Jobs, Donigian, *Hydrological Simulation Program – Fortran Version 12 User Manual*
- [4] Donigian, A.S., Jr., Imhoff, J.C., Bicknell, Brian, Kittle, J.L., Jr., 1984, *Application guide for Hydrological Simulation Program--Fortran (HSPF)*: U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Ga., EPA-600/3-84-065, 177 p.
- [5] J. Kittle, Jr., M. Gray, P. Duda, P. Hummel, R. Dusenbury, *GenScn Version 2.0 User's Manual*
- [6] S.I. Neitsch, J.G. Arnold, J.R. Kiniry, J.R. Williams, *The Soil and Water Assessment Tool SWAT Version 2000*
- [7] United States EPA, *Better Assessment Science Integrating point and Nonpoint Sources – BASINS Version 3.0 User Manual*
- [8] Basins' web site at:
<http://www.epa.gov/OST/BASINS>

Dss for water resources planning based on environmental balance

- [9] Documentation available at Progea S.r.l.

A Spatial Decision Support System for the Evaluation Of Water Demand and Supply Management Schemes

- [10] Albert, X., Mark, O., Babel, M.S., Gupta, A.D. and Fugl, J. (2001), *Integrating Resource Management in South East Asia*, Water21 October 2001, 25-30.
- [11] Bouwer, H. (2000), *Integrated Water Management: Emerging Issues and Challenges*, Agricultural Water Management, 45, 217-228.
- [12] Dolam, A. and Aldous, J. (1993) *Networks and Algorithms: An Introductory Approach*, Wiley.
- [13] Lilburne, L, Watt, J. and Vincent, K. (1998), *A Prototype DSS to Evaluate Irrigation Management Plans*, Computers and Electronics in Agriculture, 21, 195-205.
- [14] Mannoichi, F., Mecarelli, P. (1994), *Optimization Analysis of Deficit Irrigation Systems*, J. Irrig. Drain. Eng., 120 (3), 484-503.
- [15] Mays, L.W. (1996), *Water Resources Handbook*, McGraw-Hill, New York.
- [16] McKinney, D.C, Cai, X, Rosegrant, M.W., Ringler, C. and Scott C.A. (1999), *Modelling Water Resources Management at the Basin Level: Review and Future Directions*, International Water Management Institute, SWIM Paper 6.
- [17] Reca, J., Roldan, J., Alcaide, M., Lopez, R. and Camacho, E. (2001), *Optimisation Model for Water Allocation in Deficit Irrigation Systems I. Description of the Model*, Agricultural Water Management, 48, 103-116.
- [18] Rosegrant, M.W., Ringler, C., McKinney, D.C., Cai, X, Keller, A. and Donoso, G (2000), *Integrated Economic-Hydrologic Water Modeling at the Basin Scale: the Maipo River Basin*, Agricultural Economics, 24, 33-46.
- [19] Salman, A.Z., Al-Karablieh, E.K. and Fidher, F.M. (2001), *An Inter-Seasonal Agricultural Water Allocation System (SAWAS)*, Agricultural Systems, 68, 233-252.
- [20] Sedgewick, R (2002) *Algorithms in C++ Part 5: Graph Algorithms*, Addison Wesley Longman.
- [21] Simonovic, S.P (2000), *Tools for Water Management One View of the Future*, IWRA Water International, 25, 76-88.

- [22] Staudenrausch, H. and Flugel, Q.A. (2001), *Development of an Integrated Water Resource Management System in Southern African Catchments*, Phys. Chem. Earth, 26, 561-564.
- [23] Wardlaw R. (1999), *Computer Optimisation for Better Water Allocation, Agricultural Water Management*, 40, 65-70.

Iqgm

- [24] Documentation on the IQQM web site:
<http://www.dlwc.nsw.gov.au/care/water/iqgm/>

Ensis

- [25] Bakken T.H., Dagestad K. and Wathne B.M. (2001): *ENSIS – An environmental surveillance and information system*. Proceeding from the IWA-conference Berlin.
- [26] Tor Haakon Bakken, Katherine Hilton, and Kjersti Dagestad *ENSIS powerpoint presentation of Testversion 2.0*
- [27] NIVA's and NILU's ENSIS web sites:
<http://www.niva.no/ensis>
<http://www.nilu.no/avd/imis/ensismain.html>

Realm

- [28] The REALM User Manual
- [29] Documents at the REALM web-site at:
<http://www.nre.vic.gov.au/web/root/Domino/vro/vrosite.nsf/pages/water-surfacemod>

Mulino

- [30] Mulino web-site:
<http://www.feem.it/web/loc/mulino/>

- [31] Mysiak J., Giupponi C., Fassio A., *Decision Support for Water Resource Management: An Application Example of the MULINO DSS*, 2001
- [32] Giupponi, C., J. Mysiak, A. Fassio, and V. Cogan, *MULINO: Multi-sectoral, Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale*, Ghassemi, E.; M. McAller, F. Oxley, and Scoccimarro (eds), Proceeding from MODSIM 2001, Volume 3, Canberra, Australia, 2000.

Ribasim

- [33] Documentation at Delft Hydraulics Web site:
<http://www.wldelft.nl>

Weap

- [34] Documents at the Weap web site:
<http://www.seib.org/weap>
- [35] Paul Raskin, Jack Sieber, Annette Huber-Lee, *User Guide for Weap21*

Waterware

- [36] Waterware web page within the University of Newcastle upon Tyne web site: <http://www.ncl.ac.uk/wrgi/wrsrl/projects/waterware/waterware.html>
- [37] Waterware web page within the Environmental Software and Services web site: <http://www.ess.co.at/WATERWARE>
- [38] Fedra, K. (2002), *GIS and simulation models for Water Resources Management: A case study of the Kelantan River, Malaysia*. GIS Development, August 2002, 6/8, pp. 39-43.
- [39] Fedra, K., and Jamieson, D.G. (1996), *An object-oriented approach to model integration: a river basin information system example*. In: Kovar, K. and Nachtnebel, H.P. [eds.]: IAHS Publ. no 235, pp. 669-676.

Aquatool

- [40] Andreu J., Solera A., Paredes J., *Decision support systems for integrated water resources planning and management*, paper presented by Dr. Joaquin Andreu at the International Conference on Management on Northern River Basin JUNE 6 - 8, 2001 OULU, FINLAND
- [41] Andreu J., Capilla J., Sanchis E. (1996) *Aquatool: a generalized decision-support system for water- resources planning and operational management*, Journal of Hydrology. Vol. 177, pp. 269-291
- [42] Aquatool manuals from the web-site at:
<http://www.upv.es/aquatool/>

Iras

- [43] Loucks D., French P. and Taylor M., *Iras Program Description and Operation*